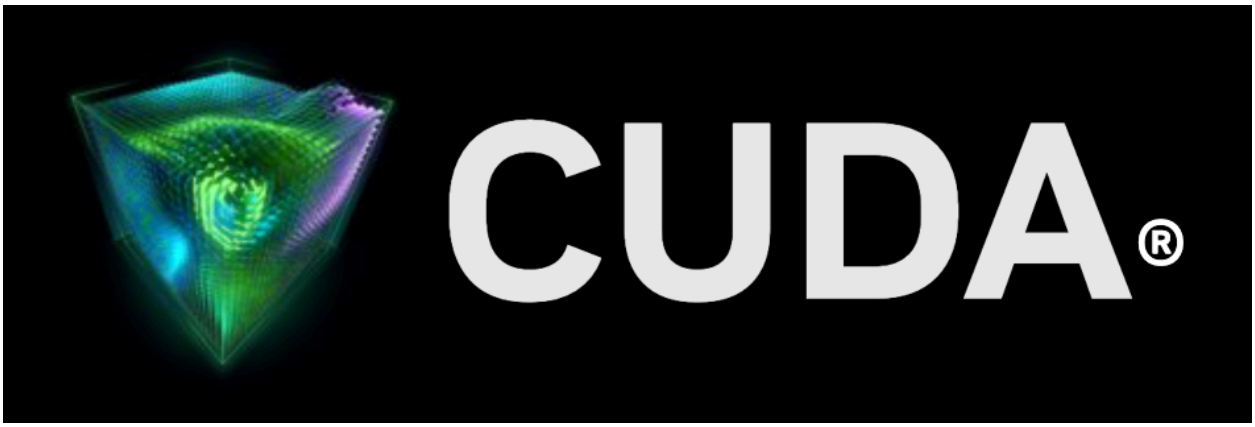

PTX ISA

Release 8.8

NVIDIA Corporation

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Chapter 1. Introduction

This document describes PTX, a low-level *parallel thread execution* virtual machine and instruction set architecture (ISA). PTX exposes the GPU as a data-parallel computing *device*.

1.1. Scalable Data-Parallel Computing using GPUs

Driven by the insatiable market demand for real-time, high-definition 3D graphics, the programmable GPU has evolved into a highly parallel, multithreaded, many-core processor with tremendous computational horsepower and very high memory bandwidth. The GPU is especially well-suited to address problems that can be expressed as data-parallel computations - the same program is executed on many data elements in parallel - with high arithmetic intensity - the ratio of arithmetic operations to memory operations. Because the same program is executed for each data element, there is a lower requirement for sophisticated flow control; and because it is executed on many data elements and has high arithmetic intensity, the memory access latency can be hidden with calculations instead of big data caches.

Data-parallel processing maps data elements to parallel processing threads. Many applications that process large data sets can use a data-parallel programming model to speed up the computations. In 3D rendering large sets of pixels and vertices are mapped to parallel threads. Similarly, image and media processing applications such as post-processing of rendered images, video encoding and decoding, image scaling, stereo vision, and pattern recognition can map image blocks and pixels to parallel processing threads. In fact, many algorithms outside the field of image rendering and processing are accelerated by data-parallel processing, from general signal processing or physics simulation to computational finance or computational biology.

PTX defines a virtual machine and ISA for general purpose parallel thread execution. PTX programs are translated at install time to the target hardware instruction set. The PTX-to-GPU translator and driver enable NVIDIA GPUs to be used as programmable parallel computers.

1.2. Goals of PTX

PTX provides a stable programming model and instruction set for general purpose parallel programming. It is designed to be efficient on NVIDIA GPUs supporting the computation features defined by the NVIDIA Tesla architecture. High level language compilers for languages such as CUDA and C/C++ generate PTX instructions, which are optimized for and translated to native target-architecture instructions.

The goals for PTX include the following:

- Provide a stable ISA that spans multiple GPU generations.
- Achieve performance in compiled applications comparable to native GPU performance.
- Provide a machine-independent ISA for C/C++ and other compilers to target.
- Provide a code distribution ISA for application and middleware developers.
- Provide a common source-level ISA for optimizing code generators and translators, which map PTX to specific target machines.
- Facilitate hand-coding of libraries, performance kernels, and architecture tests.
- Provide a scalable programming model that spans GPU sizes from a single unit to many parallel units.

1.3. PTX ISA Version 8.8

PTX ISA version 8.8 introduces the following new features:

- Adds support for `sm_103` target architecture.
- Adds support for target `sm_103a` that supports architecture-specific features.
- Adds support for `sm_121` target architecture.
- Adds support for target `sm_121a` that supports architecture-specific features.
- Introduces family-specific target architectures that are represented with “f” suffix. PTX for family-specific targets is compatible with all subsequent targets in same family. Adds support for `sm_100f`, `sm_101f`, `sm_103f`, `sm_120f`, `sm_121f`.
- Extends `min` and `max` instructions to support three input arguments.
- Extends `tcgen05.mma` instruction to add support for new `scale_vectorsize` qualifiers `.block16` and `.block32` and K dimension 96.
- Extends `.field3` of `tensormap.replace` instruction to support 96B swizzle mode.
- Adds support for `tcgen05.ld.red` instruction.
- Extends `ld`, `ld.global.nc` and `st` instructions to support 256b load/store operations.
- Following table shows the list of features that are supported on family-specific targets:

Table 1: List of features promoted to family-specific architecture

Feature	Supported targets
.m16n8, .m16n16, .m8n16 shapes and .b8 type for ldmatrix/stmatrix	sm_100f, sm_101f, sm_120f
Shapes for tcgen05 .16x64b .16x128b, .16x256b, .16x32bx2, .32x32b, .4x256b, .32x128b, .64x128b, .128x256b, .128x128b, .31x256b	sm_100f, sm_101f
setmaxnreg	sm_100f, sm_101f, sm_120f
.cta_group modifier	sm_100f, sm_101f
cvt with .e2m1x2, .e3m2x2, .e2m3x2, .ue8m0x2	sm_100f, sm_101f, sm_120f
multimem with .acc::f16 and .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4 types	sm_100f, sm_101f
tensormap.replace	sm_100f, sm_101f, sm_120f
tcgen05.ld.red	sm_101f, sm_103f
tcgen05.ld/st/fence/ wait/commit/cp/ alloc/dealloc/ relinquish_alloc_permit	sm_100f, sm_101f
tcgen05.mma{.ws}{.sp} (except kind::mxf4/ kind::mxf4nvf4 for .sp)	sm_100f, sm_101f
tcgen05 .kind::mxf4nvf4, .kind::mxf4, .kind::mxf8f6f4, .kind::f16, .kind::tf32, .kind::f8f6f4	sm_100f, sm_101f
.ashift, .collector_usage modifiers for tcgen05	sm_100f, sm_101f
Modifiers .b8x16, .b6x16_p32, .b4x16_p64	sm_100f, sm_101f, sm_120f
.block_scale modifier	sm_100f, sm_101f, sm_120f
mma{.sp} with .e3m2, .e2m3, .e2m1 types and .kind, .block_scale, .scale_vec_size modifiers (except .sp with mxf4/ mxf4nvf4)	sm_120f
.scale_vec::1X/2X/4X modifiers	sm_120f
.block16/.block32 modifiers (alias to scale_vec)	sm_100f, sm_101f
.warpx2::02_13, .warpx2::01_23, .warpx4, .pack::16b, .unpack::16b modifiers for tcgen05	sm_100f, sm_101f
clusterlaunchcontrol.try_cancel multicast::cluster::all	sm_100f, sm_101f, sm_120f
.tile::scatter4, .tile::gather4, .im2col::w, .im2col::w::128	sm_100f, sm_101f
redux.f32	sm_100f
scale-input-d for tcgen05	sm_100f

1.4. Document Structure

The information in this document is organized into the following Chapters:

- *Programming Model* outlines the programming model.
- *PTX Machine Model* gives an overview of the PTX virtual machine model.
- *Syntax* describes the basic syntax of the PTX language.
- *State Spaces, Types, and Variables* describes state spaces, types, and variable declarations.
- *Instruction Operands* describes instruction operands.
- *Abstracting the ABI* describes the function and call syntax, calling convention, and PTX support for abstracting the *Application Binary Interface (ABI)*.
- *Instruction Set* describes the instruction set.
- *Special Registers* lists special registers.
- *Directives* lists the assembly directives supported in PTX.
- *Release Notes* provides release notes for PTX ISA versions 2.x and beyond.

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Chapter 2. Programming Model

2.1. A Highly Multithreaded Coprocessor

The GPU is a compute device capable of executing a very large number of threads in parallel. It operates as a coprocessor to the main CPU, or host: In other words, data-parallel, compute-intensive portions of applications running on the host are off-loaded onto the device.

More precisely, a portion of an application that is executed many times, but independently on different data, can be isolated into a kernel function that is executed on the GPU as many different threads. To that effect, such a function is compiled to the PTX instruction set and the resulting kernel is translated at install time to the target GPU instruction set.

2.2. Thread Hierarchy

The batch of threads that executes a kernel is organized as a grid. A grid consists of either cooperative thread arrays or clusters of cooperative thread arrays as described in this section and illustrated in Figure 1 and Figure 2. *Cooperative thread arrays (CTAs)* implement CUDA thread blocks and clusters implement CUDA thread block clusters.

2.2.1. Cooperative Thread Arrays

The *Parallel Thread Execution (PTX)* programming model is explicitly parallel: a PTX program specifies the execution of a given thread of a parallel thread array. A *cooperative thread array*, or CTA, is an array of threads that execute a kernel concurrently or in parallel.

Threads within a CTA can communicate with each other. To coordinate the communication of the threads within the CTA, one can specify synchronization points where threads wait until all threads in the CTA have arrived.

Each thread has a unique thread identifier within the CTA. Programs use a data parallel decomposition to partition inputs, work, and results across the threads of the CTA. Each CTA thread uses its thread identifier to determine its assigned role, assign specific input and output positions, compute addresses, and select work to perform. The thread identifier is a three-element vector `tid`, (with elements `tid.x`, `tid.y`, and `tid.z`) that specifies the thread's position within a 1D, 2D, or 3D CTA. Each thread identifier component ranges from zero up to the number of thread ids in that CTA dimension.

Each CTA has a 1D, 2D, or 3D shape specified by a three-element vector `ntid` (with elements `ntid.x`, `ntid.y`, and `ntid.z`). The vector `ntid` specifies the number of threads in each CTA dimension.

Threads within a CTA execute in SIMT (single-instruction, multiple-thread) fashion in groups called *warps*. A *warp* is a maximal subset of threads from a single CTA, such that the threads execute the same instructions at the same time. Threads within a warp are sequentially numbered. The warp size is a machine-dependent constant. Typically, a warp has 32 threads. Some applications may be able to maximize performance with knowledge of the warp size, so PTX includes a run-time immediate constant, `WARP_SZ`, which may be used in any instruction where an immediate operand is allowed.

2.2.2. Cluster of Cooperative Thread Arrays

Cluster is a group of CTAs that run concurrently or in parallel and can synchronize and communicate with each other via shared memory. The executing CTA has to make sure that the shared memory of the peer CTA exists before communicating with it via shared memory and the peer CTA hasn't exited before completing the shared memory operation.

Threads within the different CTAs in a cluster can synchronize and communicate with each other via shared memory. Cluster-wide barriers can be used to synchronize all the threads within the cluster. Each CTA in a cluster has a unique CTA identifier within its cluster (*cluster_ctaid*). Each cluster of CTAs has 1D, 2D or 3D shape specified by the parameter *cluster_nctaid*. Each CTA in the cluster also has a unique CTA identifier (*cluster_ctarank*) across all dimensions. The total number of CTAs across all the dimensions in the cluster is specified by *cluster_nctarank*. Threads may read and use these values through predefined, read-only special registers `%cluster_ctaid`, `%cluster_nctaid`, `%cluster_ctarank`, `%cluster_nctarank`.

Cluster level is applicable only on target architecture `sm_90` or higher. Specifying cluster level during launch time is optional. If the user specifies the cluster dimensions at launch time then it will be treated as explicit cluster launch, otherwise it will be treated as implicit cluster launch with default dimension `1x1x1`. PTX provides read-only special register `%is_explicit_cluster` to differentiate between explicit and implicit cluster launch.

2.2.3. Grid of Clusters

There is a maximum number of threads that a CTA can contain and a maximum number of CTAs that a cluster can contain. However, clusters with CTAs that execute the same kernel can be batched together into a grid of clusters, so that the total number of threads that can be launched in a single kernel invocation is very large. This comes at the expense of reduced thread communication and synchronization, because threads in different clusters cannot communicate and synchronize with each other.

Each cluster has a unique cluster identifier (*clusterid*) within a grid of clusters. Each grid of clusters has a 1D, 2D , or 3D shape specified by the parameter *nclusterid*. Each grid also has a unique temporal grid identifier (*gridid*). Threads may read and use these values through predefined, read-only special registers `%tid`, `%ntid`, `%clusterid`, `%nclusterid`, and `%gridid`.

Each CTA has a unique identifier (*ctaid*) within a grid. Each grid of CTAs has 1D, 2D, or 3D shape specified by the parameter *nctaid*. Thread may use and read these values through predefined, read-only special registers `%ctaid` and `%nctaid`.

Each kernel is executed as a batch of threads organized as a grid of clusters consisting of CTAs where cluster is optional level and is applicable only for target architectures `sm_90` and higher. Figure 1 shows a grid consisting of CTAs and Figure 2 shows a grid consisting of clusters.

Grids may be launched with dependencies between one another - a grid may be a dependent grid and/or a prerequisite grid. To understand how grid dependencies may be defined, refer to the section on *CUDA Graphs* in the *Cuda Programming Guide*.

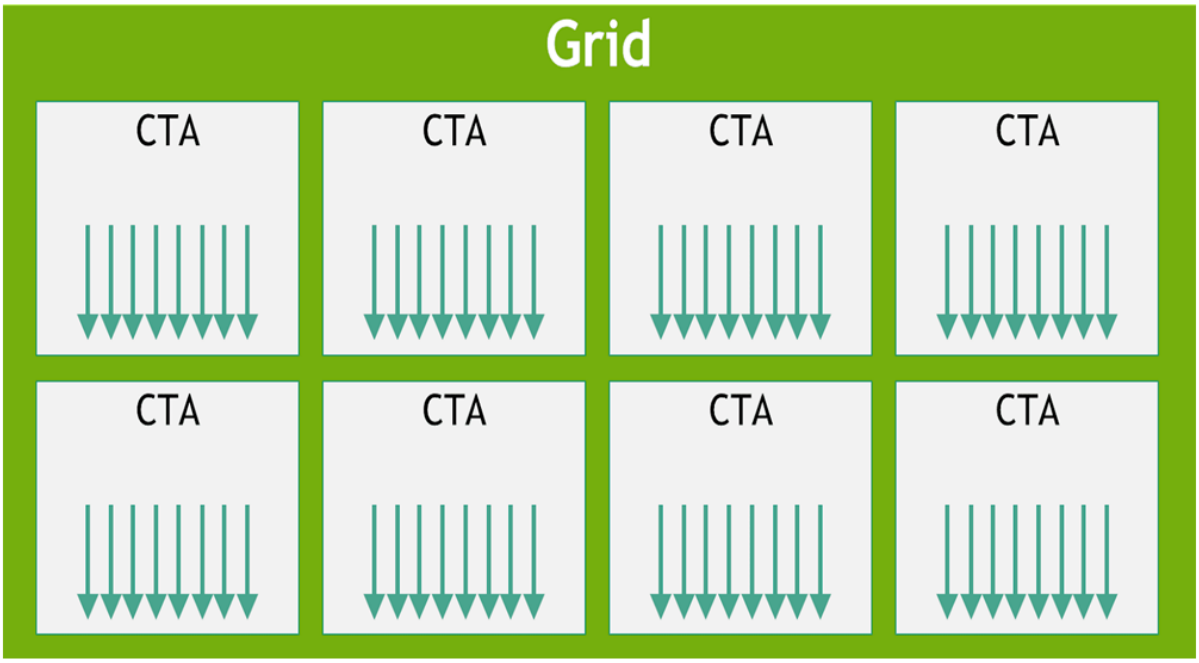

Figure 1: Grid with CTAs

2.3. Memory Hierarchy

PTX threads may access data from multiple state spaces during their execution as illustrated by Figure 3 where cluster level is introduced from target architecture `sm_90` onwards. Each thread has a private local memory. Each thread block (CTA) has a shared memory visible to all threads of the block and to all active blocks in the cluster and with the same lifetime as the block. Finally, all threads have access to the same global memory.

There are additional state spaces accessible by all threads: the constant, param, texture, and surface state spaces. Constant and texture memory are read-only; surface memory is readable and writable. The global, constant, param, texture, and surface state spaces are optimized for different memory usages. For example, texture memory offers different addressing modes as well as data filtering for specific data formats. Note that texture and surface memory is cached, and within the same kernel call, the cache is not kept coherent with respect to global memory writes and surface memory writes, so any texture fetch or surface read to an address that has been written to via a global or a surface write in the same kernel call returns undefined data. In other words, a thread can safely read some texture or surface memory location only if this memory location has been updated by a previous kernel call or memory copy, but not if it has been previously updated by the same thread or another thread from the same kernel call.

The global, constant, and texture state spaces are persistent across kernel launches by the same application.

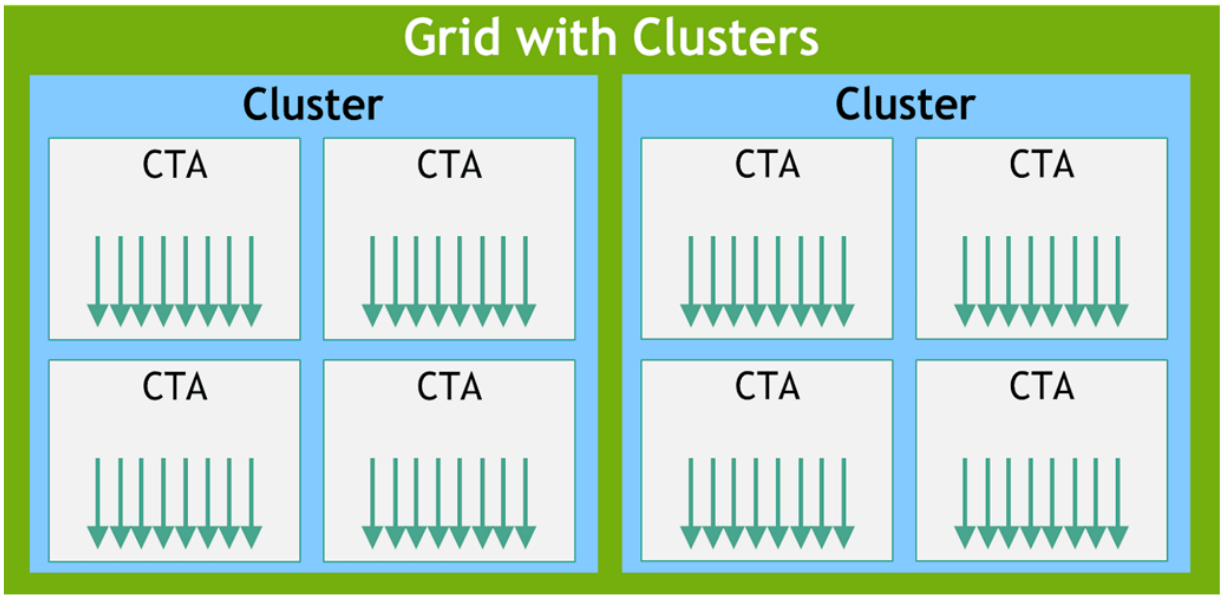

Figure 2: Grid with clusters
A cluster is a set of cooperative thread arrays (CTAs) where a CTA is a set of concurrent threads that execute the same kernel program. A grid is a set of clusters consisting of CTAs that execute independently.

Both the host and the device maintain their own local memory, referred to as *host memory* and *device memory*, respectively. The device memory may be mapped and read or written by the host, or, for more efficient transfer, copied from the host memory through optimized API calls that utilize the device's high-performance *Direct Memory Access (DMA)* engine.

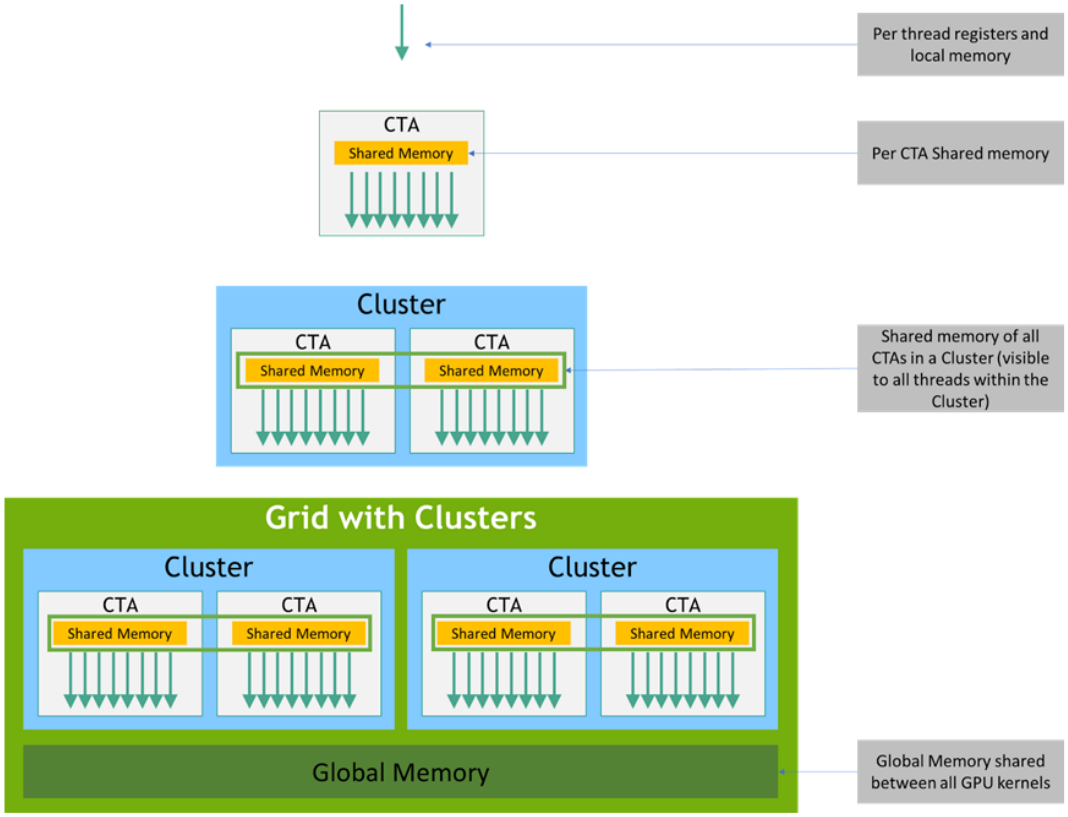

Figure 3: Memory Hierarchy

Chapter 3. PTX Machine Model

3.1. A Set of SIMT Multiprocessors

The NVIDIA GPU architecture is built around a scalable array of multithreaded *Streaming Multiprocessors (SMs)*. When a host program invokes a kernel grid, the blocks of the grid are enumerated and distributed to multiprocessors with available execution capacity. The threads of a thread block execute concurrently on one multiprocessor. As thread blocks terminate, new blocks are launched on the vacated multiprocessors.

A multiprocessor consists of multiple *Scalar Processor (SP)* cores, a multithreaded instruction unit, and on-chip shared memory. The multiprocessor creates, manages, and executes concurrent threads in hardware with zero scheduling overhead. It implements a single-instruction barrier synchronization. Fast barrier synchronization together with lightweight thread creation and zero-overhead thread scheduling efficiently support very fine-grained parallelism, allowing, for example, a low granularity decomposition of problems by assigning one thread to each data element (such as a pixel in an image, a voxel in a volume, a cell in a grid-based computation).

To manage hundreds of threads running several different programs, the multiprocessor employs an architecture we call *SIMT (single-instruction, multiple-thread)*. The multiprocessor maps each thread to one scalar processor core, and each scalar thread executes independently with its own instruction address and register state. The multiprocessor SIMT unit creates, manages, schedules, and executes threads in groups of parallel threads called *warps*. (This term originates from weaving, the first parallel thread technology.) Individual threads composing a SIMT warp start together at the same program address but are otherwise free to branch and execute independently.

When a multiprocessor is given one or more thread blocks to execute, it splits them into warps that get scheduled by the SIMT unit. The way a block is split into warps is always the same; each warp contains threads of consecutive, increasing thread IDs with the first warp containing thread 0.

At every instruction issue time, the SIMT unit selects a warp that is ready to execute and issues the next instruction to the active threads of the warp. A warp executes one common instruction at a time, so full efficiency is realized when all threads of a warp agree on their execution path. If threads of a warp diverge via a data-dependent conditional branch, the warp serially executes each branch path taken, disabling threads that are not on that path, and when all paths complete, the threads converge back to the same execution path. Branch divergence occurs only within a warp; different warps execute independently regardless of whether they are executing common or disjointed code paths.

SIMT architecture is akin to SIMD (Single Instruction, Multiple Data) vector organizations in that a single instruction controls multiple processing elements. A key difference is that SIMD vector organizations expose the SIMD width to the software, whereas SIMT instructions specify the execution and branching behavior of a single thread. In contrast with SIMD vector machines, SIMT enables programmers to write thread-level parallel code for independent, scalar threads, as well as data-parallel code for coordinated threads. For the purposes of correctness, the programmer can essentially ignore the

SIMT behavior; however, substantial performance improvements can be realized by taking care that the code seldom requires threads in a warp to diverge. In practice, this is analogous to the role of cache lines in traditional code: Cache line size can be safely ignored when designing for correctness but must be considered in the code structure when designing for peak performance. Vector architectures, on the other hand, require the software to coalesce loads into vectors and manage divergence manually.

How many blocks a multiprocessor can process at once depends on how many registers per thread and how much shared memory per block are required for a given kernel since the multiprocessor's registers and shared memory are split among all the threads of the batch of blocks. If there are not enough registers or shared memory available per multiprocessor to process at least one block, the kernel will fail to launch.

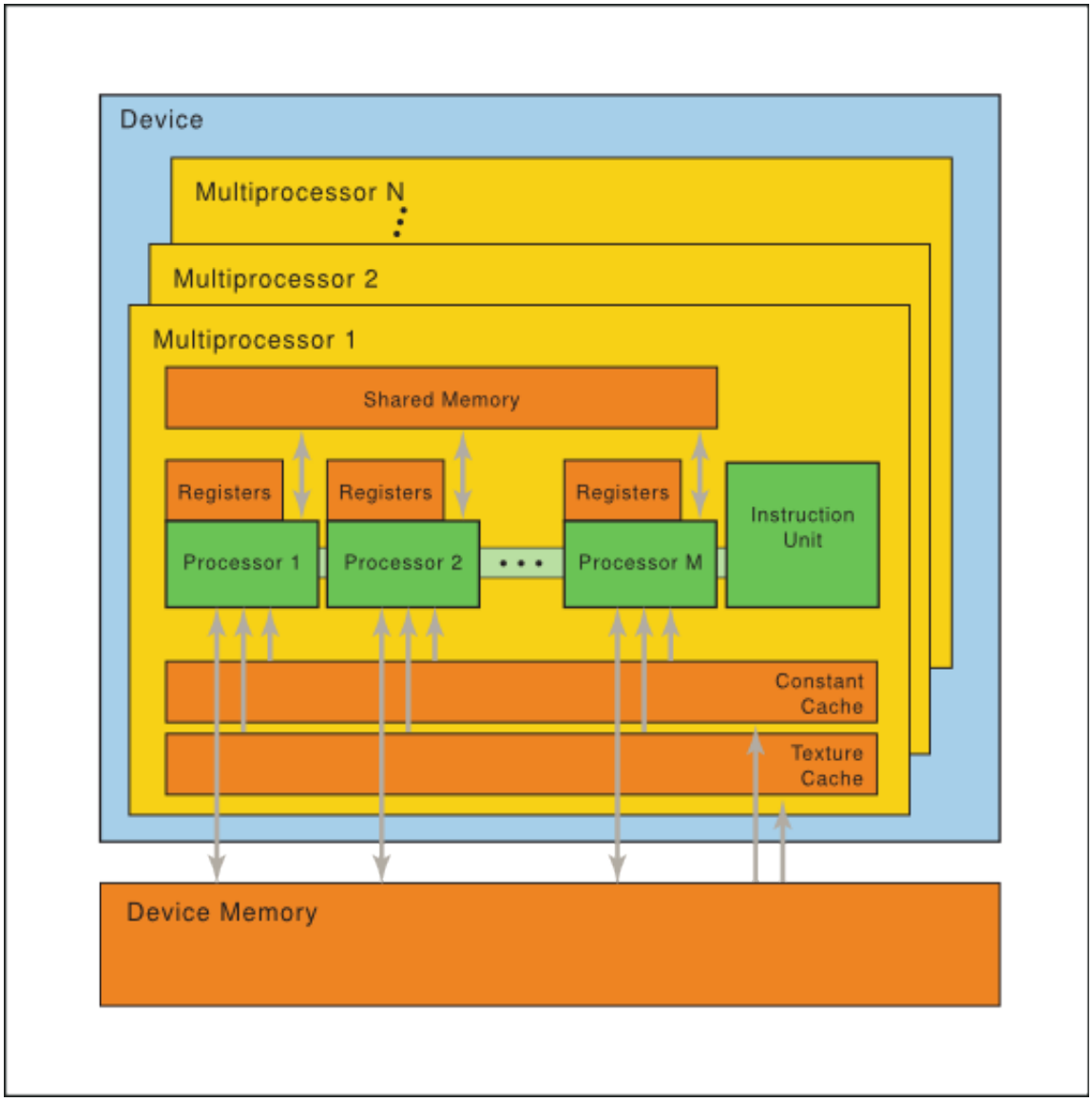

Figure 4: Hardware Model

A set of SIMT multiprocessors with on-chip shared memory.

3.2. Independent Thread Scheduling

On architectures prior to Volta, warps used a single program counter shared amongst all 32 threads in the warp together with an active mask specifying the active threads of the warp. As a result, threads from the same warp in divergent regions or different states of execution cannot signal each other or exchange data, and algorithms requiring fine-grained sharing of data guarded by locks or mutexes can easily lead to deadlock, depending on which warp the contending threads come from.

Starting with the Volta architecture, *Independent Thread Scheduling* allows full concurrency between threads, regardless of warp. With *Independent Thread Scheduling*, the GPU maintains execution state per thread, including a program counter and call stack, and can yield execution at a per-thread granularity, either to make better use of execution resources or to allow one thread to wait for data to be produced by another. A schedule optimizer determines how to group active threads from the same warp together into SIMT units. This retains the high throughput of SIMT execution as in prior NVIDIA GPUs, but with much more flexibility: threads can now diverge and reconverge at sub-warp granularity.

Independent Thread Scheduling can lead to a rather different set of threads participating in the executed code than intended if the developer made assumptions about warp-synchronicity of previous hardware architectures. In particular, any warp-synchronous code (such as synchronization-free, intra-warp reductions) should be revisited to ensure compatibility with Volta and beyond. See the section on Compute Capability 7.x in the *Cuda Programming Guide* for further details.

3.3. On-chip Shared Memory

As illustrated by Figure 4, each multiprocessor has on-chip memory of the four following types:

- One set of local 32-bit *registers* per processor,
- A parallel data cache or *shared memory* that is shared by all scalar processor cores and is where the shared memory space resides,
- A read-only *constant cache* that is shared by all scalar processor cores and speeds up reads from the constant memory space, which is a read-only region of device memory,
- A read-only *texture cache* that is shared by all scalar processor cores and speeds up reads from the texture memory space, which is a read-only region of device memory; each multiprocessor accesses the texture cache via a *texture unit* that implements the various addressing modes and data filtering.

The local and global memory spaces are read-write regions of device memory.

Chapter 4. Syntax

PTX programs are a collection of text source modules (files). PTX source modules have an assembly-language style syntax with instruction operation codes and operands. Pseudo-operations specify symbol and addressing management. The ptxas optimizing backend compiler optimizes and assembles PTX source modules to produce corresponding binary object files.

4.1. Source Format

Source modules are ASCII text. Lines are separated by the newline character (`\n`).

All whitespace characters are equivalent; whitespace is ignored except for its use in separating tokens in the language.

The C preprocessor cpp may be used to process PTX source modules. Lines beginning with # are preprocessor directives. The following are common preprocessor directives:

`#include`, `#define`, `#if`, `#ifdef`, `#else`, `#endif`, `#line`, `#file`

C: A Reference Manual by Harbison and Steele provides a good description of the C preprocessor.

PTX is case sensitive and uses lowercase for keywords.

Each PTX module must begin with a `.version` directive specifying the PTX language version, followed by a `.target` directive specifying the target architecture assumed. See *PTX Module Directives* for a more information on these directives.

4.2. Comments

Comments in PTX follow C/C++ syntax, using non-nested `/*` and `*/` for comments that may span multiple lines, and using `//` to begin a comment that extends up to the next newline character, which terminates the current line. Comments cannot occur within character constants, string literals, or within other comments.

Comments in PTX are treated as whitespace.

4.3. Statements

A PTX statement is either a directive or an instruction. Statements begin with an optional label and end with a semicolon.

Examples

```
        .reg     .b32 r1, r2;
        .global  .f32  array[N];

start:  mov.b32   r1, %tid.x;
        shl.b32   r1, r1, 2;          // shift thread id by 2 bits
        ld.global.b32 r2, array[r1];  // thread[tid] gets array[tid]
        add.f32   r2, r2, 0.5;        // add 1/2
```

4.3.1. Directive Statements

Directive keywords begin with a dot, so no conflict is possible with user-defined identifiers. The directives in PTX are listed in Table 2 and described in *State Spaces, Types, and Variables* and *Directives*.

Table 2: PTX Directives

.address_size	.explicitcluster	.maxnreg	.section
.alias	.extern	.maxntid	.shared
.align	.file	.minnctapersm	.sreg
.branchtargets	.func	.noreturn	.target
.callprototype	.global	.param	.tex
.calltargets	.loc	.pragma	.version
.common	.local	.reg	.visible
.const	.maxclusterrank	.reqnctapercluster	.weak
.entry	.maxnctapersm	.reqntid	

4.3.2. Instruction Statements

Instructions are formed from an instruction opcode followed by a comma-separated list of zero or more operands, and terminated with a semicolon. Operands may be register variables, constant expressions, address expressions, or label names. Instructions have an optional guard predicate which controls conditional execution. The guard predicate follows the optional label and precedes the opcode, and is written as `@p`, where `p` is a predicate register. The guard predicate may be optionally negated, written as `@!p`.

The destination operand is first, followed by source operands.

Instruction keywords are listed in Table 3. All instruction keywords are reserved tokens in PTX.

Table 3: Reserved Instruction Keywords

abs	cvta	membar	setp	vabsdiff
activemask	discard	min	shf	vabsdiff2
add	div	mma	shfl	vabsdiff4
addc	dp2a	mov	shl	vadd
alloca	dp4a	movmatrix	shr	vadd2
and	elect	mul	sin	vadd4
applypriority	ex2	mul24	slct	vavrg2
atom	exit	multimem	sqrt	vavrg4
bar	fence	nanosleep	st	vmad
barrier	fma	neg	stackrestore	vmax
bfe	fns	not	stacksave	vmax2
bfi	getctarank	or	stmatrix	vmax4
bfind	griddepcontrol	pmevent	sub	vmin
bmsk	isspacep	popc	subc	vmin2
bra	istypep	prefetch	suld	vmin4
brev	ld	prefetchu	suq	vote
brkpt	ldmatrix	prmt	sured	vset
brx	ldu	rcp	sust	vset2
call	lg2	red	szext	vset4
clz	lop3	redux	tanh	vshl
cnot	mad	rem	tcgen05	vshr
copysign	mad24	ret	tensormap	vsub
cos	madc	rsqrt	testp	vsub2
clusterlaunchcontrol	mapa	sad	tex	vsub4
cp	match	selp	tld4	wgmma
createpolicy	max	set	trap	wmma
cvt	mbarrier	setmaxnreg	txq	xor

4.4. Identifiers

User-defined identifiers follow extended C++ rules: they either start with a letter followed by zero or more letters, digits, underscore, or dollar characters; or they start with an underscore, dollar, or percentage character followed by one or more letters, digits, underscore, or dollar characters:

```
followsym:   [a-zA-Z0-9_$]
identifier:  [a-zA-Z]{followsym}* | {[_$%]{followsym}+
```

PTX does not specify a maximum length for identifiers and suggests that all implementations support a minimum length of at least 1024 characters.

Many high-level languages such as C and C++ follow similar rules for identifier names, except that the percentage sign is not allowed. PTX allows the percentage sign as the first character of an identifier. The percentage sign can be used to avoid name conflicts, e.g., between user-defined variable names and compiler-generated names.

PTX predefines one constant and a small number of special registers that begin with the percentage sign, listed in Table 4.

Table 4: Predefined Identifiers

%aggr_smem_size	%dynamic_smem_size	%lanemask_gt	%reserved_smem_offset_begin
%clock	%envreg<32>	%lanemask_le	%reserved_smem_offset_cap
%clock64	%globaltimer	%lanemask_lt	%reserved_smem_offset_end
%cluster_ctaid	%globaltimer_hi	%nclusterid	%smid
%cluster_ctarank	%globaltimer_lo	%nctaid	%tid
%cluster_nctaid	%gridid	%nsmid	%total_smem_size
%cluster_nctarank	%is_explicit_cluster	%ntid	%warpid
%clusterid	%laneid	%nwarpid	WARP_SZ
%ctaid	%lanemask_eq	%pm0, ..., %pm7	
%current_graph_exec	%lanemask_ge	%reserved_smem_offset_<2>	

4.5. Constants

PTX supports integer and floating-point constants and constant expressions. These constants may be used in data initialization and as operands to instructions. Type checking rules remain the same for integer, floating-point, and bit-size types. For predicate-type data and instructions, integer constants are allowed and are interpreted as in C, i.e., zero values are `False` and non-zero values are `True`.

4.5.1. Integer Constants

Integer constants are 64-bits in size and are either signed or unsigned, i.e., every integer constant has type `.s64` or `.u64`. The signed/unsigned nature of an integer constant is needed to correctly evaluate constant expressions containing operations such as division and ordered comparisons, where the behavior of the operation depends on the operand types. When used in an instruction or data initialization, each integer constant is converted to the appropriate size based on the data or instruction type at its use.

Integer literals may be written in decimal, hexadecimal, octal, or binary notation. The syntax follows that of C. Integer literals may be followed immediately by the letter U to indicate that the literal is unsigned.

```
hexadecimal literal:  0[xX]{hexdigit}+U?
octal literal:        0{octal digit}+U?
binary literal:       0[bB]{bit}+U?
decimal literal       {nonzero-digit}{digit}*U?
```

Integer literals are non-negative and have a type determined by their magnitude and optional type suffix as follows: literals are signed (`.s64`) unless the value cannot be fully represented in `.s64` or the unsigned suffix is specified, in which case the literal is unsigned (`.u64`).

The predefined integer constant `WARP_SZ` specifies the number of threads per warp for the target platform; to date, all target architectures have a `WARP_SZ` value of 32.

4.5.2. Floating-Point Constants

Floating-point constants are represented as 64-bit double-precision values, and all floating-point constant expressions are evaluated using 64-bit double precision arithmetic. The only exception is the 32-bit hex notation for expressing an exact single-precision floating-point value; such values retain their exact 32-bit single-precision value and may not be used in constant expressions. Each 64-bit floating-point constant is converted to the appropriate floating-point size based on the data or instruction type at its use.

Floating-point literals may be written with an optional decimal point and an optional signed exponent. Unlike C and C++, there is no suffix letter to specify size; literals are always represented in 64-bit double-precision format.

PTX includes a second representation of floating-point constants for specifying the exact machine representation using a hexadecimal constant. To specify IEEE 754 double-precision floating point values, the constant begins with `0d` or `0D` followed by 16 hex digits. To specify IEEE 754 single-precision floating point values, the constant begins with `0f` or `0F` followed by 8 hex digits.

```
0[fF]{hexdigit}{8}      // single-precision floating point
0[dD]{hexdigit}{16}     // double-precision floating point
```

Example

```
mov.f32  $f3, 0F3f800000;       //  1.0
```

4.5.3. Predicate Constants

In PTX, integer constants may be used as predicates. For predicate-type data initializers and instruction operands, integer constants are interpreted as in C, i.e., zero values are `False` and non-zero values are `True`.

4.5.4. Constant Expressions

In PTX, constant expressions are formed using operators as in C and are evaluated using rules similar to those in C, but simplified by restricting types and sizes, removing most casts, and defining full semantics to eliminate cases where expression evaluation in C is implementation dependent.

Constant expressions are formed from constant literals, unary plus and minus, basic arithmetic operators (addition, subtraction, multiplication, division), comparison operators, the conditional ternary operator (`?:`), and parentheses. Integer constant expressions also allow unary logical negation (`!`), bitwise complement (~), remainder (%), shift operators (<< and >>), bit-type operators (&, |, and ^), and logical operators (&&, ||).

Constant expressions in PTX do not support casts between integer and floating-point.

Constant expressions are evaluated using the same operator precedence as in C. Table 5 gives operator precedence and associativity. Operator precedence is highest for unary operators and decreases with each line in the chart. Operators on the same line have the same precedence and are evaluated right-to-left for unary operators and left-to-right for binary operators.

Table 5: Operator Precedence

Kind	Operator Symbols	Operator Names	Associates
Primary	`( )`	parenthesis	n/a
Unary	`+- ! ~`	plus, minus, negation, complement	right
	`(.s64)(.u64)`	casts	right
Binary	`*/ %`	multiplication, division, remainder	left
	`+-`	addition, subtraction	
	`>> <<`	shifts	
	`< > <= >=`	ordered comparisons	
	`== !=`	equal, not equal	
	`&`	bitwise AND	
	`^`	bitwise XOR	
	`|`	bitwise OR	
	`&&`	logical AND	
	`||`	logical OR	
Ternary	`?:`	conditional	right

4.5.5. Integer Constant Expression Evaluation

Integer constant expressions are evaluated at compile time according to a set of rules that determine the type (signed `.s64` versus unsigned `.u64`) of each sub-expression. These rules are based on the rules in C, but they've been simplified to apply only to 64-bit integers, and behavior is fully defined in all cases (specifically, for remainder and shift operators).

- Literals are signed unless unsigned is needed to prevent overflow, or unless the literal uses a U suffix. For example:
  - 42, `0x1234`, `0123` are signed.
  - `0xfabc123400000000`, `42U`, `0x1234U` are unsigned.
- Unary plus and minus preserve the type of the input operand. For example:
  - `+123`, `-1`, `-(-42)` are signed.
  - `-1U`, `-0xfabc123400000000` are unsigned.
- Unary logical negation (`!`) produces a signed result with value `0` or `1`.
- Unary bitwise complement (`~`) interprets the source operand as unsigned and produces an unsigned result.
- Some binary operators require normalization of source operands. This normalization is known as *the usual arithmetic conversions* and simply converts both operands to unsigned type if either operand is unsigned.

- Addition, subtraction, multiplication, and division perform the usual arithmetic conversions and produce a result with the same type as the converted operands. That is, the operands and result are unsigned if either source operand is unsigned, and is otherwise signed.
- Remainder (%) interprets the operands as unsigned. Note that this differs from C, which allows a negative divisor but defines the behavior to be implementation dependent.
- Left and right shift interpret the second operand as unsigned and produce a result with the same type as the first operand. Note that the behavior of right-shift is determined by the type of the first operand: right shift of a signed value is arithmetic and preserves the sign, and right shift of an unsigned value is logical and shifts in a zero bit.
- AND (&), OR (|), and XOR (^) perform the usual arithmetic conversions and produce a result with the same type as the converted operands.
- AND_OP (&&), OR_OP (||), Equal (==), and Not_Equal (!=) produce a signed result. The result value is 0 or 1.
- Ordered comparisons (<, <=, >, >=) perform the usual arithmetic conversions on source operands and produce a signed result. The result value is 0 or 1.
- Casting of expressions to signed or unsigned is supported using (.s64) and (.u64) casts.
- For the conditional operator (? :) , the first operand must be an integer, and the second and third operands are either both integers or both floating-point. The usual arithmetic conversions are performed on the second and third operands, and the result type is the same as the converted type.

4.5.6. Summary of Constant Expression Evaluation Rules

Table 6 contains a summary of the constant expression evaluation rules.

Table 6: Constant Expression Evaluation Rules

Kind	Operator	Operand Types	Operand Interpretation	Result Type
Primary	( )	any type	same as source	same as source
	constant literal	n/a	n/a	.u64, .s64, or .f64
Unary	+-	any type	same as source	same as source
	!	integer	zero or non-zero	.s64
	~	integer	.u64	.u64
Cast	(.u64)	integer	.u64	.u64
	(.s64)	integer	.s64	.s64
Binary	+- * /	.f64	.f64	.f64
		integer	use usual conversions	converted type
	< > <= >=	.f64	.f64	.s64
		integer	use usual conversions	.s64
	== !=	.f64	.f64	.s64
		integer	use usual conversions	.s64
	%	integer	.u64	.s64
	>> <<	integer	1st unchanged, 2nd is .u64	same as 1st operand
	& | ^	integer	.u64	.u64
	&& ||	integer	zero or non-zero	.s64
Ternary	?:	int ? .f64 : .f64	same as sources	.f64
		int ? int : int	use usual conversions	converted type

Chapter 5. State Spaces, Types, and Variables

While the specific resources available in a given target GPU will vary, the kinds of resources will be common across platforms, and these resources are abstracted in PTX through state spaces and data types.

5.1. State Spaces

A state space is a storage area with particular characteristics. All variables reside in some state space. The characteristics of a state space include its size, addressability, access speed, access rights, and level of sharing between threads.

The state spaces defined in PTX are a byproduct of parallel programming and graphics programming. The list of state spaces is shown in Table 7,and properties of state spaces are shown in Table 8.

Table 7: State Spaces

Name	Description
`.reg`	Registers, fast.
`.sreg`	Special registers. Read-only; pre-defined; platform-specific.
`.const`	Shared, read-only memory.
`.global`	Global memory, shared by all threads.
`.local`	Local memory, private to each thread.
`.param`	Kernel parameters, defined per-grid; or Function or local parameters, defined per-thread.
`.shared`	Addressable memory, defined per CTA, accessible to all threads in the cluster throughout the lifetime of the CTA that defines it.
`.tex`	Global texture memory (deprecated).

Table 8: Properties of State Spaces

Name	Addressable	Initializable	Access	Sharing
`.reg`	No	No	R/W	per-thread
`.sreg`	No	No	RO	per-CTA
`.const`	Yes	Yes[1]	RO	per-grid
`.global`	Yes	Yes[1]	R/W	Context
`.local`	Yes	No	R/W	per-thread
`.param` (as input to kernel)	Yes[2]	No	RO	per-grid
`.param` (used in functions)	Restricted[3]	No	R/W	per-thread
`.shared`	Yes	No	R/W	per-cluster[5]
`.tex`	No[4]	Yes, via driver	RO	Context

Notes:
[1] Variables in `.const` and `.global` state spaces are initialized to zero by default.
[2] Accessible only via the `ld.param{::entry}` instruction. Address may be taken via `mov` instruction.
[3] Accessible via `ld.param{::func}` and `st.param{::func}` instructions. Device function input and return parameters may have their address taken via `mov`; the parameter is then located on the stack frame and its address is in the `.local` state space.
[4] Accessible only via the `tex` instruction.
[5] Visible to the owning CTA and other active CTAs in the cluster.

5.1.1. Register State Space

Registers (`.reg` state space) are fast storage locations. The number of registers is limited, and will vary from platform to platform. When the limit is exceeded, register variables will be spilled to memory, causing changes in performance. For each architecture, there is a recommended maximum number of registers to use (see the *CUDA Programming Guide* for details).

Registers may be typed (signed integer, unsigned integer, floating point, predicate) or untyped. Register size is restricted; aside from predicate registers which are 1-bit, scalar registers have a width of 8-, 16-, 32-, 64-, or 128-bits, and vector registers have a width of 16-, 32-, 64-, or 128-bits. The most common use of 8-bit registers is with `ld`, `st`, and `cvt` instructions, or as elements of vector tuples.

Registers differ from the other state spaces in that they are not fully addressable, i.e., it is not possible to refer to the address of a register. When compiling to use the Application Binary Interface (ABI), register variables are restricted to function scope and may not be declared at module scope. When compiling legacy PTX code (ISA versions prior to 3.0) containing module-scoped `.reg` variables, the compiler silently disables use of the ABI. Registers may have alignment boundaries required by multi-word loads and stores.

5.1.2. Special Register State Space

The special register (`.sreg`) state space holds predefined, platform-specific registers, such as grid, cluster, CTA, and thread parameters, clock counters, and performance monitoring registers. All special registers are predefined.

5.1.3. Constant State Space

The constant (`.const`) state space is a read-only memory initialized by the host. Constant memory is accessed with a `ld.const` instruction. Constant memory is restricted in size, currently limited to 64 KB which can be used to hold statically-sized constant variables. There is an additional 640 KB of constant memory, organized as ten independent 64 KB regions. The driver may allocate and initialize constant buffers in these regions and pass pointers to the buffers as kernel function parameters. Since the ten regions are not contiguous, the driver must ensure that constant buffers are allocated so that each buffer fits entirely within a 64 KB region and does not span a region boundary.

Statically-sized constant variables have an optional variable initializer; constant variables with no explicit initializer are initialized to zero by default. Constant buffers allocated by the driver are initialized by the host, and pointers to such buffers are passed to the kernel as parameters. See the description of kernel parameter attributes in *Kernel Function Parameter Attributes* for more details on passing pointers to constant buffers as kernel parameters.

5.1.3.1 Banked Constant State Space (deprecated)

Previous versions of PTX exposed constant memory as a set of eleven 64 KB banks, with explicit bank numbers required for variable declaration and during access.

Prior to PTX ISA version 2.2, the constant memory was organized into fixed size banks. There were eleven 64 KB banks, and banks were specified using the `.const[bank]` modifier, where *bank* ranged from 0 to 10. If no bank number was given, bank zero was assumed.

By convention, bank zero was used for all statically-sized constant variables. The remaining banks were used to declare *incomplete* constant arrays (as in C, for example), where the size is not known at compile time. For example, the declaration

```
.extern .const[2] .b32 const_buffer[];
```

resulted in `const_buffer` pointing to the start of constant bank two. This pointer could then be used to access the entire 64 KB constant bank. Multiple incomplete array variables declared in the same bank were aliased, with each pointing to the start address of the specified constant bank.

To access data in contant banks 1 through 10, the bank number was required in the state space of the load instruction. For example, an incomplete array in bank 2 was accessed as follows:

```
.extern .const[2] .b32 const_buffer[];
ld.const[2].b32  %r1, [const_buffer+4]; // load second word
```

In PTX ISA version 2.2, we eliminated explicit banks and replaced the incomplete array representation of driver-allocated constant buffers with kernel parameter attributes that allow pointers to constant buffers to be passed as kernel parameters.

5.1.4. Global State Space

The global (`.global`) state space is memory that is accessible by all threads in a context. It is the mechanism by which threads in different CTAs, clusters, and grids can communicate. Use `ld.global`, `st.global`, and `atom.global` to access global variables.

Global variables have an optional variable initializer; global variables with no explicit initializer are initialized to zero by default.

5.1.5. Local State Space

The local state space (`.local`) is private memory for each thread to keep its own data. It is typically standard memory with cache. The size is limited, as it must be allocated on a per-thread basis. Use `ld.local` and `st.local` to access local variables.

When compiling to use the *Application Binary Interface (ABI)*, `.local` state-space variables must be declared within function scope and are allocated on the stack. In implementations that do not support a stack, all local memory variables are stored at fixed addresses, recursive function calls are not supported, and `.local` variables may be declared at module scope. When compiling legacy PTX code (ISA versions prior to 3.0) containing module-scoped `.local` variables, the compiler silently disables use of the ABI.

5.1.6. Parameter State Space

The parameter (`.param`) state space is used (1) to pass input arguments from the host to the kernel, (2a) to declare formal input and return parameters for device functions called from within kernel execution, and (2b) to declare locally-scoped byte array variables that serve as function call arguments, typically for passing large structures by value to a function. Kernel function parameters differ from device function parameters in terms of access and sharing (read-only versus read-write, per-kernel versus per-thread). Note that PTX ISA versions 1.x supports only kernel function parameters in .param space; device function parameters were previously restricted to the register state space. The use of parameter state space for device function parameters was introduced in PTX ISA version 2.0 and requires target architecture `sm_20` or higher. Additional sub-qualifiers `::entry` or `::func` can be specified on instructions with `.param` state space to indicate whether the address refers to kernel function parameter or device function parameter. If no sub-qualifier is specified with the `.param` state space, then the default sub-qualifier is specific to and dependent on the exact instruction. For example, `st.param` is equivalent to `st.param::func` whereas `isspacep.param` is equivalent to `isspacep.param::entry`. Refer to the instruction description for more details on default sub-qualifier assumption.

Note: The location of parameter space is implementation specific. For example, in some implementations kernel parameters reside in global memory. No access protection is provided between parameter and global space in this case. Though the exact location of the kernel parameter space is implementation specific, the kernel parameter space window is always contained within the global space window. Similarly, function parameters are mapped to parameter passing registers and/or stack locations based on the function calling conventions of the *Application Binary Interface (ABI)*. Therefore, PTX code should make no assumptions about the relative locations or ordering of `.param` space variables.

5.1.6.1 Kernel Function Parameters

Each kernel function definition includes an optional list of parameters. These parameters are addressable, read-only variables declared in the `.param` state space. Values passed from the host to the kernel are accessed through these parameter variables using `ld.param` instructions. The kernel parameter variables are shared across all CTAs from all clusters within a grid.

The address of a kernel parameter may be moved into a register using the `mov` instruction. The resulting address is in the `.param` state space and is accessed using `ld.param` instructions.

Example

```
.entry foo ( .param .b32 N, .param .align 8 .b8 buffer[64] )
{
    .reg .u32 %n;
    .reg .f64 %d;

    ld.param.u32 %n, [N];
    ld.param.f64 %d, [buffer];
    ...
```

Example

```
.entry bar ( .param .b32 len )
{
    .reg .u32 %ptr, %n;

    mov.u32      %ptr, len;
    ld.param.u32 %n, [%ptr];
    ...
```

Kernel function parameters may represent normal data values, or they may hold addresses to objects in constant, global, local, or shared state spaces. In the case of pointers, the compiler and runtime system need information about which parameters are pointers, and to which state space they point. Kernel parameter attribute directives are used to provide this information at the PTX level. See *Kernel Function Parameter Attributes* for a description of kernel parameter attribute directives.

Note: The current implementation does not allow creation of generic pointers to constant variables (`cvta.const`) in programs that have pointers to constant buffers passed as kernel parameters.

5.1.6.2 Kernel Function Parameter Attributes

Kernel function parameters may be declared with an optional .ptr attribute to indicate that a parameter is a pointer to memory, and also indicate the state space and alignment of the memory being pointed to. *Kernel Parameter Attribute: .ptr* describes the `.ptr` kernel parameter attribute.

5.1.6.3 Kernel Parameter Attribute: .ptr

.ptr

Kernel parameter alignment attribute.

Syntax

```
.param .type .ptr .space .align N  varname
.param .type .ptr        .align N  varname

.space = { .const, .global, .local, .shared };
```

Description

Used to specify the state space and, optionally, the alignment of memory pointed to by a pointer type kernel parameter. The alignment value *N*, if present, must be a power of two. If no state space is specified, the pointer is assumed to be a generic address pointing to one of const, global, local, or shared memory. If no alignment is specified, the memory pointed to is assumed to be aligned to a 4 byte boundary.

Spaces between `.ptr`, `.space`, and `.align` may be eliminated to improve readability.

PTX ISA Notes

- Introduced in PTX ISA version 2.2.
- Support for generic addressing of .const space added in PTX ISA version 3.1.

Target ISA Notes

- Supported on all target architectures.

Examples

```
.entry foo ( .param .u32 param1,
             .param .u32 .ptr.global.align 16 param2,
             .param .u32 .ptr.const.align 8 param3,
             .param .u32 .ptr.align 16 param4  // generic address
                                               // pointer
) { .. }
```

5.1.6.4 Device Function Parameters

PTX ISA version 2.0 extended the use of parameter space to device function parameters. The most common use is for passing objects by value that do not fit within a PTX register, such as C structures larger than 8 bytes. In this case, a byte array in parameter space is used. Typically, the caller will declare a locally-scoped `.param` byte array variable that represents a flattened C structure or union. This will be passed by value to a callee, which declares a `.param` formal parameter having the same size and alignment as the passed argument.

Example

```
// pass object of type struct { double d; int y; };
.func foo ( .reg .b32 N, .param .align 8 .b8 buffer[12] )
{
    .reg .f64 %d;
    .reg .s32 %y;

    ld.param.f64 %d, [buffer];
    ld.param.s32 %y, [buffer+8];
    ...
}

// code snippet from the caller
// struct { double d; int y; } mystruct; is flattened, passed to foo
    ...
    .reg .f64 dbl;
    .reg .s32 x;
    .param .align 8 .b8 mystruct;
    ...
    st.param.f64 [mystruct+0], dbl;
    st.param.s32 [mystruct+8], x;
    call foo, (4, mystruct);
    ...
```

See the section on function call syntax for more details.

Function input parameters may be read via `ld.param` and function return parameters may be written using `st.param`; it is illegal to write to an input parameter or read from a return parameter.

Aside from passing structures by value, `.param` space is also required whenever a formal parameter has its address taken within the called function. In PTX, the address of a function input parameter may be moved into a register using the `mov` instruction. Note that the parameter will be copied to the stack if necessary, and so the address will be in the `.local` state space and is accessed via `ld.local` and `st.local` instructions. It is not possible to use `mov` to get the address of or a locally-scoped `.param` space variable. Starting PTX ISA version 6.0, it is possible to use `mov` instruction to get address of return parameter of device function.

Example

```
// pass array of up to eight floating-point values in buffer
.func foo ( .param .b32 N, .param .b32 buffer[32] )
{
    .reg .u32  %n, %r;
    .reg .f32  %f;
    .reg .pred %p;

    ld.param.u32 %n, [N];
    mov.u32      %r, buffer;  // forces buffer to .local state space
Loop:
    setp.eq.u32  %p, %n, 0;
@%p bra         Done;
    ld.local.f32 %f, [%r];
    ...
    add.u32      %r, %r, 4;
    sub.u32      %n, %n, 1;
    bra          Loop;
Done:
    ...
}
```

5.1.7. Shared State Space

The shared (`.shared`) state space is a memory that is owned by an executing CTA and is accessible to the threads of all the CTAs within a cluster. An address in shared memory can be read and written by any thread in a CTA cluster.

Additional sub-qualifiers `::cta` or `::cluster` can be specified on instructions with `.shared` state space to indicate whether the address belongs to the shared memory window of the executing CTA or of any CTA in the cluster respectively. The addresses in the `.shared::cta` window also fall within the `.shared::cluster` window. If no sub-qualifier is specified with the `.shared` state space, then it defaults to `::cta`. For example, `ld.shared` is equivalent to `ld.shared::cta`.

Variables declared in `.shared` state space refer to the memory addresses in the current CTA. Instruction `mapa` gives the `.shared::cluster` address of the corresponding variable in another CTA in the cluster.

Shared memory typically has some optimizations to support the sharing. One example is broadcast; where all threads read from the same address. Another is sequential access from sequential threads.

5.1.8. Texture State Space (deprecated)

The texture (`.tex`) state space is global memory accessed via the texture instruction. It is shared by all threads in a context. Texture memory is read-only and cached, so accesses to texture memory are not coherent with global memory stores to the texture image.

The GPU hardware has a fixed number of texture bindings that can be accessed within a single kernel (typically 128). The .tex directive will bind the named texture memory variable to a hardware texture identifier, where texture identifiers are allocated sequentially beginning with zero. Multiple names may be bound to the same physical texture identifier. An error is generated if the maximum number of physical resources is exceeded. The texture name must be of type `.u32` or `.u64`.

Physical texture resources are allocated on a per-kernel granularity, and `.tex` variables are required to be defined in the global scope.

Texture memory is read-only. A texture's base address is assumed to be aligned to a 16 byte boundary.

Example

```
.tex .u32 tex_a;         // bound to physical texture 0
.tex .u32 tex_c, tex_d;  // both bound to physical texture 1
.tex .u32 tex_d;         // bound to physical texture 2
.tex .u32 tex_f;         // bound to physical texture 3
```

Note: Explicit declarations of variables in the texture state space is deprecated, and programs should instead reference texture memory through variables of type `.texref`. The `.tex` directive is retained for backward compatibility, and variables declared in the `.tex` state space are equivalent to module-scoped `.texref` variables in the `.global` state space.

For example, a legacy PTX definitions such as

```
.tex .u32 tex_a;
```

is equivalent to:

```
.global .texref tex_a;
```

See *Texture Sampler and Surface Types* for the description of the `.texref` type and *Texture Instructions* for its use in texture instructions.

5.2. Types

5.2.1. Fundamental Types

In PTX, the fundamental types reflect the native data types supported by the target architectures. A fundamental type specifies both a basic type and a size. Register variables are always of a fundamental type, and instructions operate on these types. The same type-size specifiers are used for both variable definitions and for typing instructions, so their names are intentionally short.

Table 9 lists the fundamental type specifiers for each basic type:

Table 9: Fundamental Type Specifiers

Basic Type	Fundamental Type Specifiers
Signed integer	`.s8`, `.s16`, `.s32`, `.s64`
Unsigned integer	`.u8`, `.u16`, `.u32`, `.u64`
Floating-point	`.f16`, `.f16x2`, `.f32`, `.f64`
Bits (untyped)	`.b8`, `.b16`, `.b32`, `.b64`, `.b128`
Predicate	`.pred`

Most instructions have one or more type specifiers, needed to fully specify instruction behavior. Operand types and sizes are checked against instruction types for compatibility.

Two fundamental types are compatible if they have the same basic type and are the same size. Signed and unsigned integer types are compatible if they have the same size. The bit-size type is compatible with any fundamental type having the same size.

In principle, all variables (aside from predicates) could be declared using only bit-size types, but typed variables enhance program readability and allow for better operand type checking.

5.2.2. Restricted Use of Sub-Word Sizes

The `.u8`, `.s8`, and `.b8` instruction types are restricted to `ld`, `st`, and `cvt` instructions. The `.f16` floating-point type is allowed only in conversions to and from `.f32`, `.f64` types, in half precision floating point instructions and texture fetch instructions. The `.f16x2` floating point type is allowed only in half precision floating point arithmetic instructions and texture fetch instructions.

For convenience, `ld`, `st`, and `cvt` instructions permit source and destination data operands to be wider than the instruction-type size, so that narrow values may be loaded, stored, and converted using regular-width registers. For example, 8-bit or 16-bit values may be held directly in 32-bit or 64-bit registers when being loaded, stored, or converted to other types and sizes.

5.2.3. Alternate Floating-Point Data Formats

The fundamental floating-point types supported in PTX have implicit bit representations that indicate the number of bits used to store exponent and mantissa. For example, the `.f16` type indicates 5 bits reserved for exponent and 10 bits reserved for mantissa. In addition to the floating-point representations assumed by the fundamental types, PTX allows the following alternate floating-point data formats:

`bf16` data format:
This data format is a 16-bit floating point format with 8 bits for exponent and 7 bits for mantissa. A register variable containing `bf16` data must be declared with `.b16` type.

`e4m3` data format:
This data format is an 8-bit floating point format with 4 bits for exponent and 3 bits for mantissa. The `e4m3` encoding does not support infinity and `NaN` values are limited to `0x7f` and `0xff`. A register variable containing `e4m3` value must be declared using bit-size type.

`e5m2` data format:
This data format is an 8-bit floating point format with 5 bits for exponent and 2 bits for mantissa. A register variable containing `e5m2` value must be declared using bit-size type.

`tf32` data format:
This data format is a special 32-bit floating point format supported by the matrix multiply-and-accumulate instructions, with the same range as `.f32` and reduced precision (>=10 bits). The internal layout of `tf32` format is implementation defined. PTX facilitates conversion from single precision `.f32` type to `tf32` format. A register variable containing `tf32` data must be declared with `.b32` type.

`e2m1` data format:
This data format is a 4-bit floating point format with 2 bits for exponent and 1 bit for mantissa. The `e2m1` encoding does not support infinity and `NaN`. `e2m1` values must be used in a packed

format specified as `e2m1x2`. A register variable containing two `e2m1` values must be declared with `.b8` type.

`e2m3` data format:
This data format is a 6-bit floating point format with 2 bits for exponent and 3 bits for mantissa. The `e2m3` encoding does not support infinity and `NaN`. `e2m3` values must be used in a packed format specified as `e2m3x2`. A register variable containing two `e2m3` values must be declared with `.b16` type where each `.b8` element has 6-bit floating point value and 2 MSB bits padded with zeros.

`e3m2` data format:
This data format is a 6-bit floating point format with 3 bits for exponent and 2 bits for mantissa. The `e3m2` encoding does not support infinity and `NaN`. `e3m2` values must be used in a packed format specified as `e3m2x2`. A register variable containing two `e3m2` values must be declared with `.b16` type where each `.b8` element has 6-bit floating point value and 2 MSB bits padded with zeros.

`ue8m0` data format:
This data format is an 8-bit unsigned floating-point format with 8 bits for exponent and 0 bits for mantissa. The `ue8m0` encoding does not support infinity. `NaN` value is limited to `0xff`. `ue8m0` values must be used in a packed format specified as `ue8m0x2`. A register variable containing two `ue8m0` values must be declared with `.b16` type.

`ue4m3` data format:
This data format is a 7-bit unsigned floating-point format with 4 bits for exponent and 3 bits for mantissa. The `ue4m3` encoding does not support infinity. `NaN` value is limited to `0x7f`. A register variable containing single `ue4m3` value must be declared with `.b8` type having MSB bit padded with zero.

Alternate data formats cannot be used as fundamental types. They are supported as source or destination formats by certain instructions.

5.2.4. Packed Data Types

Certain PTX instructions operate on two or more sets of inputs in parallel, and produce two or more outputs. Such instructions can use the data stored in a packed format. PTX supports packing two or four values of the same scalar data type into a single, larger value. The packed value is considered as a value of a *packed data type*. In this section we describe the packed data types supported in PTX.

5.2.4.1 Packed Floating Point Data Types

PTX supports various variants of packed floating point data types. Out of them, only `.f16x2` is supported as a fundamental type, while others cannot be used as fundamental types - they are supported as instruction types on certain instructions. When using an instruction with such non-fundamental types, the operand data variables must be of bit type of appropriate size. For example, all of the operand variables must be of type `.b32` for an instruction with instruction type as `.bf16x2`. Table 10 described various variants of packed floating point data types in PTX.

Table 10: Operand types for packed floating point instruction type.

Packed floating point type	Number of elements contained in a packed format	Type of each element	Register variable type to be used in the declaration
.f16x2	Two	.f16	.f16x2 or .b32
.f32x2		.f32	.b64
.bf16x2		.bf16	.b32
.e4m3x2		.e4m3	.b16
.e5m2x2		.e5m2	
.e2m3x2		.e2m3	
.e3m2x2		.e3m2	
.ue8m0x2		.ue8m0	
.e2m1x2		.e2m1	.b8
.e4m3x4	Four	.e4m3	.b32
.e5m2x4		.e5m2	
.e2m3x4		.e2m3	
.e3m2x4		.e3m2	
.e2m1x4		.e2m1	

5.2.4.2 Packed Integer Data Types

PTX supports two variants of packed integer data types: .u16x2 and .s16x2. The packed data type consists of two .u16 or .s16 values. A register variable containing .u16x2 or .s16x2 data must be declared with .b32 type. Packed integer data types cannot be used as fundamental types. They are supported as instruction types on certain instructions.

5.3. Texture Sampler and Surface Types

PTX includes built-in *opaque* types for defining texture, sampler, and surface descriptor variables. These types have named fields similar to structures, but all information about layout, field ordering, base address, and overall size is hidden to a PTX program, hence the term *opaque*. The use of these opaque types is limited to:

- Variable definition within global (module) scope and in kernel entry parameter lists.
- Static initialization of module-scope variables using comma-delimited static assignment expressions for the named members of the type.
- Referencing textures, samplers, or surfaces via texture and surface load/store instructions (tex, suld, sust, sured).
- Retrieving the value of a named member via query instructions (txq, suq).

- Creating pointers to opaque variables using `mov`, e.g., `mov.u64 reg, opaque_var;`. The resulting pointer may be stored to and loaded from memory, passed as a parameter to functions, and de-referenced by texture and surface load, store, and query instructions, but the pointer cannot otherwise be treated as an address, i.e., accessing the pointer with `ld` and `st` instructions, or performing pointer arithmetic will result in undefined results.
- Opaque variables may not appear in initializers, e.g., to initialize a pointer to an opaque variable.

Note: Indirect access to textures and surfaces using pointers to opaque variables is supported beginning with PTX ISA version 3.1 and requires target `sm_20` or later.

Indirect access to textures is supported only in unified texture mode (see below).

The three built-in types are `.texref`, `.samplerref`, and `.surfref`. For working with textures and samplers, PTX has two modes of operation. In the *unified mode,* texture and sampler information is accessed through a single `.texref` handle. In the *independent mode*, texture and sampler information each have their own handle, allowing them to be defined separately and combined at the site of usage in the program. In independent mode, the fields of the `.texref` type that describe sampler properties are ignored, since these properties are defined by `.samplerref` variables.

Table 11 and Table 12 list the named members of each type for unified and independent texture modes. These members and their values have precise mappings to methods and values defined in the texture `HW` class as well as exposed values via the API.

Table 11: Opaque Type Fields in Unified Texture Mode

Member	.texref values	.surfref values
`width`	in elements	
`height`	in elements	
`depth`	in elements	
`channel_data_type`	`enum` type corresponding to source language API	
`channel_order`	`enum` type corresponding to source language API	
`normalized_coords`	`0`, `1`	N/A
`filter_mode`	`nearest`, `linear`	N/A
`addr_mode_0`, `addr_mode_1`, `addr_mode_2`	`wrap`, `mirror`, `clamp_ogl`, `clamp_to_edge`, `clamp_to_border`	N/A
`array_size`	as number of textures in a texture array	as number of surfaces in a surface array
`num_mipmap_levels`	as number of levels in a mipmapped texture	N/A
`num_samples`	as number of samples in a multi-sample texture	N/A
`memory_layout`	N/A	1 for linear memory layout; `0` otherwise

5.3.1. Texture and Surface Properties

Fields `width`, `height`, and `depth` specify the size of the texture or surface in number of elements in each dimension.

The `channel_data_type` and `channel_order` fields specify these properties of the texture or surface using enumeration types corresponding to the source language API. For example, see *Channel Data Type and Channel Order Fields* for the OpenCL enumeration types currently supported in PTX.

5.3.2. Sampler Properties

The `normalized_coords` field indicates whether the texture or surface uses normalized coordinates in the range [0.0, 1.0) instead of unnormalized coordinates in the range [0, N). If no value is specified, the default is set by the runtime system based on the source language.

The `filter_mode` field specifies how the values returned by texture reads are computed based on the input texture coordinates.

The `addr_mode_{0,1,2}` fields define the addressing mode in each dimension, which determine how out-of-range coordinates are handled.

See the *CUDA C++ Programming Guide* for more details of these properties.

Table 12: Opaque Type Fields in Independent Texture Mode

Member	.samplerref values	.texref values	.surfref values
width	N/A	in elements	
height	N/A	in elements	
depth	N/A	in elements	
channel_data_type	N/A	enum type corresponding to source language API	
channel_order	N/A	enum type corresponding to source language AP	
normalized_coords	N/A	0, 1	N/A
force_unnormalized_coords	0, 1	N/A	N/A
filter_mode	nearest, linear	ignored	N/A
addr_mode_0, addr_mode_1, addr_mode_2	wrap, mirror, clamp_ogl, clamp_to_edge, clamp_to_border	N/A	N/A
array_size	N/A	as number of textures in a texture array	as number of surfaces in a surface array
num_mipmap_levels	N/A	as number of levels in a mipmapped texture	N/A
num_samples	N/A	as number of samples in a multi-sample texture	N/A
memory_layout	N/A	N/A	1 for linear memory layout; 0 otherwise

In independent texture mode, the sampler properties are carried in an independent .samplerref variable, and these fields are disabled in the .texref variables. One additional sampler property, force_unnormalized_coords, is available in independent texture mode.

The force_unnormalized_coords field is a property of .samplerref variables that allows the sampler to override the texture header normalized_coords property. This field is defined only in independent texture mode. When True, the texture header setting is overridden and unnormalized coordinates are used; when False, the texture header setting is used.

The force_unnormalized_coords property is used in compiling OpenCL; in OpenCL, the property of normalized coordinates is carried in sampler headers. To compile OpenCL to PTX, texture headers are always initialized with normalized_coords set to True, and the OpenCL sampler-based normalized_coords flag maps (negated) to the PTX-level force_unnormalized_coords flag.

Variables using these types may be declared at module scope or within kernel entry parameter lists. At module scope, these variables must be in the .global state space. As kernel parameters, these

variables are declared in the `.param` state space.

Example

```
.global .texref     my_texture_name;
.global .samplerref my_sampler_name;
.global .surfref    my_surface_name;
```

When declared at module scope, the types may be initialized using a list of static expressions assigning values to the named members.

Example

```
.global .texref tex1;
.global .samplerref tsamp1 = { addr_mode_0 = clamp_to_border,
                               filter_mode = nearest
                             };
```

5.3.3. Channel Data Type and Channel Order Fields

The `channel_data_type` and `channel_order` fields have enumeration types corresponding to the source language API. Currently, OpenCL is the only source language that defines these fields. Table 14 and Table 13 show the enumeration values defined in OpenCL version 1.0 for channel data type and channel order.

Table 13: OpenCL 1.0 Channel Data Type Definition

CL_SNORM_INT8	0x10D0
CL_SNORM_INT16	0x10D1
CL_UNORM_INT8	0x10D2
CL_UNORM_INT16	0x10D3
CL_UNORM_SHORT_565	0x10D4
CL_UNORM_SHORT_555	0x10D5
CL_UNORM_INT_101010	0x10D6
CL_SIGNED_INT8	0x10D7
CL_SIGNED_INT16	0x10D8
CL_SIGNED_INT32	0x10D9
CL_UNSIGNED_INT8	0x10DA
CL_UNSIGNED_INT16	0x10DB
CL_UNSIGNED_INT32	0x10DC
CL_HALF_FLOAT	0x10DD
CL_FLOAT	0x10DE

Table 14: OpenCL 1.0 Channel Order Definition

CL_R	0x10B0
CL_A	0x10B1
CL_RG	0x10B2
CL_RA	0x10B3
CL_RGB	0x10B4
CL_RGBA	0x10B5
CL_BGRA	0x10B6
CL_ARGB	0x10B7
CL_INTENSITY	0x10B8
CL_LUMINANCE	0x10B9

5.4. Variables

In PTX, a variable declaration describes both the variable's type and its state space. In addition to fundamental types, PTX supports types for simple aggregate objects such as vectors and arrays.

5.4.1. Variable Declarations

All storage for data is specified with variable declarations. Every variable must reside in one of the state spaces enumerated in the previous section.

A variable declaration names the space in which the variable resides, its type and size, its name, an optional array size, an optional initializer, and an optional fixed address for the variable.

Predicate variables may only be declared in the register state space.

Examples

```
.global .u32 loc;
.reg    .s32 i;
.const  .f32 bias[] = {-1.0, 1.0};
.global .u8  bg[4] = {0, 0, 0, 0};
.reg    .v4 .f32 accel;
.reg    .pred p, q, r;
```

5.4.2. Vectors

Limited-length vector types are supported. Vectors of length 2 and 4 of any non-predicate fundamental type can be declared by prefixing the type with `.v2` or `.v4`. Vectors must be based on a fundamental type, and they may reside in the register space. Vectors cannot exceed 128-bits in length; for example, `.v4 .f64` is not allowed. Three-element vectors may be handled by using a `.v4` vector, where the fourth element provides padding. This is a common case for three-dimensional grids, textures, etc.

Examples

```
.global .v4 .f32 V;   // a length-4 vector of floats
.shared .v2 .u16 uv;  // a length-2 vector of unsigned ints
.global .v4 .b8  v;   // a length-4 vector of bytes
```

By default, vector variables are aligned to a multiple of their overall size (vector length times base-type size), to enable vector load and store instructions which require addresses aligned to a multiple of the access size.

5.4.3. Array Declarations

Array declarations are provided to allow the programmer to reserve space. To declare an array, the variable name is followed with dimensional declarations similar to fixed-size array declarations in C. The size of each dimension is a constant expression.

Examples

```
.local  .u16 kernel[19][19];
.shared .u8  mailbox[128];
```

The size of the array specifies how many elements should be reserved. For the declaration of array *kernel* above, 19*19 = 361 halfwords are reserved, for a total of 722 bytes.

When declared with an initializer, the first dimension of the array may be omitted. The size of the first array dimension is determined by the number of elements in the array initializer.

Examples

```
.global .u32 index[] = { 0, 1, 2, 3, 4, 5, 6, 7 };
.global .s32 offset[][2] = { {-1, 0}, {0, -1}, {1, 0}, {0, 1} };
```

Array *index* has eight elements, and array *offset* is a 4x2 array.

5.4.4. Initializers

Declared variables may specify an initial value using a syntax similar to C/C++, where the variable name is followed by an equals sign and the initial value or values for the variable. A scalar takes a single value, while vectors and arrays take nested lists of values inside of curly braces (the nesting matches the dimensionality of the declaration).

As in C, array initializers may be incomplete, i.e., the number of initializer elements may be less than the extent of the corresponding array dimension, with remaining array locations initialized to the default value for the specified array type.

Examples

```
.const  .f32 vals[8] = { 0.33, 0.25, 0.125 };
.global .s32 x[3][2] = { {1,2}, {3} };
```

is equivalent to

```
.const  .f32 vals[8] = { 0.33, 0.25, 0.125, 0.0, 0.0, 0.0, 0.0, 0.0 };
.global .s32 x[3][2] = { {1,2}, {3,0}, {0,0} };
```

Currently, variable initialization is supported only for constant and global state spaces. Variables in constant and global state spaces with no explicit initializer are initialized to zero by default. Initializers are not allowed in external variable declarations.

Variable names appearing in initializers represent the address of the variable; this can be used to statically initialize a pointer to a variable. Initializers may also contain *var+offset* expressions, where *offset* is a byte offset added to the address of *var*. Only variables in `.global` or `.const` state spaces may be used in initializers. By default, the resulting address is the offset in the variable's state space (as is the case when taking the address of a variable with a `mov` instruction). An operator, `generic()`, is provided to create a generic address for variables used in initializers.

Starting PTX ISA version 7.1, an operator `mask()` is provided, where `mask` is an integer immediate. The only allowed expressions in the `mask()` operator are integer constant expression and symbol expression representing address of variable. The `mask()` operator extracts `n` consecutive bits from the expression used in initializers and inserts these bits at the lowest position of the initialized variable. The number `n` and the starting position of the bits to be extracted is specified by the integer immediate `mask`. PTX ISA version 7.1 only supports extracting a single byte starting at byte boundary from the address of the variable. PTX ISA version 7.3 supports Integer constant expression as an operand in the `mask()` operator.

Supported values for `mask` are: 0xFF, 0xFF00, 0XFF0000, 0xFF000000, 0xFF00000000, 0xFF0000000000, 0xFF000000000000, 0xFF00000000000000.

Examples

```
.const  .u32 foo = 42;
.global .u32 bar[] = { 2, 3, 5 };
.global .u32 p1 = foo;          // offset of foo in .const space
.global .u32 p2 = generic(foo); // generic address of foo

// array of generic-address pointers to elements of bar
.global .u32 parr[] = { generic(bar), generic(bar)+4,
generic(bar)+8 };

// examples using mask() operator are pruned for brevity
.global .u8 addr[] = {0xff(foo), 0xff00(foo), 0xff0000(foo), ...};

.global .u8 addr2[] = {0xff(foo+4), 0xff00(foo+4), 0xff0000(foo+4),...}

.global .u8 addr3[] = {0xff(generic(foo)), 0xff00(generic(foo)),...}

.global .u8 addr4[] = {0xff(generic(foo)+4), 0xff00(generic(foo)+4),...}

// mask() operator with integer const expression
.global .u8 addr5[] = { 0xFF(1000 + 546), 0xFF00(131187), ...};
```

Note: PTX 3.1 redefines the default addressing for global variables in initializers, from generic addresses to offsets in the global state space. Legacy PTX code is treated as having an implicit `generic()` operator for each global variable used in an initializer. PTX 3.1 code should either include explicit `generic()` operators in initializers, use `cvta.global` to form generic addresses at runtime, or load from the non-generic address using `ld.global`.

Device function names appearing in initializers represent the address of the first instruction in the function; this can be used to initialize a table of function pointers to be used with indirect calls. Beginning in PTX ISA version 3.1, kernel function names can be used as initializers e.g. to initialize a table of kernel function pointers, to be used with CUDA Dynamic Parallelism to launch kernels from GPU. See the *CUDA Dynamic Parallelism Programming Guide* for details.

Labels cannot be used in initializers.

Variables that hold addresses of variables or functions should be of type `.u8` or `.u32` or `.u64`.

Type `.u8` is allowed only if the `mask()` operator is used.

Initializers are allowed for all types except `.f16`, `.f16x2` and `.pred`.

Examples

```
.global .s32 n = 10;
.global .f32 blur_kernel[][3]
               = {{.05,.1,.05},{.1,.4,.1},{.05,.1,.05}};

.global .u32 foo[] = { 2, 3, 5, 7, 9, 11 };
.global .u64 ptr = generic(foo);   // generic address of foo[0]
.global .u64 ptr = generic(foo)+8; // generic address of foo[2]
```

5.4.5. Alignment

Byte alignment of storage for all addressable variables can be specified in the variable declaration. Alignment is specified using an optional `.align` *byte-count* specifier immediately following the state-space specifier. The variable will be aligned to an address which is an integer multiple of byte-count. The alignment value byte-count must be a power of two. For arrays, alignment specifies the address alignment for the starting address of the entire array, not for individual elements.

The default alignment for scalar and array variables is to a multiple of the base-type size. The default alignment for vector variables is to a multiple of the overall vector size.

Examples

```
 // allocate array at 4-byte aligned address.  Elements are bytes.
.const .align 4 .b8 bar[8] = {0,0,0,0,2,0,0,0};
```

Note that all PTX instructions that access memory require that the address be aligned to a multiple of the access size. The access size of a memory instruction is the total number of bytes accessed in memory. For example, the access size of `ld.v4.b32` is 16 bytes, while the access size of `atom.f16x2` is 4 bytes.

5.4.6. Parameterized Variable Names

Since PTX supports virtual registers, it is quite common for a compiler frontend to generate a large number of register names. Rather than require explicit declaration of every name, PTX supports a syntax for creating a set of variables having a common prefix string appended with integer suffixes.

For example, suppose a program uses a large number, say one hundred, of `.b32` variables, named `%r0`, `%r1`, ..., `%r99`. These 100 register variables can be declared as follows:

```
.reg .b32 %r<100>;    // declare %r0, %r1, ..., %r99
```

This shorthand syntax may be used with any of the fundamental types and with any state space, and may be preceded by an alignment specifier. Array variables cannot be declared this way, nor are initializers permitted.

5.4.7. Variable Attributes

Variables may be declared with an optional `.attribute` directive which allows specifying special attributes of variables. Keyword `.attribute` is followed by attribute specification inside parenthesis. Multiple attributes are separated by comma.

Variable and Function Attribute Directive: .attribute describes the `.attribute` directive.

5.4.8. Variable and Function Attribute Directive: .attribute

.attribute

Variable and function attributes

Description

Used to specify special attributes of a variable or a function.

The following attributes are supported.

.managed
: .managed attribute specifies that variable will be allocated at a location in unified virtual memory environment where host and other devices in the system can reference the variable directly. This attribute can only be used with variables in .global state space. See the *CUDA UVM-Lite Programming Guide* for details.

.unified
: .unified attribute specifies that function has the same memory address on the host and on other devices in the system. Integer constants uuid1 and uuid2 respectively specify upper and lower 64 bits of the unique identifier associated with the function or the variable. This attribute can only be used on device functions or on variables in the .global state space. Variables with .unified attribute are read-only and must be loaded by specifying .unified qualifier on the address operand of ld instruction, otherwise the behavior is undefined.

PTX ISA Notes

- Introduced in PTX ISA version 4.0.
- Support for function attributes introduced in PTX ISA version 8.0.

Target ISA Notes

- .managed attribute requires sm_30 or higher.
- .unified attribute requires sm_90 or higher.

Examples

```
.global .attribute(.managed) .s32 g;
.global .attribute(.managed) .u64 x;

.global .attribute(.unified(19,95)) .f32 f;

.func .attribute(.unified(0xAB, 0xCD)) bar() { ... }
```

5.5. Tensors

A tensor is a multi-dimensional matrix structure in the memory. Tensor is defined by the following properties:

- Dimensionality
- Dimension sizes across each dimension
- Individual element types
- Tensor stride across each dimension

PTX supports instructions which can operate on the tensor data. PTX Tensor instructions include:

- Copying data between global and shared memories
- Reducing the destination tensor data with the source.

The Tensor data can be operated on by various `wmma.mma`, `mma` and `wgmma.mma_async` instructions.

PTX Tensor instructions treat the tensor data in the global memory as a multi-dimensional structure and treat the data in the shared memory as a linear data.

5.5.1. Tensor Dimension, size and format

Tensors can have dimensions: 1D, 2D, 3D, 4D or 5D.

Each dimension has a size which represents the number of elements along the dimension. The elements can have one the following types:

- Bit-sized type: `.b32`, `.b64`
- Sub-byte types: `.b4x16`, `.b4x16_p64`, `.b6x16_p32`, `.b6p2x16`
- Integer: `.u8`, `.u16`, `.u32`, `.s32`, `.u64`, `.s64`
- Floating point and alternate floating point: `.f16`, `.bf16`, `.tf32`, `.f32`, `.f64` (rounded to nearest even).

Tensor can have padding at the end in each of the dimensions to provide alignment for the data in the subsequent dimensions. Tensor stride can be used to specify the amount of padding in each dimension.

5.5.1.1 Sub-byte Types

5.5.1.1.1 Padding and alignment of the sub-byte types

The sub-byte types are expected to packed contiguously in the global memory and the Tensor copy instruction will expand them by appending empty spaces as shown below:

1. Type `.b4x16`: With this type, there is no padding involved and the packed sixteen `.b4` elements in a 64-bits container is copied as is between the shared memory and the global memory.
2. Type `.b4x16_p64`: With this type, sixteen contiguous 4-bits of data is copied from global memory to the shared memory with the append of 64-bits of padding as shown in Figure 5

   The padded region that gets added is un-initialized.

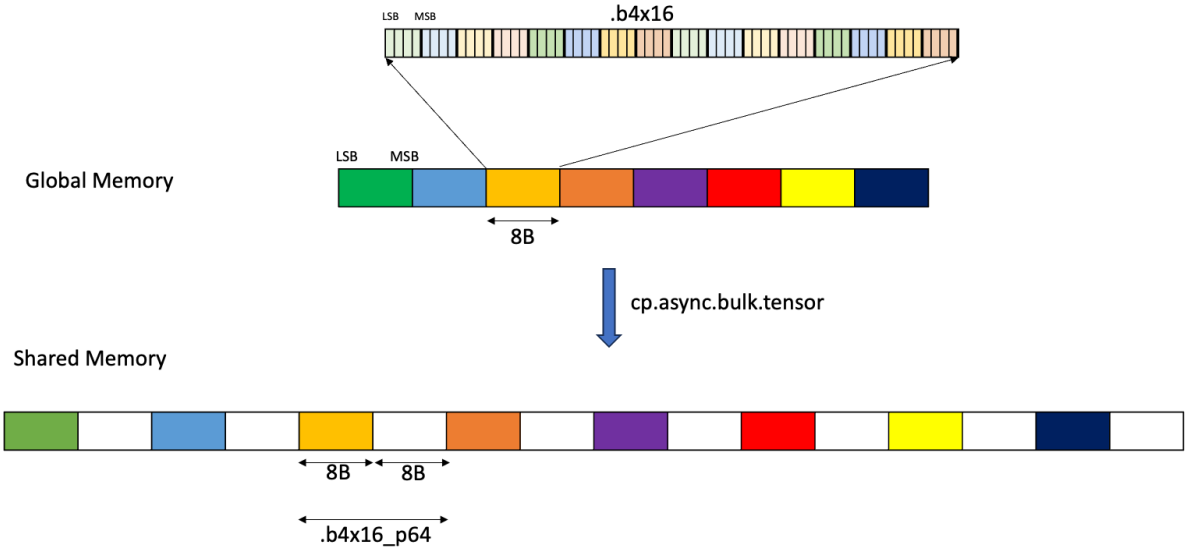

Figure 5: Layout for .b4x16_p64

3. Type `.b6x16_p32`: With this type, sixteen 6-bits of data is copied from global memory to the shared memory with an append of 32-bits of padding as shown in Figure 6

   The padded region that gets added is un-initialized.

4. Type `.b6p2x16`: With this type, sixteen elements, each containing 6-bits of data at the LSB and 2-bits of padding at the MSB, are copied from shared memory into the global memory by discarding the 2-bits of padding data and packing the 6-bits data contiguously as shown in Figure 7

In case of `.b6x16_p32` and `.b4x16_p64`, the padded region that gets added is un-initialized.

The types `.b6x16_p32` and `.b6p2x16` share the same encoding value in the descriptor (value 15) as the two types are applicable for different types of tensor copy operations:

Type	Valid Tensor Copy Direction
`.b6x16_p32`	`.shared::cluster.global`, `.shared::cta.global`
`.b6p2x16`	`.global.shared::cta`

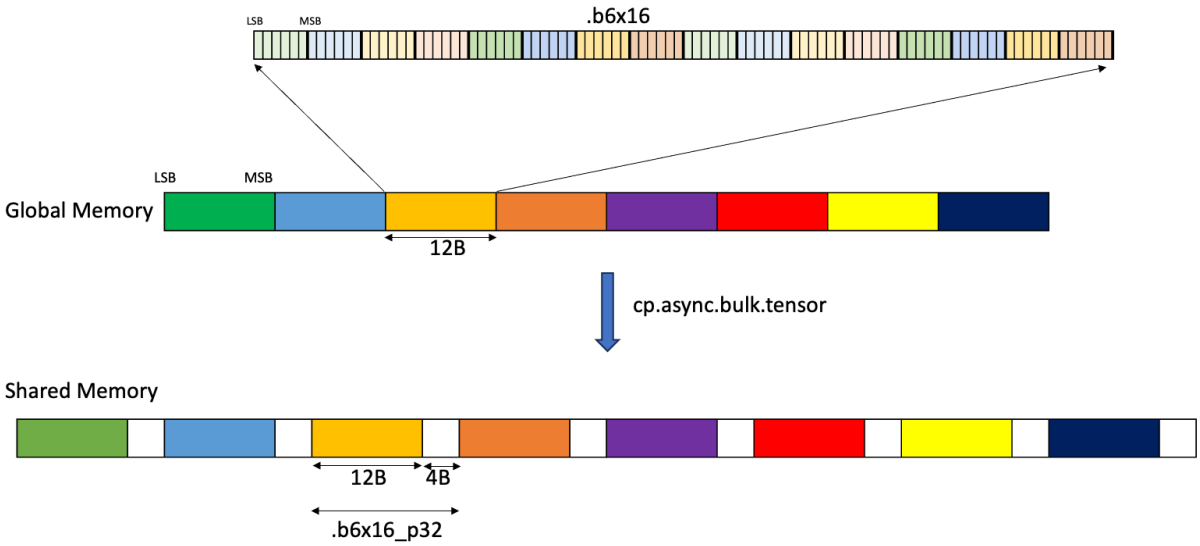

Figure 6: Layout for .b6x16_p32

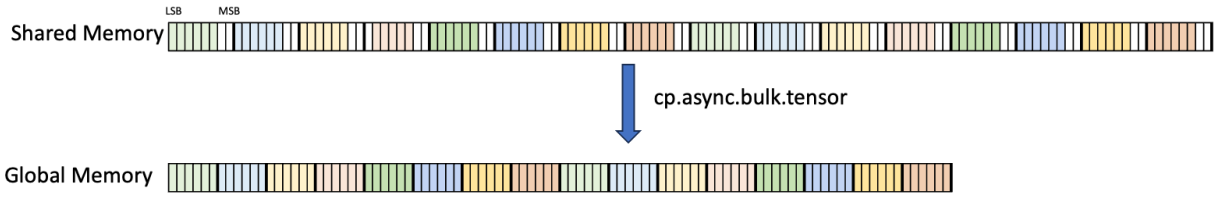

Figure 7: Layout for .b6p2x16

5.5.2. Tensor Access Modes

Tensor data can be accessed in two modes:

- Tiled mode:

  In tiled mode, the source multi-dimensional tensor layout is preserved at the destination.

- Im2col mode:

  In im2col mode, the elements in the Bounding Box of the source tensor are rearranged into columns at the destination. Refer here for more details.

5.5.3. Tiled Mode

This section talks about how Tensor and Tensor access work in tiled mode.

5.5.3.1 Bounding Box

A tensor can be accessed in chunks known as *Bounding Box*. The Bounding Box has the same dimensionality as the tensor they are accessing into. Size of each bounding Box must be a multiple of 16 bytes. The address of the bounding Box must also be aligned to 16 bytes.

Bounding Box has the following access properties:

- Bounding Box dimension sizes
- Out of boundary access mode
- Traversal strides

The tensor-coordinates, specified in the PTX tensor instructions, specify the starting offset of the bounding box. Starting offset of the bounding box along with the rest of the bounding box information together are used to determine the elements which are to be accessed.

5.5.3.2 Traversal-Stride

While the Bounding Box is iterating the tensor across a dimension, the traversal stride specifies the exact number of elements to be skipped. If no jump over is required, default value of 1 must be specified.

The traversal stride in dimension 0 can be used for the *Interleave layout*. For non-interleaved layout, the traversal stride in dimension 0 must always be 1.

Figure 8 illustrates tensor, tensor size, tensor stride, Bounding Box size and traversal stride.

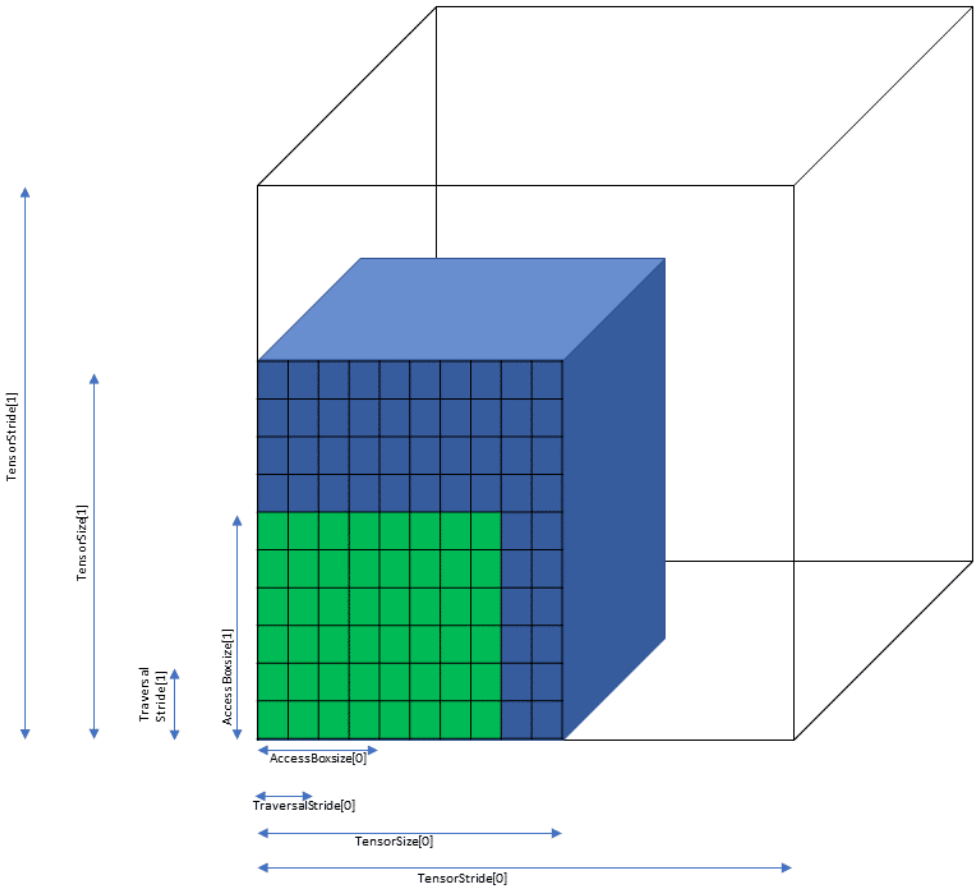

Figure 8: Tiled mode bounding box, tensor size and traversal stride

5.5.3.3 Out of Boundary Access

PTX Tensor operation can detect and handle the case when the Bounding Box crosses the tensor boundary in any dimension. There are 2 modes:

- Zero fill mode:

  Elements in the Bounding Box which fall outside of the tensor boundary are set to 0.

- `OOB-NaN` fill mode:

  Elements in the Bounding Box which fall outside of the tensor boundary are set to a special NaN called `OOB-NaN`.

Figure 9 shows an example of the out of boundary access.

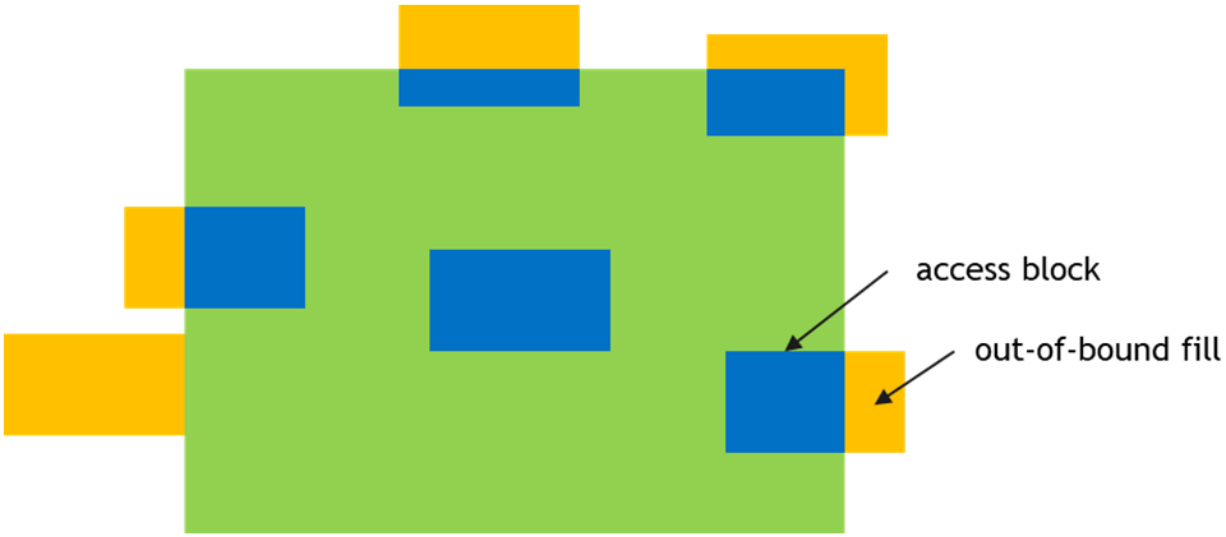

Figure 9: Out of boundary access

5.5.3.4 .tile::scatter4 and .tile::gather4 modes

These modes are similar to the tiled mode with restriction that these modes work only on 2D tensor data. `Tile::scatter4` and `Tile::gather4` modes are used to access multiple non-contiguous rows of tensor data.

In `Tile::scatter4` mode single 2D source tensor is divided into four rows in the 2D destination tensor. In `Tile::gather4` mode four rows in the source 2D tensor are combined to form single 2D destination tensor.

These modes work on four rows and hence the instruction will take:

1. four tensor coordinates across the dimension 0
2. one tensor coordinate across the dimension 1

The interleave layout is not supported for `.tile::scatter4` and `.tile::gather4` modes.

All other constraints and rules of the tile mode apply to these modes as well.

5.5.3.4.1 Bounding Box

For `Tile::scatter4` and `Tile::gather4` modes, four request coordinates will form four Bounding Boxes in the tensor space.

Figure 10 shows an example of the same with start coordinates (1, 2), (1, 5), (1, 0) and (1, 9).

The size of the bounding box in the dimension 0 represents the length of the rows. The size of the bounding box in the dimension 1 must be one.

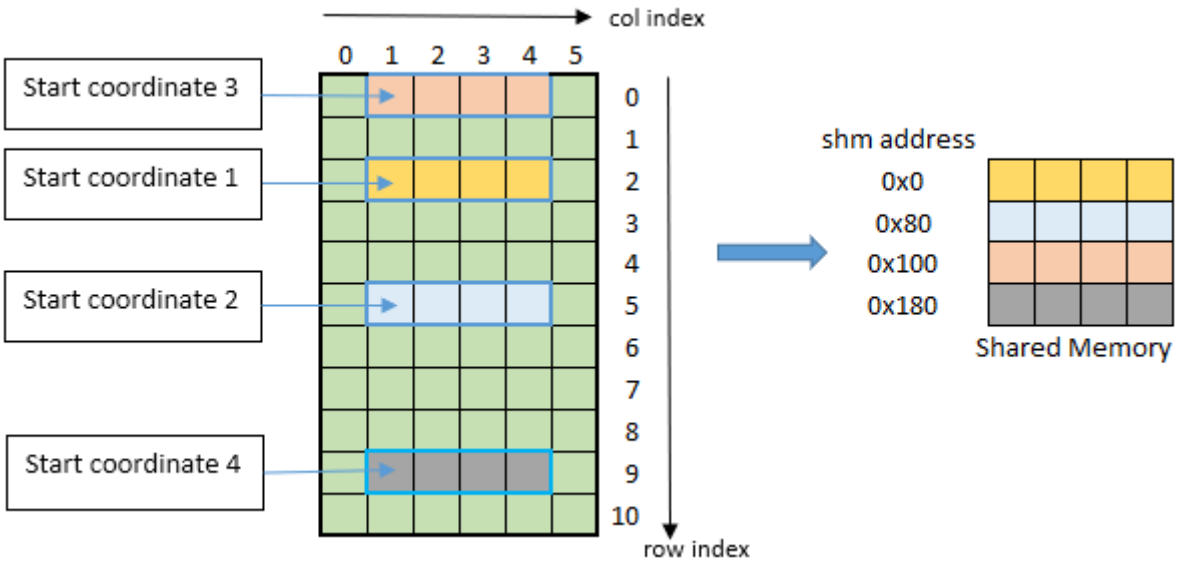

Figure 10: tiled::scatter4/tiled::gather4 mode bounding box example

5.5.4. `im2col` mode

Im2col mode supports the following tensor dimensions : 3D, 4D and 5D. In this mode, the tensor data is treated as a batch of images with the following properties:

- N : number of images in the batch
- D, H, W : size of a 3D image (depth, height and width)
- C: channels per image element

The above properties are associated with 3D, 4D and 5D tensors as follows:

Dimension	N/D/H/W/C applicability
3D	NWC
4D	NHWC
5D	NDHWC

5.5.4.1 Bounding Box

In im2col mode, the Bounding Box is defined in DHW space. Boundaries along other dimensions are specified by Pixels-per-Column and Channels-per-Pixel parameters as described below.

The dimensionality of the Bounding Box is two less than the tensor dimensionality.

The following properties describe how to access of the elements in im2col mode:

- Bounding-Box Lower-Corner
- Bounding-Box Upper-Corner
- Pixels-per-Column
- Channels-per-Pixel

Bounding-box Lower-Corner and *Bounding-box Upper-Corner* specify the two opposite corners of the Bounding Box in the DHW space. *Bounding-box Lower-Corner* specifies the corner with the smallest coordinate and *Bounding-box Upper-Corner* specifies the corner with the largest coordinate.

Bounding-box Upper- and *Lower-Corners* are 16-bit signed values whose limits varies across the dimensions and are as shown below:

	3D	4D	5D
Upper- / Lower- Corner sizes	$[-2^{15}, 2^{15}-1]$	$[-2^{7}, 2^{7}-1]$	$[-2^{4}, 2^{4}-1]$

Figure 11 and Figure 12 show the Upper-Corners and Lower-Corners.

The *Bounding-box Upper-* and *Lower- Corners* specify only the boundaries and not the number of elements to be accessed. *Pixels-per-Column* specifies the number of elements to be accessed in the NDHW space.

Channels-per-Pixel specifies the number of elements to access across the C dimension.

The tensor coordinates, specified in the PTX tensor instructions, behaves differently in different dimensions:

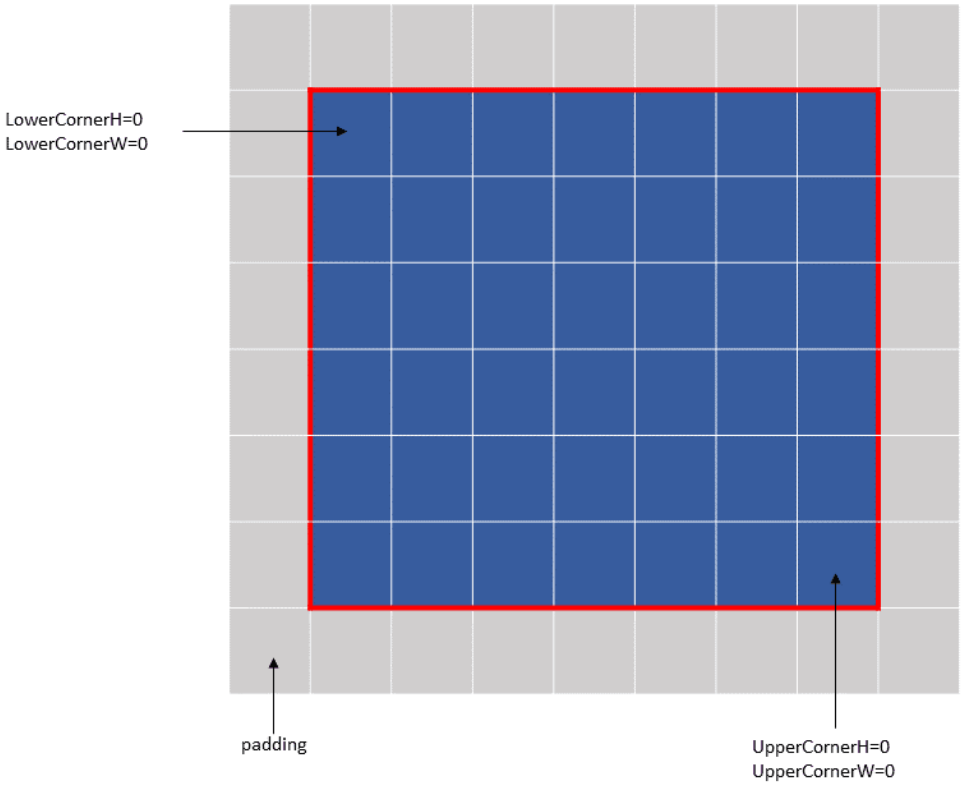

Figure 11: im2col mode bounding box example 1

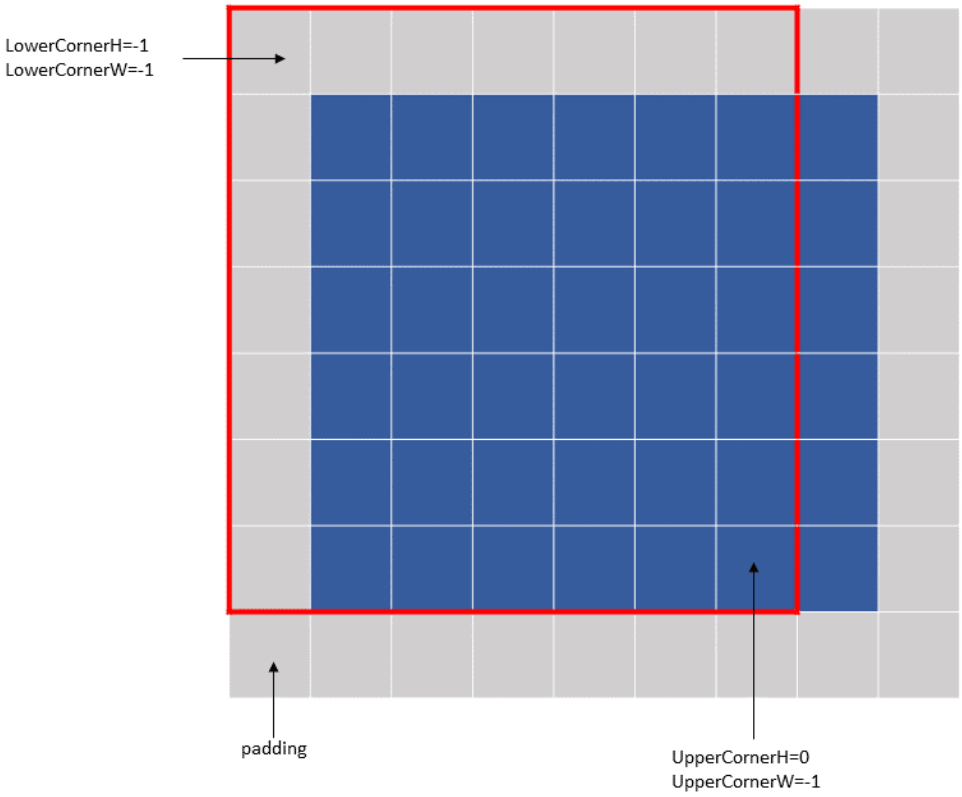

Figure 12: im2col mode bounding box example 2

- Across N and C dimensions: specify the starting offsets along the dimension, similar to the tiled mode.
- Across DHW dimensions: specify the location of the convolution filter base in the tensor space. The filter corner location must be within the bounding box.

The im2col offsets, specified in the PTX tensor instructions in im2col mode, are added to the filter base coordinates to determine the starting location in the tensor space from where the elements are accessed.

The size of the im2col offsets varies across the dimensions and their valid ranges are as shown below:

	3D	**4D**	**5D**
im2col offsets range	[0, 2^{16}-1]	[0, 2^{8}-1]	[0, 2^{5}-1]

Following are some examples of the im2col mode accesses:

- Example 1 (Figure 13):

```
Tensor Size[0] = 64
Tensor Size[1] = 9
Tensor Size[2] = 14
Tensor Size[3] = 64
Pixels-per-Column = 64
channels-per-pixel = 8
Bounding-Box Lower-Corner W = -1
Bounding-Box Lower-Corner H = -1
Bounding-Box Upper-Corner W = -1
Bounding-Box Upper-Corner H = -1.

tensor coordinates = (7, 7, 4, 0)
im2col offsets : (0, 0)
```

- Example 2 (Figure 14):

```
Tensor Size[0] = 64
Tensor Size[1] = 9
Tensor Size[2] = 14
Tensor Size[3] = 64
Pixels-per-Column = 64
channels-per-pixel = 8
Bounding-Box Lower-Corner W = 0
Bounding-Box Lower-Corner H = 0
Bounding-Box Upper-Corner W = -2
Bounding-Box Upper-Corner H = -2

tensor coordinates = (7, 7, 4, 0)
im2col offsets: (2, 2)
```

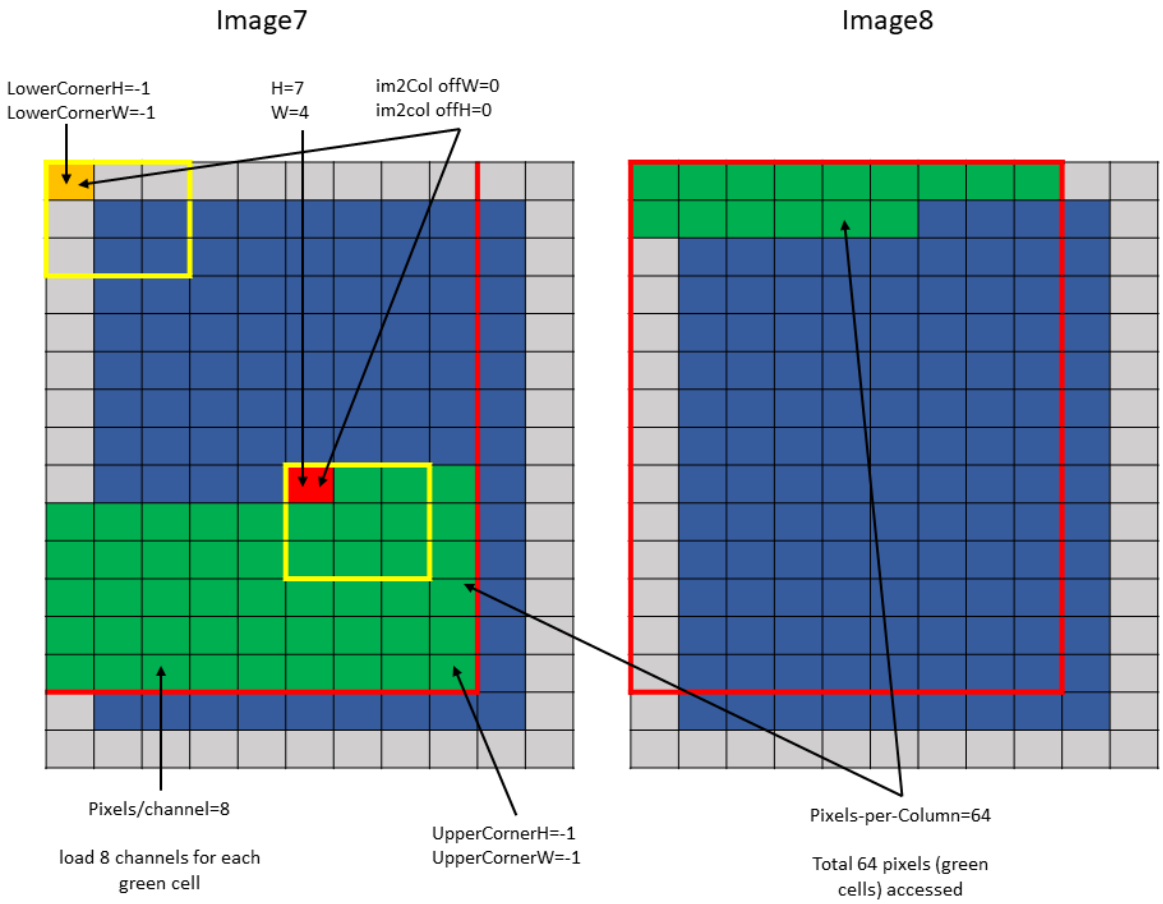

Figure 13: im2col mode example 1

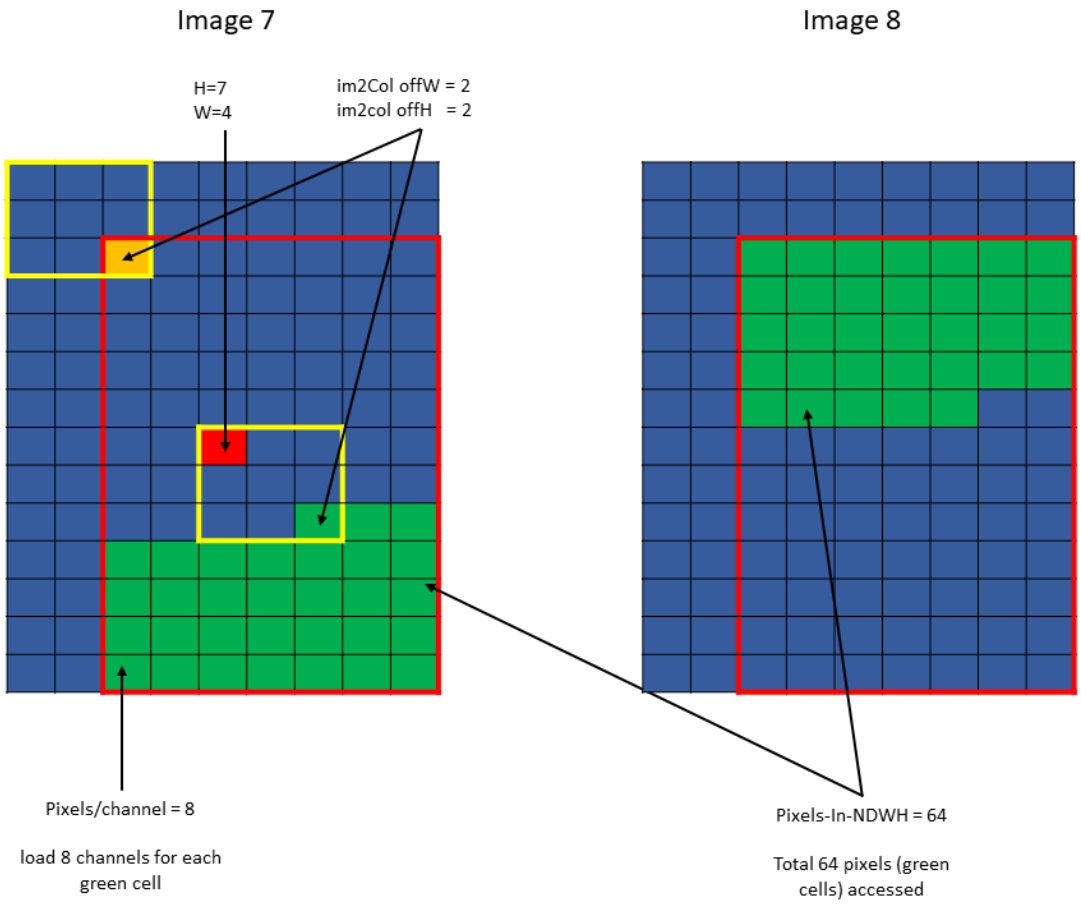

Figure 14: im2col mode example 2

5.5.4.2 Traversal Stride

The traversal stride, in im2col mode, does not impact the total number of elements (or pixels) being accessed unlike the tiled mode. Pixels-per-Column determines the total number of elements being accessed, in im2col mode.

The number of elements traversed along the D, H and W dimensions is strided by the traversal stride for that dimension.

The following example with Figure 15 illustrates accesse with traversal-strides:

```
Tensor Size[0] = 64
Tensor Size[1] = 8
Tensor Size[2] = 14
Tensor Size[3] = 64
Traversal Stride = 2
Pixels-per-Column = 32
channels-per-pixel = 16
Bounding-Box Lower-Corner W = -1
Bounding-Box Lower-Corner H = -1
Bounding-Box Upper-Corner W = -1
Bounding-Box Upper-Corner H = -1.
Tensor coordinates in the instruction = (7, 7, 5, 0)
Im2col offsets in the instruction : (1, 1)
```

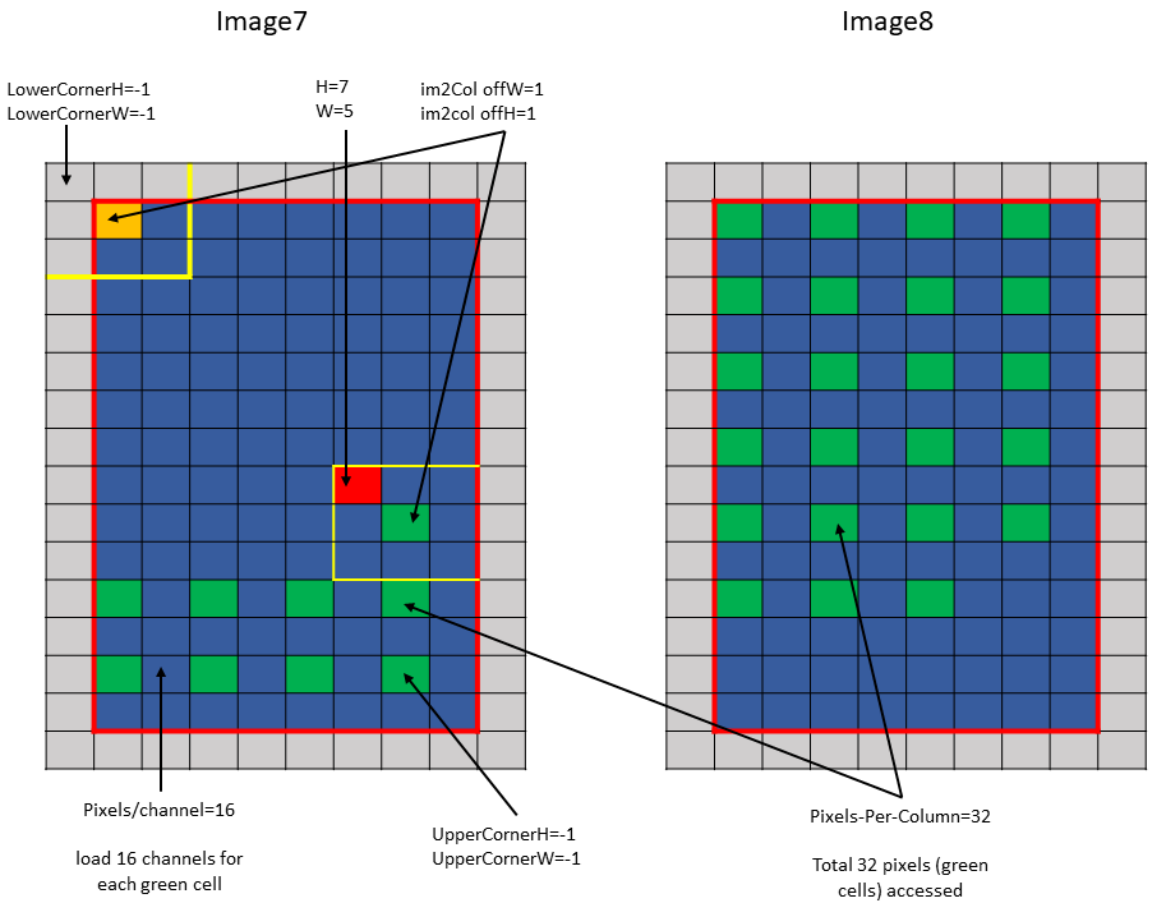

Figure 15: im2col mode traversal stride example

5.5.4.3 Out of Boundary Access

In im2col mode, when the number of requested pixels in NDHW space specified by *Pixels-per-Column* exceeds the number of available pixels in the image batch then out-of-bounds access is performed.

Similar to tiled mode, zero fill or `OOB-NaN` fill can be performed based on the Fill-Mode specified.

5.5.5. `im2col::w` and `im2col::w::128` modes

These modes are similar to the im2col mode with the restriction that elements are accessed across the `W` dimension only while keeping the `H` and `D` dimension constant.

All the constraints and rules of the im2col mode apply to these modes as well.

The number of elements accessed in the `im2col::w::128` mode is fixed and is equal to 128. The number of elements accessed in the `im2col::w` mode depends on the field Pixels-per-Column field in the TensorMap.

5.5.5.1 Bounding Box

In these modes, the size of the bounding box in `D` and `H` dimensions are `1`.

The `D` and `H` dimensions in the tensor coordinates argument in the PTX instruction specify the position of the bounding box in the tensor space.

The Bounding-Box `Lower-Corner-W` and Bounding-Box `Upper-Corner-W` specify the two opposite corners of the Bounding Box in the `W` dimension.

The `W` dimension in the tensor coordinates argument in the PTX instruction specify the location of the first element that is to be accessed in the bounding box.

Number of pixels loaded in `im2col::w` mode is as specified by Pixels-per-Column in the TensorMap. Number of pixels loaded in `im2col::w::128` mode is always 128. So, Pixels-per-Column is ignored in `im2col::w::128` mode.

Figure 16 shows an example of the `im2col::w` and `im2col::w:128` modes.

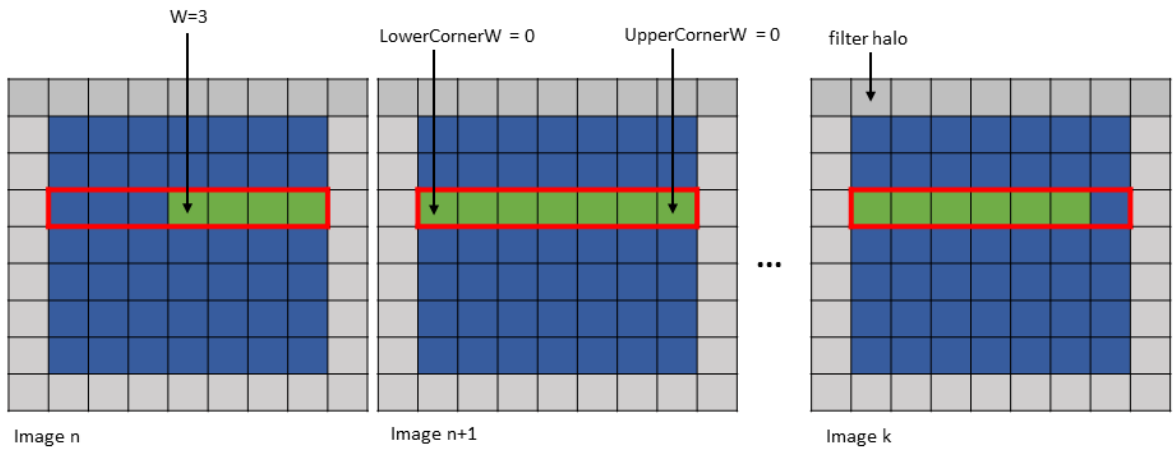

Figure 16: im2col::w and im2col::w::128 modes example

The first element can lie outside of the Bounding Box in the W-dimension only and only on the left side of the Bounding Box. Figure 17 shows of an example of this.

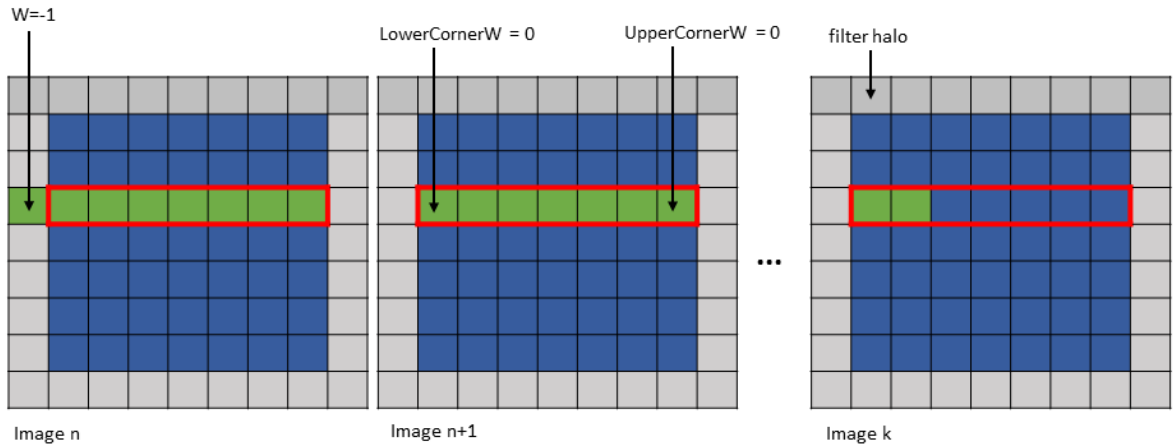

Figure 17: im2col::w and im2col::w::128 modes first element outside Bounding Box example

5.5.5.2 Traversal Stride

This is similar to im2col mode with the exception of that the number of elements traversed along only the `W` dimension is strided by the traversal stride as specified in the TensorMap.

5.5.5.3 wHalo

In `im2col::w` mode, the `wHalo` argument in the PTX instruction specifies how many filter halo elements must be loaded at the end of the image.

In `im2col::w::128` mode, the halo elements are loaded after every 32 elements in the bounding box along the `W` dimension. The `wHalo` argument in the PTX instruction specifies how many halo elements must be loaded after every 32 elements.

Following is an example of `.im2col::w` mode access:

```
Tensor Size [0] = 128
Tensor Size [1] = 9
Tensor Size [2] = 7
Tensor Size [3] = 64
Pixels-per-column = 128
Channels-per-pixel = 64
Bounding Box Lower Corner W = 0
Bounding Box Upper Corner W = 0

Tensor Coordinates in the instruction = (7, 2, 3, 0)
wHalo in the instruction = 2 (as 3x3 convolution filter is used)
```

A tensor copy operation with the above parameters loads 128 pixels and the two halo pixels as shown in Figure 18.

The halo pixels are always loaded in the shared memory next to the main row pixels as shown in Figure 18.

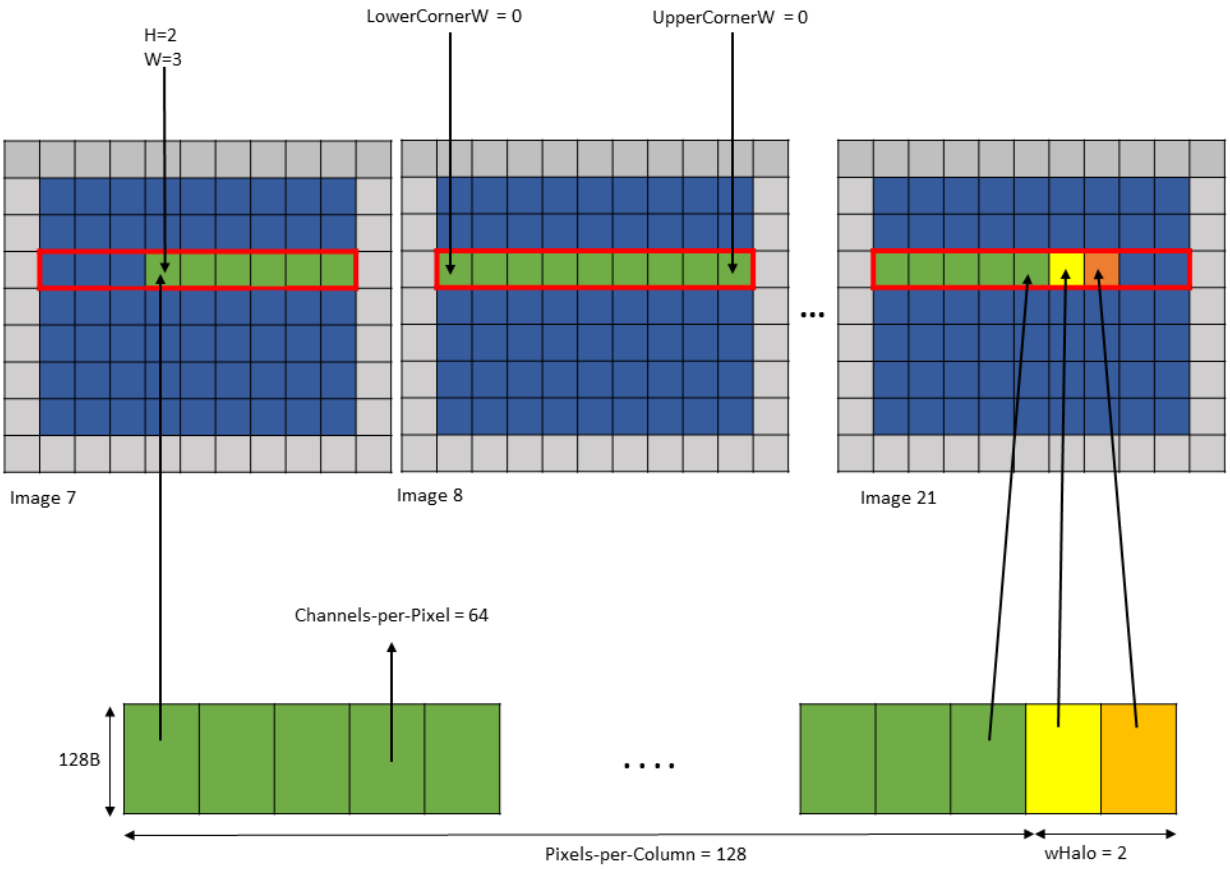

Figure 18: tensor copy operation with im2col::w mode example

Following is an example of `.im2col::w::128` mode access:

```
Tensor Size [0] = 128
Tensor Size [1] = 9
Tensor Size [2] = 7
Tensor Size [3] = 64
Channels-per-pixel = 64
Bounding Box Lower Corner W = 0
Bounding Box Upper Corner W = 0

Tensor Coordinates in the instruction = (7, 2, 3, 0)
wHalo in the instruction = 2 (as 3x3 convolution filter is used)
```

A tensor copy operation with the above parameters loads 128 elements such that after every 32 elements, wHalo number of elements are loaded as shown in Figure 19.

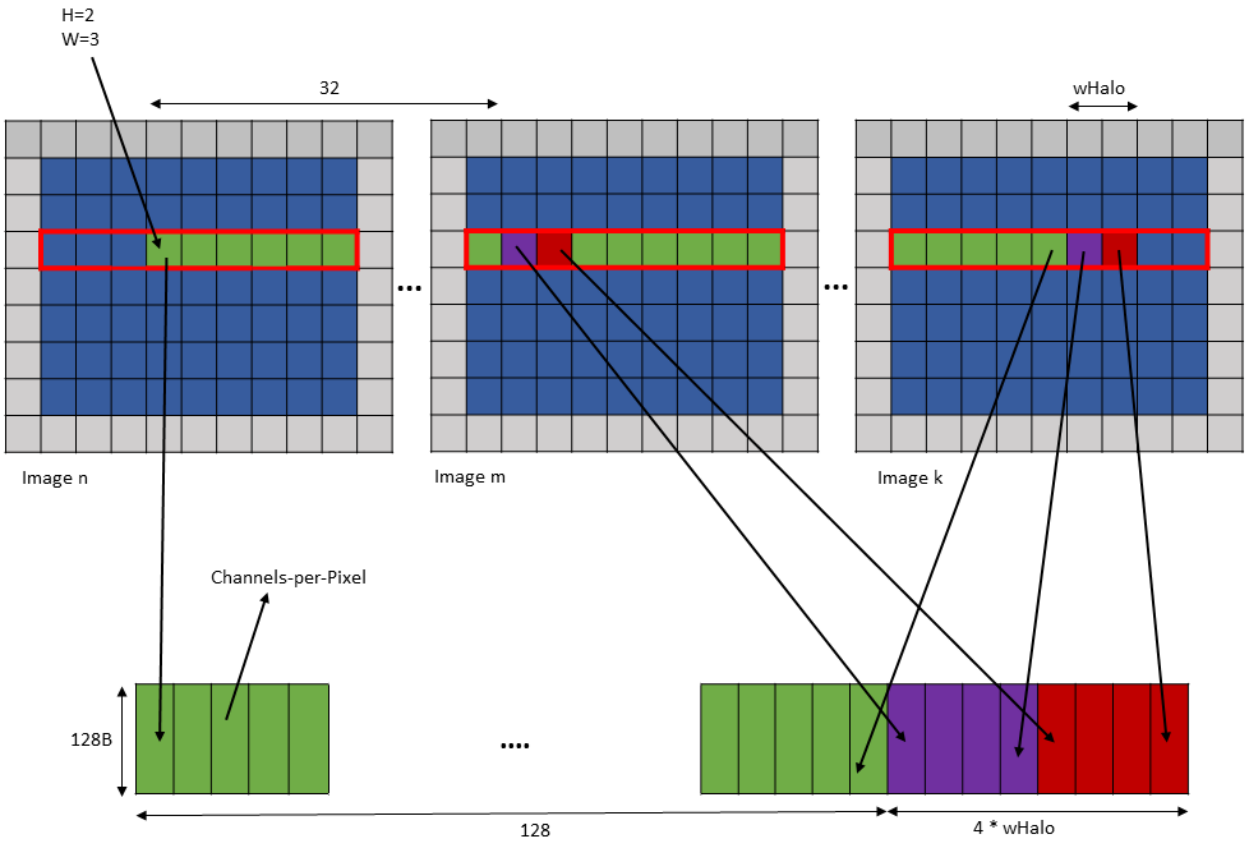

Figure 19: tensor copy operation with im2col::w::128 mode example

5.5.5.4 wOffset

In the convolution calculations, the same elements along the W dimension are reused for different locations within the convolution filter footprint. Based on the number of times a pixel is used, the pixels may be loaded into different shared memory buffers. Each buffer can be loaded by a separate tensor copy operation.

The wOffset argument in the tensor copy and prefetch instruction adjusts the source pixel location for each buffer. The exact position of the buffer is adjusted along the W dimension using the following formula:

```
Bounding Box Lower Corner W += wOffset
Bounding Box Upper Corner W += wOffset
W += wOffset
```

Following are examples of tensor copy to multiple buffers with various wHalo and wOffset values:

Example 1:

```
Tensor Size [0] = 128
Tensor Size [1] = 9
Tensor Size [2] = 67
Tensor Size [3] = 64
Pixels-per-Column = 128
Channels-per-pixel = 64
Bounding Box Lower Corner W = -1
Bounding Box Upper Corner W = 0
Traversal Stride = 2

Tensor Coordinates in the instruction = (7, 2, -1, 0)

Shared memory buffer 1:
   wHalo = 1
   wOffset = 0

Shared memory buffer 2:
   wHalo = 0
   wOffset = 1
```

Example 2:

```
Tensor Size [0] = 128
Tensor Size [1] = 7
Tensor Size [2] = 7
Tensor Size [3] = 64
Pixels-per-Column = 128
Channels-per-pixel = 64
Bounding Box Lower Corner W = -1
Bounding Box Upper Corner W = -1
Traversal Stride = 3

Tensor Coordinates in the instruction = (7, 2, -1, 0)

Shared memory buffer 1:
   wHalo = 0
   wOffset = 0

Shared memory buffer 2:
```

(continues on next page)

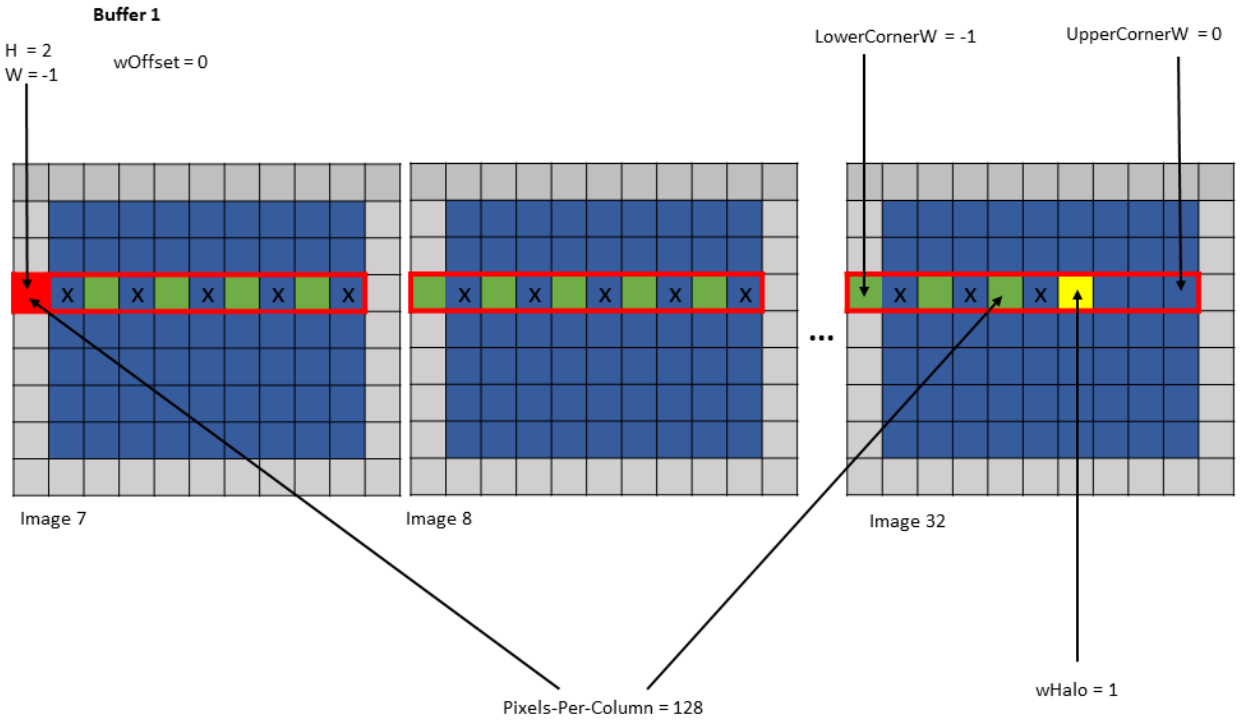

Figure 20: tensor copy operation to buffer 1 of Example 1

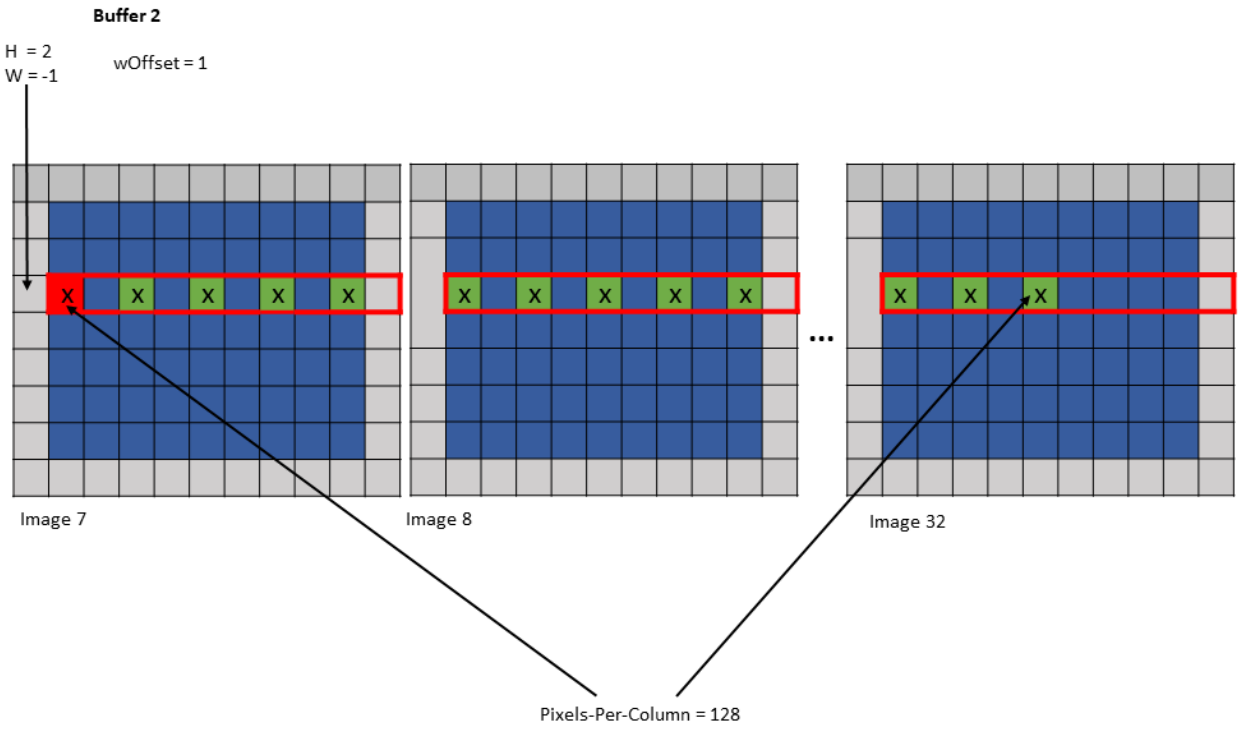

Figure 21: tensor copy operation to buffer 2 of Example 1

(continued from previous page)

```
   wHalo = 0
   wOffset = 1

Shared memory buffer 3:
   wHalo = 0
   wOffset = 2
```

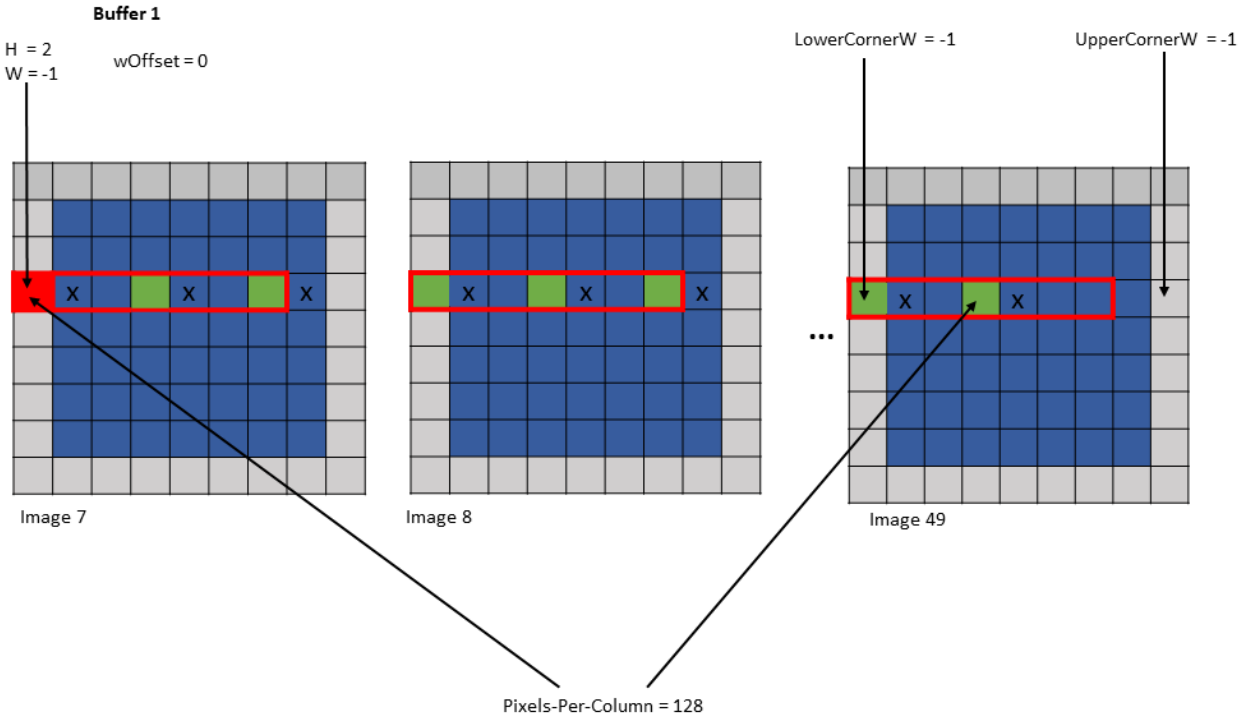

Figure 22: tensor copy operation to buffer 1 of Example 2

5.5.6. Interleave layout

Tensor can be interleaved and the following interleave layouts are supported:

- No interleave (NDHWC)
- 8 byte interleave (NC/8DHWC8) : C8 utilizes 16 bytes in memory assuming 2B per channel.
- 16 byte interleave (NC/16HWC16) : C16 utilizes 32 bytes in memory assuming 4B per channel.

The *C* information is organized in slices where sequential C elements are grouped in 16 byte or 32 byte quantities.

If the total number of channels is not a multiple of the number of channels per slice, then the last slice must be padded with zeros to make it complete 16B or 32B slice.

Interleaved layouts are supported only for the dimensionalities : 3D, 4D and 5D.

The interleave layout is not supported for `.im2col::w` and `.im2col::w::128` modes.

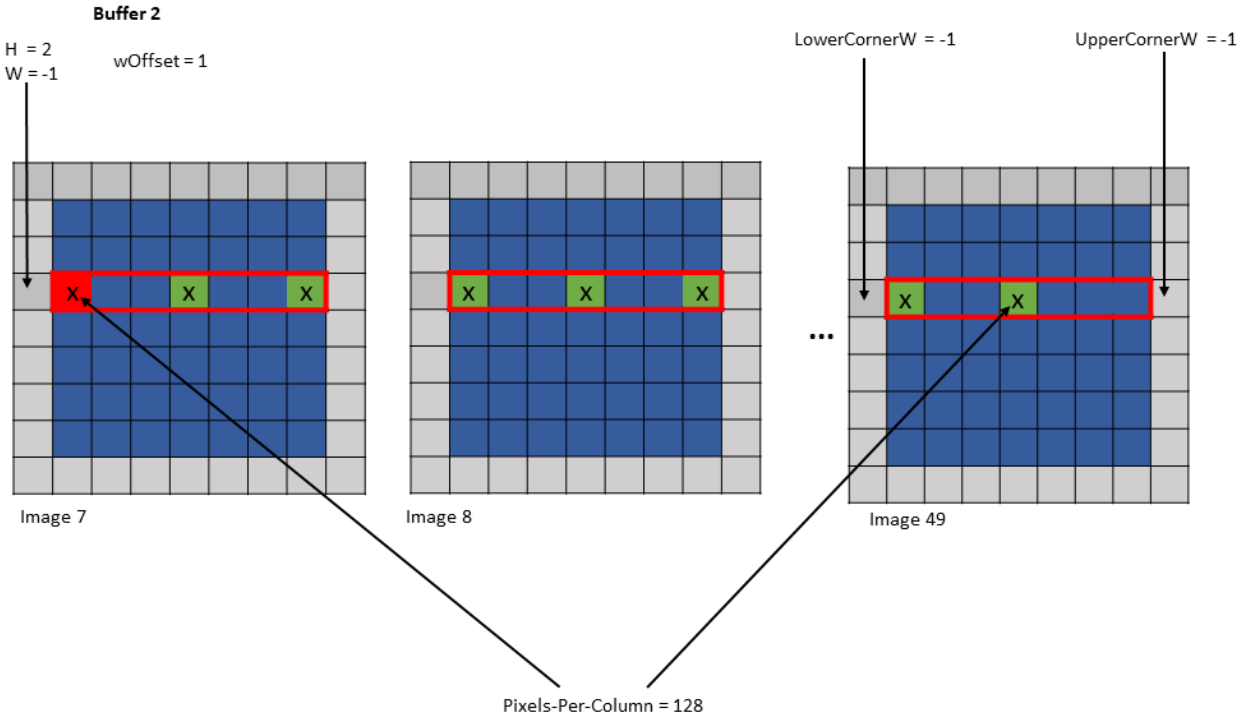

Figure 23: tensor copy operation to buffer 2 of Example 2

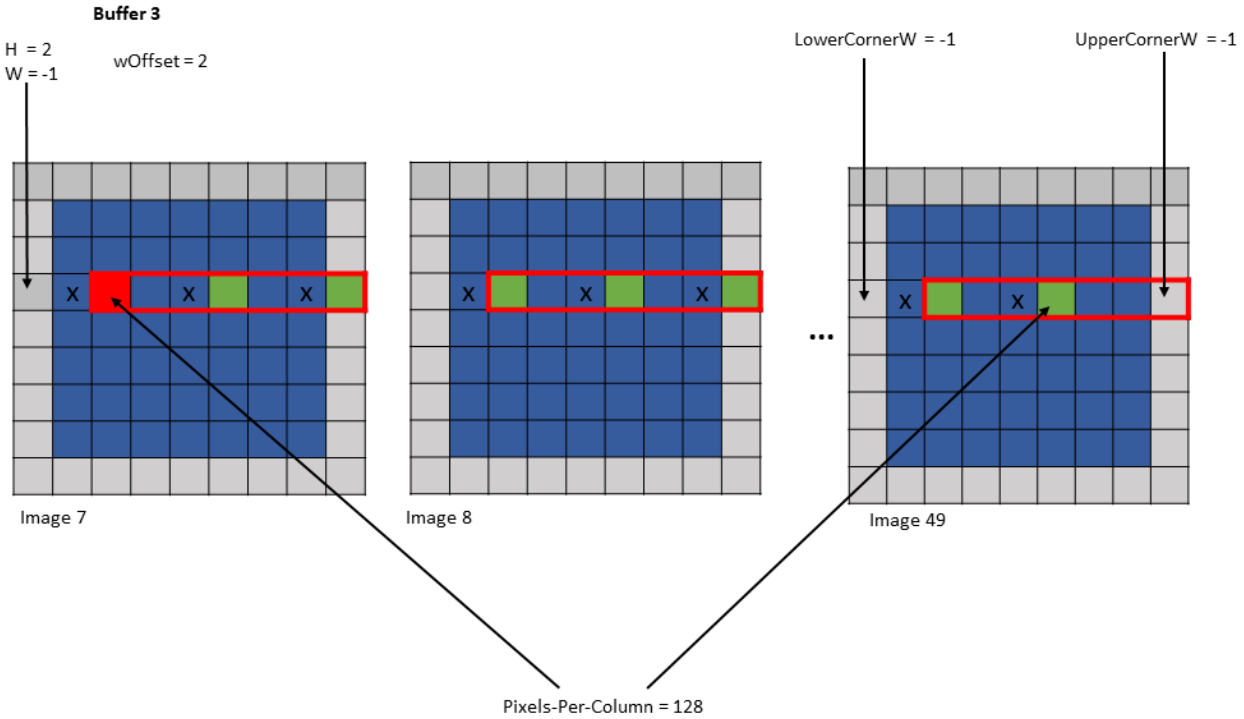

Figure 24: tensor copy operation to buffer 3 of Example 2

5.5.7. Swizzling Modes

The layout of the data in the shared memory can be different to that of global memory, for access performance reasons. The following describes various swizzling modes:

- No swizzle mode:

  There is no swizzling in this mode and the destination data layout is exactly similar to the source data layout.

0	1	2	3	4	5	6	7
0	1	2	3	4	5	6	7
... Pattern repeats ...							

- 32 byte swizzle mode:

  The following table, where each elements (numbered cell) is 16 byte and the starting address is 256 bytes aligned, shows the pattern of the destination data layout:

0	1	2	3	4	5	6	7
1	0	3	2	5	4	7	6
... Pattern repeats ...							

  An example of the 32 byte swizzle mode for NC/(32B)HWC(32B) tensor of 1x2x10x10xC16 dimension, with the innermost dimension holding slice of 16 channels with 2 byte/channel, is shown in Figure 25.

  Figure 26 shows the two fragments of the tensor : one for C/(32B) = 0 and another for C/(32B) = 1.

  Figure 27 shows the destination data layout with 32 byte swizzling.

- 64 byte swizzle mode:

  The following table, where each elements (numbered cell) is 16 byte and the starting address is 512 bytes aligned, shows the pattern of the destination data layout:

0	1	2	3	4	5	6	7
1	0	3	2	5	4	7	6
2	3	0	1	6	7	4	5
3	2	1	0	7	6	5	4
... Pattern repeats ...							

  An example of the 64 byte swizzle mode for NHWC tensor of 1x10x10x64 dimension, with 2 bytes / channel and 32 channels, is shown in Figure 28.

  Each colored cell represents 8 channels. Figure 29 shows the source data layout.

  Figure 30 shows the destination data layout with 64 byte swizzling.

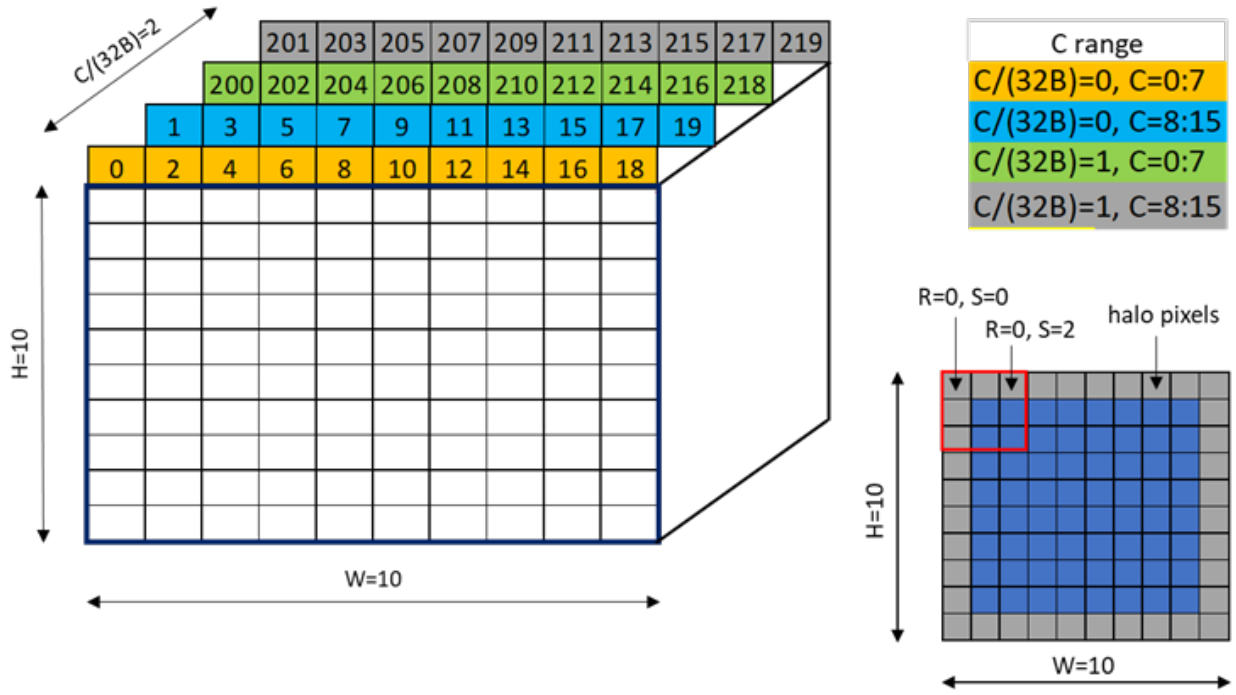

Figure 25: 32-byte swizzle mode example

- 96 byte swizzle mode:

  The following table where each element (numbered cell) is 16 byte shows the swizzling pattern at the destination data layout:

0	1	2	3	4	5	6	7
1	0	3	2	5	4	7	6
... Pattern repeats ...							

  An example of the data layout in global memory and its swizzled data layout in shared memory where each element (colored cell) is 16 bytes and the starting address is 256 bytes aligned is shown in Figure 31.

- 128 byte swizzle mode:

  The 128-byte swizzling mode supports the following sub-modes:

  - 16-byte atomicity sub-mode:

    In this sub-mode, the 16-byte of data is kept intact while swizzling.

  The following table, where each elements (numbered cell) is 16 byte and the starting address is 1024 bytes aligned, shows the pattern of the destination data layout:

C/(32B)	H	C(32B)x4							
0	0	0	1	2	3	4	5	6	7
		8	9	10	11	12	13	14	15
	0,1	16	17	18	19	20	21	22	23
	1	24	25	26	27	28	29	30	31
		32	33	34	35	36	37	38	39
	2	40	41	42	43	44	45	46	47
		48	49	50	51	52	53	54	55
	2,3	56	57	58	59	60	61	62	63
	3	64	65	66	67	68	69	70	71
		72	73	74	75	76	77	78	79

C/(32B)	H	C(32B)x4							
1	0	200	201	202	203	204	205	206	207
	0,1	208	209	210	211	212	213	214	215
	0,1	216	217	218	219	220	221	222	223
	1	224	225	226	227	228	229	230	231
	8,9	232	233	234	235	236	237	238	239
	2	240	241	242	243	244	245	246	247
	2,3	248	249	250	251	252	253	254	255
	2,3	256	257	258	259	260	261	262	263
	3	264	265	266	267	268	269	270	271
	8,9	272	273	274	275	276	277	278	279

Figure 26: 32-byte swizzle mode fragments

C/(32B)	H	C(32B)x4							
0	0	0	1	2	3	4	5	6	7
		9	8	11	10	13	12	15	14
	0,1	16	17	18	19	20	21	22	23
	1	25	24	27	26	29	28	31	30
		32	33	34	35	36	37	38	39
	2	41	40	43	42	45	44	47	46
		48	49	50	51	52	53	54	55
	2,3	57	56	59	58	61	60	63	62
	3	64	65	66	67	68	69	70	71
		73	72	75	74	77	76	79	78

C/(32B)	H	C(32B)x4							
1	0	200	201	202	203	204	205	206	207
	0,1	209	208	211	210	213	212	215	214
	0,1	216	217	218	219	220	221	222	223
	1	225	224	227	226	229	228	231	230
	8,9	232	233	234	235	236	237	238	239
	2	241	240	243	242	245	244	247	246
	2,3	248	249	250	251	252	253	254	255
	2,3	257	256	259	258	261	260	263	262
	3	264	265	266	267	268	269	270	271
	8,9	273	272	275	274	277	276	279	278

Figure 27: 32-byte swizzle mode destination data layout

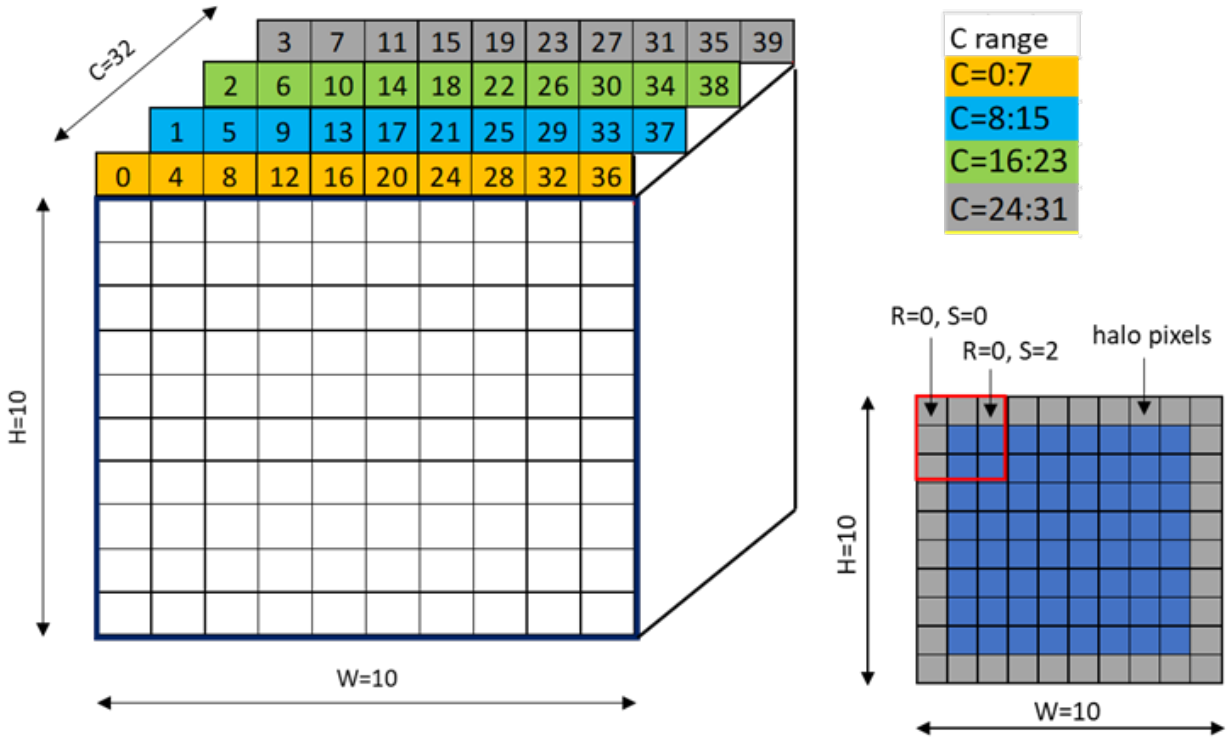

Figure 28: 64-byte swizzle mode example

0	1	2	3	4	5	6	7
1	0	3	2	5	4	7	6
2	3	0	1	6	7	4	5
3	2	1	0	7	6	5	4
4	5	6	7	0	1	2	3
5	4	7	6	1	0	3	2
6	7	4	5	2	3	0	1
7	6	5	4	3	2	1	0
... Pattern repeats ...							

An example of the 128 byte swizzle mode for NHWC tensor of 1x10x10x64 dimension, with 2 bytes / channel and 64 channels, is shown in Figure 32.

Each colored cell represents 8 channels. Figure 33 shows the source data layout.

Figure 34 shows the destination data layout with 128 byte swizzling.

- 32-byte atomicity sub-mode:

  In this sub-mode, the 32-byte of data is kept intact while swizzling.

  The following table where each element (numbered cell) is 16 byte shows the swizzling pattern at the destination data layout:

W	H	C = 0-63							
0,1	0	0	1	2	3	4	5	6	7
2,3		8	9	10	11	12	13	14	15
4,5		16	17	18	19	20	21	22	23
6,7		24	25	26	27	28	29	30	31
8,9		32	33	34	35	36	37	38	39
0,1	1	40	41	42	43	44	45	46	47
2,3		48	49	50	51	52	53	54	55
4,5		56	57	58	59	60	61	62	63
6,7		64	65	66	67	68	69	70	71
8,9		72	73	74	75	76	77	78	79

Figure 29: 64-byte swizzle mode source data layout

W	H	C = 0-63							
0,1	0	0	1	2	3	4	5	6	7
2,3		9	8	11	10	13	12	15	14
4,5		18	19	16	17	22	23	20	21
6,7		27	26	25	24	31	30	29	28
8,9		32	33	34	35	36	37	38	39
0,1	1	41	40	43	42	45	44	47	46
2,3		50	51	48	49	54	55	52	53
4,5		59	58	57	56	63	62	61	60
6,7		64	65	66	67	68	69	70	71
8,9		73	72	75	74	77	76	79	78

Figure 30: 64-byte swizzle mode destination data layout

0	1	2	3	4	5	6	7
8	9	10	11	12	13	14	15
16	17	18	19	20	21	22	23
24	25	26	27	28	29	30	31
32	33	34	35	36	37	38	39
40	41	42	43	44	45	46	47
48	49	50	51	52	53	54	55
56	57	58	59	60	61	62	63

global memory layout

0	1	2	3	4	5	8	9
11	10	13	12	17	16	19	18
20	21	24	25	26	27	28	29
33	32	35	34	37	36	41	40
42	43	44	45	48	49	50	51
53	52	57	56	59	58	61	60

swizzled shared memory layout

Figure 31: 96-byte swizzle mode example

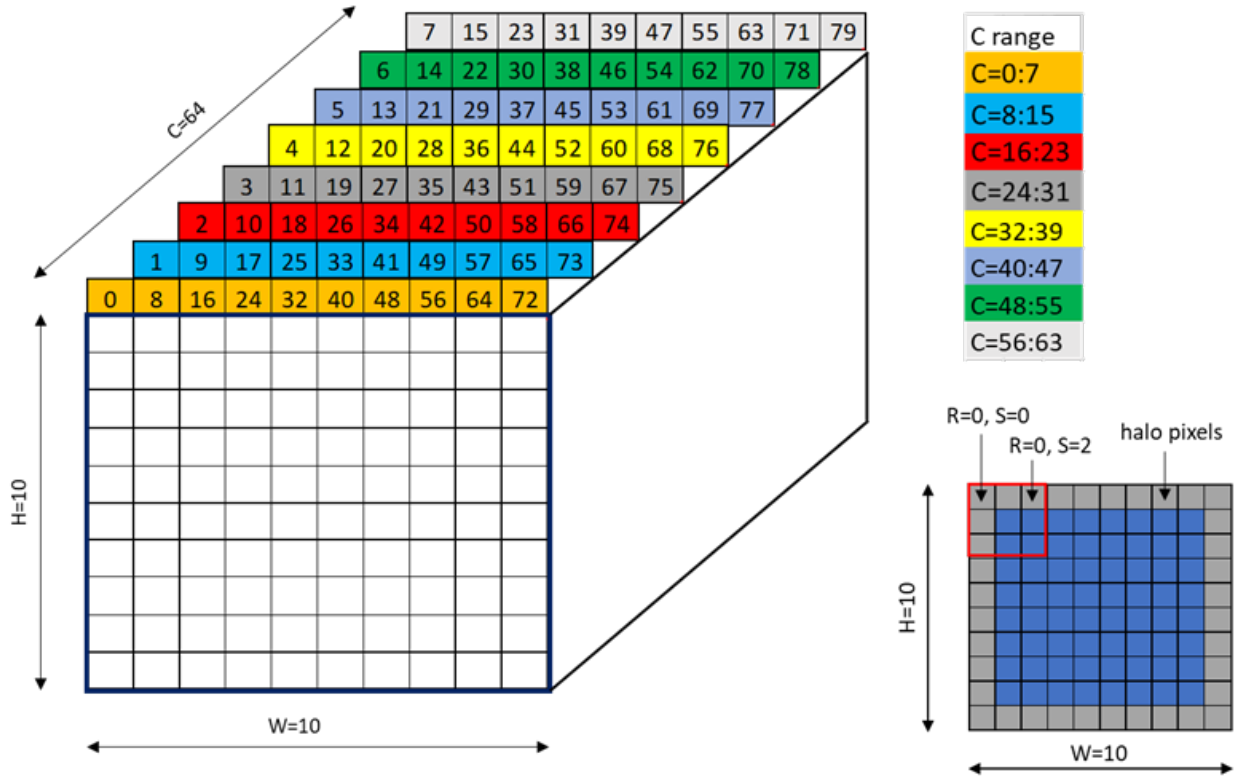

Figure 32: 128-byte swizzle mode example

0 1	2 3	4 5	6 7
2 3	0 1	6 7	4 5
4 5	6 7	0 1	2 3
6 7	4 5	2 3	0 1
... Pattern repeats ...			

This sub-mode requires 32 byte alignment at shared memory.

An example of the data layout in global memory and its swizzled data layout in shared memory where each element (colored cell) is 16 bytes is shown in Figure 35

- 32-byte atomicity with 8-byte flip sub-mode:

  The swizzling pattern for this sub-mode is similar to the 32-byte atomicity sub-mode except that there is a flip of adjacent 8-bytes within the 16-byte data at every alternate shared memory line.

  An example of the data layout in global memory and its swizzled data layout in shared memory where each element (colored cell) is 16 bytes (two 8-byte sub-elements for each 16-byte colored cell are shown to show the flip) is shown in Figure 36

- 64-byte atomicity sub-mode:

  In this sub-mode, the 64-byte of data is kept intact while swizzling.

W	H	C = 0-63							
0	0	0	1	2	3	4	5	6	7
1		8	9	10	11	12	13	14	15
2		16	17	18	19	20	21	22	23
3		24	25	26	27	28	29	30	31
4		32	33	34	35	36	37	38	39
5		40	41	42	43	44	45	46	47
6		48	49	50	51	52	53	54	55
7		56	57	58	59	60	61	62	63
8		64	65	66	67	68	69	70	71
9		72	73	74	75	76	77	78	79
0	1	80	81	82	83	84	85	86	87
1		88	89	90	91	92	93	94	95
2		96	97	98	99	100	101	102	103
3		104	105	106	107	108	109	110	111
4		112	113	114	115	116	117	118	119
5		120	121	122	123	124	125	126	127
6		128	129	130	131	132	133	134	135
7		136	137	138	139	140	141	142	143
8		144	145	146	147	148	149	150	151
9		152	153	154	155	156	157	159	159

Figure 33: 128-byte swizzle mode source data layout

W	H	C = 0-63							
0	0	0	1	2	3	4	5	6	7
1		9	8	11	10	13	12	15	14
2		18	19	16	17	22	23	20	21
3		27	26	25	24	31	30	29	28
4		36	37	38	39	32	33	34	35
5		45	44	47	46	41	40	43	42
6		54	55	52	53	50	51	48	49
7		63	62	61	60	59	58	57	56
8		64	65	66	67	68	69	70	71
9		73	72	75	74	77	76	79	78
0	1	82	83	80	81	86	87	84	85
1		91	90	89	88	95	94	93	92
2		100	101	102	103	96	97	98	99
3		109	108	111	110	105	104	107	106
4		118	119	116	117	114	115	112	113
5		127	126	125	124	123	122	121	120
6		128	129	130	131	132	133	134	135
7		137	136	139	138	141	140	143	142
8		146	147	144	145	150	151	148	149
9		155	154	153	152	159	158	157	156

Figure 34: 128-byte swizzle mode destination data layout

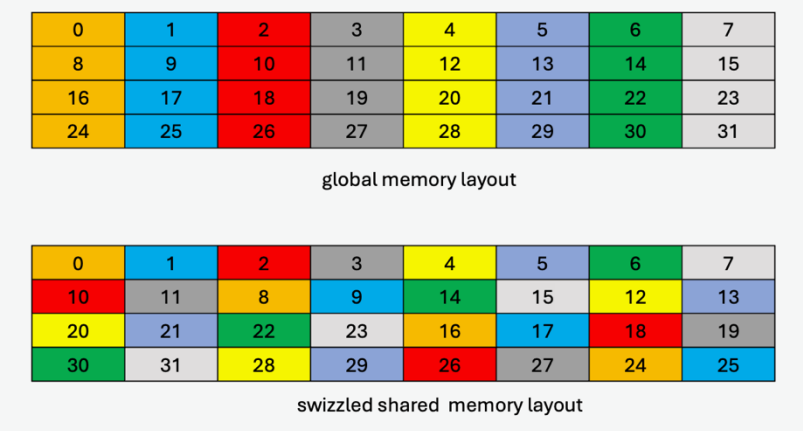

Figure 35: 128-byte swizzle mode example with 32-byte atomicity

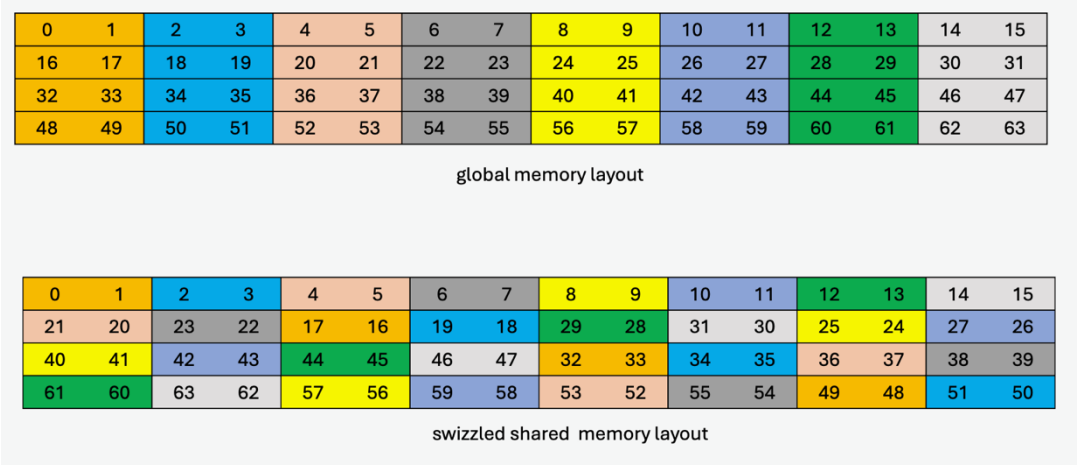

Figure 36: 128-byte swizzle mode example with 32-byte atomicity with 8-byte flip

The following table where each element (numbered cell) is 16 byte shows the swizzling pattern at the destination data layout:

0 1 2 3	4 5 6 7
4 5 6 7	0 1 2 3
... Pattern repeats ...	

This sub-mode requires 64-byte alignment at shared memory.

An example of the data layout in global memory and its swizzled data layout in shared memory where each element (colored cell) is 16 bytes is shown in Figure 37

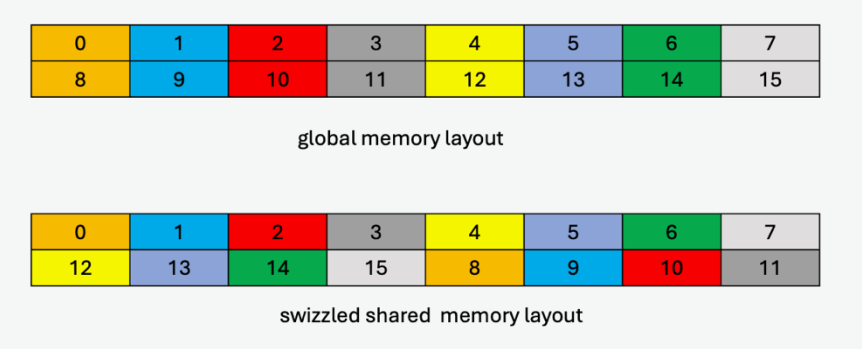

Figure 37: 128-byte swizzle mode example with 64-byte atomicity

Table 15 lists the valid combination of swizzle-atomicity with the swizzling-mode.

Table 15: Valid combination of swizzle-atomicity with swizzling-mode

Swizzling Mode	Swizzle-Atomicity
No Swizzling	–
32B Swizzling Mode	16B
64B Swizzling Mode	16B
96B Swizzling Mode	16B
128B Swizzling Mode	▶ 16B ▶ 32B ▶ 32B + 8B-flip ▶ 64B

The value of swizzle base offset is 0 when the `dstMem` shared memory address is located at the following boundary:

Swizzling Mode	Starting address of the repeating pattern
128-Byte swizzle	1024-Byte boundary
96-Byte swizzle	256-Byte boundary
64-Byte swizzle	512-Byte boundary
32-Byte swizzle	256-Byte boundary

Otherwise, the swizzle base offset is a non-zero value, computed using following formula:

Swizzling Mode	Formula
128-Byte swizzle	base offset = (dstMem / 128) % 8
96-Byte swizzle	base offset = (dstMem / 128) % 2
64-Byte swizzle	base offset = (dstMem / 128) % 4
32-Byte swizzle	base offset = (dstMem / 128) % 2

5.5.8. Tensor-map

The tensor-map is a 128-byte opaque object either in `.const` space or `.param` (kernel function parameter) space or `.global` space which describes the tensor properties and the access properties of the tensor data described in previous sections.

Tensor-Map can be created using CUDA APIs. Refer to *CUDA programming guide* for more details.

Chapter 6. Instruction Operands

6.1. Operand Type Information

All operands in instructions have a known type from their declarations. Each operand type must be compatible with the type determined by the instruction template and instruction type. There is no automatic conversion between types.

The bit-size type is compatible with every type having the same size. Integer types of a common size are compatible with each other. Operands having type different from but compatible with the instruction type are silently cast to the instruction type.

6.2. Source Operands

The source operands are denoted in the instruction descriptions by the names `a`, `b`, and `c`. PTX describes a load-store machine, so operands for ALU instructions must all be in variables declared in the `.reg` register state space. For most operations, the sizes of the operands must be consistent.

The `cvt` (convert) instruction takes a variety of operand types and sizes, as its job is to convert from nearly any data type to any other data type (and size).

The `ld`, `st`, `mov`, and `cvt` instructions copy data from one location to another. Instructions `ld` and `st` move data from/to addressable state spaces to/from registers. The `mov` instruction copies data between registers.

Most instructions have an optional predicate guard that controls conditional execution, and a few instructions have additional predicate source operands. Predicate operands are denoted by the names `p`, `q`, `r`, `s`.

6.3. Destination Operands

PTX instructions that produce a single result store the result in the field denoted by `d` (for destination) in the instruction descriptions. The result operand is a scalar or vector variable in the register state space.

6.4. Using Addresses, Arrays, and Vectors

Using scalar variables as operands is straightforward. The interesting capabilities begin with addresses, arrays, and vectors.

6.4.1. Addresses as Operands

All the memory instructions take an address operand that specifies the memory location being accessed. This addressable operand is one of:

[var]
: the name of an addressable variable `var`.

[reg]
: an integer or bit-size type register `reg` containing a byte address.

[reg+immOff]
: a sum of register `reg` containing a byte address plus a constant integer byte offset (signed, 32-bit).

[var+immOff]
: a sum of address of addressable variable `var` containing a byte address plus a constant integer byte offset (signed, 32-bit).

[immAddr]
: an immediate absolute byte address (unsigned, 32-bit).

var[immOff]
: an array element as described in *Arrays as Operands*.

The register containing an address may be declared as a bit-size type or integer type.

The access size of a memory instruction is the total number of bytes accessed in memory. For example, the access size of `ld.v4.b32` is 16 bytes, while the access size of `atom.f16x2` is 4 bytes.

The address must be naturally aligned to a multiple of the access size. If an address is not properly aligned, the resulting behavior is undefined. For example, among other things, the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

The address size may be either 32-bit or 64-bit. 128-bit adresses are not supported. Addresses are zero-extended to the specified width as needed, and truncated if the register width exceeds the state space address width for the target architecture.

Address arithmetic is performed using integer arithmetic and logical instructions. Examples include pointer arithmetic and pointer comparisons. All addresses and address computations are byte-based; there is no support for C-style pointer arithmetic.

The `mov` instruction can be used to move the address of a variable into a pointer. The address is an offset in the state space in which the variable is declared. Load and store operations move data between registers and locations in addressable state spaces. The syntax is similar to that used in many assembly languages, where scalar variables are simply named and addresses are de-referenced by enclosing the address expression in square brackets. Address expressions include variable names, address registers, address register plus byte offset, and immediate address expressions which evaluate at compile-time to a constant address.

Here are a few examples:

```
.shared .u16 x;
.reg    .u16 r0;
.global .v4 .f32 V;
.reg    .v4 .f32 W;
.const  .s32 tbl[256];
.reg    .b32 p;
.reg    .s32 q;

ld.shared.u16   r0,[x];
ld.global.v4.f32 W, [V];
ld.const.s32    q, [tbl+12];
mov.u32         p, tbl;
```

6.4.1.1 Generic Addressing

If a memory instruction does not specify a state space, the operation is performed using generic addressing. The state spaces `.const`, *Kernel Function Parameters* (`.param`), `.local` and `.shared` are modeled as windows within the generic address space. Each window is defined by a window base and a window size that is equal to the size of the corresponding state space. A generic address maps to `global` memory unless it falls within the window for `const`, `local`, or `shared` memory. The *Kernel Function Parameters* (`.param`) window is contained within the `.global` window. Within each window, a generic address maps to an address in the underlying state space by subtracting the window base from the generic address.

6.4.2. Arrays as Operands

Arrays of all types can be declared, and the identifier becomes an address constant in the space where the array is declared. The size of the array is a constant in the program.

Array elements can be accessed using an explicitly calculated byte address, or by indexing into the array using square-bracket notation. The expression within square brackets is either a constant integer, a register variable, or a simple *register with constant offset* expression, where the offset is a constant expression that is either added or subtracted from a register variable. If more complicated indexing is desired, it must be written as an address calculation prior to use. Examples are:

```
ld.global.u32  s, a[0];
ld.global.u32  s, a[N-1];
mov.u32        s, a[1];  // move address of a[1] into s
```

6.4.3. Vectors as Operands

Vector operands are supported by a limited subset of instructions, which include `mov`, `ld`, `st`, `atom`, `red` and `tex`. Vectors may also be passed as arguments to called functions.

Vector elements can be extracted from the vector with the suffixes `.x`, `.y`, `.z` and `.w`, as well as the typical color fields `.r`, `.g`, `.b` and `.a`.

A brace-enclosed list is used for pattern matching to pull apart vectors.

```
.reg .v4 .f32 V;
.reg .f32     a, b, c, d;

mov.v4.f32 {a,b,c,d}, V;
```

Vector loads and stores can be used to implement wide loads and stores, which may improve memory performance. The registers in the load/store operations can be a vector, or a brace-enclosed list of similarly typed scalars. Here are examples:

```
ld.global.v4.f32  {a,b,c,d}, [addr+16];
ld.global.v2.u32  V2, [addr+8];
```

Elements in a brace-enclosed vector, say {Ra, Rb, Rc, Rd}, correspond to extracted elements as follows:

```
Ra = V.x = V.r
Rb = V.y = V.g
Rc = V.z = V.b
Rd = V.w = V.a
```

6.4.4. Labels and Function Names as Operands

Labels and function names can be used only in `bra`/`brx.idx` and `call` instructions respectively. Function names can be used in `mov` instruction to get the address of the function into a register, for use in an indirect call.

Beginning in PTX ISA version 3.1, the `mov` instruction may be used to take the address of kernel functions, to be passed to a system call that initiates a kernel launch from the GPU. This feature is part of the support for CUDA Dynamic Parallelism. See the *CUDA Dynamic Parallelism Programming Guide* for details.

6.5. Type Conversion

All operands to all arithmetic, logic, and data movement instruction must be of the same type and size, except for operations where changing the size and/or type is part of the definition of the instruction. Operands of different sizes or types must be converted prior to the operation.

6.5.1. Scalar Conversions

Table 16 and Table 17 show what precision and format the cvt instruction uses given operands of differing types. For example, if a `cvt.s32.u16` instruction is given a `u16` source operand and `s32` as a destination operand, the `u16` is zero-extended to `s32`.

Conversions to floating-point that are beyond the range of floating-point numbers are represented with the maximum floating-point value (IEEE 754 Inf for `f32` and `f64`, and ~131,000 for `f16`).

Table 16: Convert Instruction Precision and Format Table 1

		Destination Format												
		s8	**s16**	**s32**	**s64**	**u8**	**u16**	**u32**	**u64**	**f16**	**f32**	**f64**	**bf16**	**tf32**
Source Format	**s8**	–	sext	sext	sext	–	sext	sext	sext	s2f	s2f	s2f	s2f	–
	s16	chop[1]	–	sext	sext	chop[1]	–	sext	sext	s2f	s2f	s2f	s2f	–
	s32	chop[1]	chop[1]	–	sext	chop[1]	chop[1]	–	sext	s2f	s2f	s2f	s2f	–
	s64	chop[1]	chop[1]	chop[1]	–	chop[1]	chop[1]	chop[1]	–	s2f	s2f	s2f	s2f	–
	u8	–	zext	zext	zext	–	zext	zext	zext	u2f	u2f	u2f	u2f	–
	u16	chop[1]	–	zext	zext	chop[1]	–	zext	zext	u2f	u2f	u2f	u2f	–
	u32	chop[1]	chop[1]	–	zext	chop[1]	chop[1]	–	zext	u2f	u2f	u2f	u2f	–
	u64	chop[1]	chop[1]	chop[1]	–	chop[1]	chop[1]	chop[1]	–	u2f	u2f	u2f	u2f	–
	f16	f2s	f2s	f2s	f2s	f2u	f2u	f2u	f2u	–	f2f	f2f	f2f	–
	f32	f2s	f2s	f2s	f2s	f2u	f2u	f2u	f2u	f2f	–	f2f	f2f	f2f
	f64	f2s	f2s	f2s	f2s	f2u	f2u	f2u	f2u	f2f	f2f	–	f2f	–
	bf16	f2s	f2s	f2s	f2s	f2u	f2u	f2u	f2u	f2f	f2f	f2f	f2f	–
	tf32	–	–	–	–	–	–	–	–	–	–	–	–	–

Table 17: Convert Instruction Precision and Format Table 2

		Destination Format								
		f16	**f32**	**bf16**	**e4m3**	**e5m2**	**e2m3**	**e3m2**	**e2m1**	**ue8m0**
Source Format	**f16**	–	f2f	f2f	f2f	f2f	–	–	–	–
	f32	f2f	–	f2f	f2f	f2f	f2f	f2f	f2f	f2f
	bf16	f2f	f2f	f2f	–	–	–	–	–	f2f
	e4m3	f2f	–	–	–	–	–	–	–	–
	e5m2	f2f	–	–	–	–	–	–	–	–
	e2m3	f2f	–	–	–	–	–	–	–	–
	e3m2	f2f	–	–	–	–	–	–	–	–
	e2m1	f2f	–	–	–	–	–	–	–	–
	ue8m0	–	–	f2f	–	–	–	–	–	–

Notes

sext = sign-extend; zext = zero-extend; chop = keep only low bits that fit;

s2f = signed-to-float; f2s = float-to-signed; u2f = unsigned-to-float;

f2u = float-to-unsigned; f2f = float-to-float.

[1] If the destination register is wider than the destination format, the result is extended to the destination register width after chopping. The type of extension (sign or zero) is based on the destination

format. For example, cvt.s16.u32 targeting a 32-bit register first chops to 16-bit, then sign-extends to 32-bit.

6.5.2. Rounding Modifiers

Conversion instructions may specify a rounding modifier. In PTX, there are four integer rounding modifiers and four floating-point rounding modifiers. Table 18 and Table 19 summarize the rounding modifiers.

Table 18: Floating-Point Rounding Modifiers

Modifier	Description
`.rn`	rounds to nearest even
`.rna`	rounds to nearest, ties away from zero
`.rz`	rounds towards zero
`.rm`	rounds towards negative infinity
`.rp`	rounds towards positive infinity
`.rs`	rounds either towards zero or away from zero based on the carry out of the integer addition of random bits and the discarded bits of mantissa

Table 19: Integer Rounding Modifiers

Modifier	Description
`.rni`	round to nearest integer, choosing even integer if source is equidistant between two integers.
`.rzi`	round to nearest integer in the direction of zero
`.rmi`	round to nearest integer in direction of negative infinity
`.rpi`	round to nearest integer in direction of positive infinity

6.6. Operand Costs

Operands from different state spaces affect the speed of an operation. Registers are fastest, while global memory is slowest. Much of the delay to memory can be hidden in a number of ways. The first is to have multiple threads of execution so that the hardware can issue a memory operation and then switch to other execution. Another way to hide latency is to issue the load instructions as early as possible, as execution is not blocked until the desired result is used in a subsequent (in time) instruction. The register in a store operation is available much more quickly. Table 20 gives estimates of the costs of using different kinds of memory.

Table 20: Cost Estimates for Accessing State-Spaces

Space	Time	Notes
Register	0	
Shared	0	
Constant	0	Amortized cost is low, first access is high
Local	> 100 clocks	
Parameter	0	
Immediate	0	
Global	> 100 clocks	
Texture	> 100 clocks	
Surface	> 100 clocks	

Chapter 7. Abstracting the ABI

Rather than expose details of a particular calling convention, stack layout, and Application Binary Interface (ABI), PTX provides a slightly higher-level abstraction and supports multiple ABI implementations. In this section, we describe the features of PTX needed to achieve this hiding of the ABI. These include syntax for function definitions, function calls, parameter passing, and memory allocated on the stack (`alloca`).

Refer to *PTX Writers Guide to Interoperability* for details on generating PTX compliant with Application Binary Interface (ABI) for the CUDA® architecture.

7.1. Function Declarations and Definitions

In PTX, functions are declared and defined using the `.func` directive. A function *declaration* specifies an optional list of return parameters, the function name, and an optional list of input parameters; together these specify the function's interface, or prototype. A function *definition* specifies both the interface and the body of the function. A function must be declared or defined prior to being called.

The simplest function has no parameters or return values, and is represented in PTX as follows:

```
.func foo
{
    ...
    ret;
}

    ...
    call foo;
    ...
```

Here, execution of the `call` instruction transfers control to `foo`, implicitly saving the return address. Execution of the `ret` instruction within `foo` transfers control to the instruction following the call.

Scalar and vector base-type input and return parameters may be represented simply as register variables. At the call, arguments may be register variables or constants, and return values may be placed directly into register variables. The arguments and return variables at the call must have type and size that match the callee's corresponding formal parameters.

Example

```
.func (.reg .u32 %res) inc_ptr ( .reg .u32 %ptr, .reg .u32 %inc )
{
    add.u32 %res, %ptr, %inc;
    ret;
}

    ...
    call (%r1), inc_ptr, (%r1,4);
    ...
```

When using the ABI, `.reg` state space parameters must be at least 32-bits in size. Subword scalar objects in the source language should be promoted to 32-bit registers in PTX, or use `.param` state space byte arrays described next.

Objects such as C structures and unions are flattened into registers or byte arrays in PTX and are represented using `.param` space memory. For example, consider the following C structure, passed by value to a function:

```
struct {
    double dbl;
    char   c[4];
};
```

In PTX, this structure will be flattened into a byte array. Since memory accesses are required to be aligned to a multiple of the access size, the structure in this example will be a 12 byte array with 8 byte alignment so that accesses to the `.f64` field are aligned. The `.param` state space is used to pass the structure by value:

Example

```
.func (.reg .s32 out) bar (.reg .s32 x, .param .align 8 .b8 y[12])
{
    .reg .f64 f1;
    .reg .b32 c1, c2, c3, c4;
    ...
    ld.param.f64 f1, [y+0];
    ld.param.b8  c1, [y+8];
    ld.param.b8  c2, [y+9];
    ld.param.b8  c3, [y+10];
    ld.param.b8  c4, [y+11];
    ...
    ... // computation using x,f1,c1,c2,c3,c4;
}

{
     .param .b8 .align 8 py[12];
     ...
     st.param.b64 [py+ 0], %rd;
     st.param.b8  [py+ 8], %rc1;
     st.param.b8  [py+ 9], %rc2;
     st.param.b8  [py+10], %rc1;
     st.param.b8  [py+11], %rc2;
     // scalar args in .reg space, byte array in .param space
```

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```
    call (%out), bar, (%x, py);
    ...
```

In this example, note that `.param` space variables are used in two ways. First, a `.param` variable `y` is used in function definition bar to represent a formal parameter. Second, a `.param` variable `py` is declared in the body of the calling function and used to set up the structure being passed to bar.

The following is a conceptual way to think about the `.param` state space use in device functions.

For a caller,

- The `.param` state space is used to set values that will be passed to a called function and/or to receive return values from a called function. Typically, a `.param` byte array is used to collect together fields of a structure being passed by value.

For a callee,

- The `.param` state space is used to receive parameter values and/or pass return values back to the caller.

The following restrictions apply to parameter passing.

For a caller,

- Arguments may be `.param` variables, `.reg` variables, or constants.
- In the case of `.param` space formal parameters that are byte arrays, the argument must also be a `.param` space byte array with matching type, size, and alignment. A `.param` argument must be declared within the local scope of the caller.
- In the case of `.param` space formal parameters that are base-type scalar or vector variables, the corresponding argument may be either a `.param` or `.reg` space variable with matching type and size, or a constant that can be represented in the type of the formal parameter.
- In the case of `.reg` space formal parameters, the corresponding argument may be either a `.param` or `.reg` space variable of matching type and size, or a constant that can be represented in the type of the formal parameter.
- In the case of `.reg` space formal parameters, the register must be at least 32-bits in size.
- All `st.param` instructions used for passing arguments to function call must immediately precede the corresponding `call` instruction and `ld.param` instruction used for collecting return value must immediately follow the `call` instruction without any control flow alteration. `st.param` and `ld.param` instructions used for argument passing cannot be predicated. This enables compiler optimization and ensures that the `.param` variable does not consume extra space in the caller's frame beyond that needed by the ABI. The `.param` variable simply allows a mapping to be made at the call site between data that may be in multiple locations (e.g., structure being manipulated by caller is located in registers and memory) to something that can be passed as a parameter or return value to the callee.

For a callee,

- Input and return parameters may be `.param` variables or `.reg` variables.
- Parameters in `.param` memory must be aligned to a multiple of 1, 2, 4, 8, or 16 bytes.
- Parameters in the `.reg` state space must be at least 32-bits in size.
- The `.reg` state space can be used to receive and return base-type scalar and vector values, including sub-word size objects when compiling in non-ABI mode. Supporting the `.reg` state space provides legacy support.

Note that the choice of `.reg` or `.param` state space for parameter passing has no impact on whether the parameter is ultimately passed in physical registers or on the stack. The mapping of parameters to physical registers and stack locations depends on the ABI definition and the order, size, and alignment of parameters.

7.1.1. Changes from PTX ISA Version 1.x

In PTX ISA version 1.x, formal parameters were restricted to .reg state space, and there was no support for array parameters. Objects such as C structures were flattened and passed or returned using multiple registers. PTX ISA version 1.x supports multiple return values for this purpose.

Beginning with PTX ISA version 2.0, formal parameters may be in either `.reg` or `.param` state space, and `.param` space parameters support arrays. For targets `sm_20` or higher, PTX restricts functions to a single return value, and a `.param` byte array should be used to return objects that do not fit into a register. PTX continues to support multiple return registers for `sm_1x` targets.

Note: PTX implements a stack-based ABI only for targets `sm_20` or higher.

PTX ISA versions prior to 3.0 permitted variables in `.reg` and `.local` state spaces to be defined at module scope. When compiling to use the ABI, PTX ISA version 3.0 and later disallows module-scoped `.reg` and `.local` variables and restricts their use to within function scope. When compiling without use of the ABI, module-scoped `.reg` and `.local` variables are supported as before. When compiling legacy PTX code (ISA versions prior to 3.0) containing module-scoped `.reg` or `.local` variables, the compiler silently disables use of the ABI.

7.2. Variadic Functions

Note: Support for variadic functions which was unimplemented has been removed from the spec.

PTX version 6.0 supports passing unsized array parameter to a function which can be used to implement variadic functions.

Refer to *Kernel and Function Directives: .func* for details

7.3. Alloca

PTX provides `alloca` instruction for allocating storage at runtime on the per-thread local memory stack. The allocated stack memory can be accessed with `ld.local` and `st.local` instructions using the pointer returned by `alloca`.

In order to facilitate deallocation of memory allocated with `alloca`, PTX provides two additional instructions: `stacksave` which allows reading the value of stack pointer in a local variable, and `stackrestore` which can restore the stack pointer with the saved value.

`alloca`, `stacksave`, and `stackrestore` instructions are described in *Stack Manipulation Instructions*.

Preview Feature

Stack manipulation instructions `alloca`, `stacksave` and `stackrestore` are preview features in PTX ISA version 7.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Chapter 8. Memory Consistency Model

In multi-threaded executions, the side-effects of memory operations performed by each thread become visible to other threads in a partial and non-identical order. This means that any two operations may appear to happen in no order, or in different orders, to different threads. The axioms introduced by the memory consistency model specify exactly which contradictions are forbidden between the orders observed by different threads.

In the absence of any constraint, each read operation returns the value committed by some write operation to the same memory location, including the initial write to that memory location. The memory consistency model effectively constrains the set of such candidate writes from which a read operation can return a value.

8.1. Scope and applicability of the model

The constraints specified under this model apply to PTX programs with any PTX ISA version number, running on `sm_70` or later architectures.

The memory consistency model does not apply to texture (including `ld.global.nc`) and surface accesses.

8.1.1. Limitations on atomicity at system scope

When communicating with the host CPU, certain strong operations with system scope may not be performed atomically on some systems. For more details on atomicity guarantees to host memory, see the *CUDA Atomicity Requirements*.

8.2. Memory operations

The fundamental storage unit in the PTX memory model is a byte, consisting of 8 bits. Each state space available to a PTX program is a sequence of contiguous bytes in memory. Every byte in a PTX state space has a unique address relative to all threads that have access to the same state space.

Each PTX memory instruction specifies an address operand and a data type. The address operand contains a virtual address that gets converted to a physical address during memory access. The physical address and the size of the data type together define a physical memory location, which is the range of bytes starting from the physical address and extending up to the size of the data type in bytes.

The memory consistency model specification uses the terms “address” or “memory address” to indicate a virtual address, and the term “memory location” to indicate a physical memory location.

Each PTX memory instruction also specifies the operation — either a read, a write or an atomic read-modify-write — to be performed on all the bytes in the corresponding memory location.

8.2.1. Overlap

Two memory locations are said to overlap when the starting address of one location is within the range of bytes constituting the other location. Two memory operations are said to overlap when they specify the same virtual address and the corresponding memory locations overlap. The overlap is said to be complete when both memory locations are identical, and it is said to be partial otherwise.

8.2.2. Aliases

Two distinct virtual addresses are said to be aliases if they map to the same memory location.

8.2.3. Multimem Addresses

A multimem address is a virtual address which points to multiple distinct memory locations across devices.

Only *multimem.** operations are valid on multimem addresses. That is, the behavior of accessing a multimem address in any other memory operation is undefined.

8.2.4. Memory Operations on Vector Data Types

The memory consistency model relates operations executed on memory locations with scalar data types, which have a maximum size and alignment of 64 bits. Memory operations with a vector data type are modelled as a set of equivalent memory operations with a scalar data type, executed in an unspecified order on the elements in the vector.

8.2.5. Memory Operations on Packed Data Types

A packed data type consists of two values of the same scalar data type, as described in *Packed Data Types*. These values are accessed in adjacent memory locations. A memory operation on a packed data type is modelled as a pair of equivalent memory operations on the scalar data type, executed in an unspecified order on each element of the packed data.

8.2.6. Initialization

Each byte in memory is initialized by a hypothetical write *W0* executed before starting any thread in the program. If the byte is included in a program variable, and that variable has an initial value, then *W0* writes the corresponding initial value for that byte; else *W0* is assumed to have written an unknown but constant value to the byte.

8.3. State spaces

The relations defined in the memory consistency model are independent of state spaces. In particular, causality order closes over all memory operations across all the state spaces. But the side-effect of a memory operation in one state space can be observed directly only by operations that also have access to the same state space. This further constrains the synchronizing effect of a memory operation in addition to scope. For example, the synchronizing effect of the PTX instruction `ld.relaxed.shared.sys` is identical to that of `ld.relaxed.shared.cluster`, since no thread outside the same cluster can execute an operation that accesses the same memory location.

8.4. Operation types

For simplicity, the rest of the document refers to the following operation types, instead of mentioning specific instructions that give rise to them.

Table 21: Operation Types

Operation Type	Instruction/Operation
atomic operation	`atom` or `red` instruction.
read operation	All variants of `ld` instruction and `atom` instruction (but not `red` instruction).
write operation	All variants of `st` instruction, and *atomic* operations if they result in a write.
memory operation	A *read* or *write* operation.
volatile operation	An instruction with `.volatile` qualifier.
acquire operation	A *memory* operation with `.acquire` or `.acq_rel` qualifier.
release operation	A *memory* operation with `.release` or `.acq_rel` qualifier.
mmio operation	An `ld` or `st` instruction with `.mmio` qualifier.
memory fence operation	A `membar`, `fence.sc` or `fence.acq_rel` instruction.
proxy fence operation	A `fence.proxy` or a `membar.proxy` instruction.
strong operation	A *memory fence* operation, or a *memory* operation with a `.relaxed`, `.acquire`, `.release`, `.acq_rel`, `.volatile`, or `.mmio` qualifier.
weak operation	An `ld` or `st` instruction with a `.weak` qualifier.
synchronizing operation	A `barrier` instruction, *fence* operation, *release* operation or *acquire* operation.

8.4.1. mmio Operation

An *mmio* operation is a memory operation with `.mmio` qualifier specified. It is usually performed on a memory location which is mapped to the control registers of peer I/O devices. It can also be used for communication between threads but has poor performance relative to non-*mmio* operations.

The semantic meaning of *mmio* operations cannot be defined precisely as it is defined by the underlying I/O device. For formal specification of semantics of *mmio* operation from Memory Consistency Model perspective, it is equivalent to the semantics of a *strong* operation. But it follows a few implementation-specific properties, if it meets the *CUDA atomicity requirements* at the specified scope:

- Writes are always performed and are never combined within the scope specified.
- Reads are always performed, and are not forwarded, prefetched, combined, or allowed to hit any cache within the scope specified.
  - As an exception, in some implementations, the surrounding locations may also be loaded. In such cases the amount of data loaded is implementation specific and varies between 32 and 128 bytes in size.

8.4.2. volatile Operation

A *volatile* operation is a memory operation with `.volatile` qualifier specified. The semantics of volatile operations are equivalent to a relaxed memory operation with system-scope but with the following extra implementation-specific constraints:

- The number of volatile *instructions* (not operations) executed by a program is preserved. Hardware may combine and merge volatile *operations* issued by multiple different volatile *instructions*, that is, the number of volatile *operations* in the program is not preserved.
- Volatile *instructions* are not re-ordered around other volatile *instructions*, but the memory *operations* performed by those *instructions* may be re-ordered around each other.

Note: PTX volatile operations are intended for compilers to lower volatile read and write operations from CUDA C++, and other programming languages sharing CUDA C++ volatile semantics, to PTX.

Since volatile operations are relaxed at system-scope with extra constraints, prefer using other *strong* read or write operations (e.g. `ld.relaxed.sys` or `st.relaxed.sys`) for **Inter-Thread Synchronization** instead, which may deliver better performance.

PTX volatile operations are not suited for **Memory Mapped IO (MMIO)** because volatile operations do not preserve the number of memory operations performed, and may perform more or less operations than requested in a non-deterministic way. Use *.mmio operations* instead, which strictly preserve the number of operations performed.

8.5. Scope

Each *strong* operation must specify a *scope*, which is the set of threads that may interact directly with that operation and establish any of the relations described in the memory consistency model. There are four scopes:

Table 22: Scopes

Scope	Description
`.cta`	The set of all threads executing in the same CTA as the current thread.
`.cluster`	The set of all threads executing in the same cluster as the current thread.
`.gpu`	The set of all threads in the current program executing on the same compute device as the current thread. This also includes other kernel grids invoked by the host program on the same compute device.
`.sys`	The set of all threads in the current program, including all kernel grids invoked by the host program on all compute devices, and all threads constituting the host program itself.

Note that the warp is not a *scope*; the CTA is the smallest collection of threads that qualifies as a *scope* in the memory consistency model.

8.6. Proxies

A *memory proxy*, or a *proxy* is an abstract label applied to a method of memory access. When two memory operations use distinct methods of memory access, they are said to be different *proxies*.

Memory operations as defined in *Operation types* use *generic* method of memory access, i.e. a *generic proxy*. Other operations such as textures and surfaces all use distinct methods of memory access, also distinct from the *generic* method.

A *proxy fence* is required to synchronize memory operations across different *proxies*. Although virtual aliases use the *generic* method of memory access, since using distinct virtual addresses behaves as if using different *proxies*, they require a *proxy fence* to establish memory ordering.

8.7. Morally strong operations

Two operations are said to be *morally strong* relative to each other if they satisfy all of the following conditions:

1. The operations are related in *program order* (i.e, they are both executed by the same thread), or each operation is *strong* and specifies a *scope* that includes the thread executing the other operation.
2. Both operations are performed via the same *proxy*.
3. If both are memory operations, then they overlap completely.

Most (but not all) of the axioms in the memory consistency model depend on relations between *morally strong* operations.

8.7.1. Conflict and Data-races

Two *overlapping* memory operations are said to *conflict* when at least one of them is a *write*.

Two *conflicting* memory operations are said to be in a *data-race* if they are not related in *causality order* and they are not *morally strong*.

8.7.2. Limitations on Mixed-size Data-races

A *data-race* between operations that *overlap* completely is called a *uniform-size data-race*, while a *data-race* between operations that *overlap* partially is called a *mixed-size data-race*.

The axioms in the memory consistency model do not apply if a PTX program contains one or more *mixed-size data-races*. But these axioms are sufficient to describe the behavior of a PTX program with only *uniform-size data-races*.

Atomicity of mixed-size RMW operations

In any program with or without *mixed-size data-races*, the following property holds for every pair of *overlapping atomic* operations A1 and A2 such that each specifies a *scope* that includes the other: Either the *read-modify-write* operation specified by A1 is performed completely before A2 is initiated, or vice versa. This property holds irrespective of whether the two operations A1 and A2 overlap partially or completely.

8.8. Release and Acquire Patterns

Some sequences of instructions give rise to patterns that participate in memory synchronization as described later. The *release* pattern makes prior operations from the current thread[1] visible to some operations from other threads. The *acquire* pattern makes some operations from other threads visible to later operations from the current thread.

A *release* pattern on a location M consists of one of the following:

1. A *release* operation on M

   E.g.: `st.release [M];` or `atom.release [M];` or `mbarrier.arrive.release [M];`

2. Or a *release* or *acquire-release* operation on M followed by a *strong* write on M in *program order*

   E.g.: `st.release [M]`; `st.relaxed [M];`

#. Or a *release* or *acquire-release memory fence* followed by a *strong* write on M in *program order*

   E.g.: `fence.release; st.relaxed [M];` or `fence.release; atom.relaxed [M];`

Any *memory synchronization* established by a *release* pattern only affects operations occurring in *program order* before the first instruction in that pattern.

An *acquire* pattern on a location M consists of one of the following:

1. An *acquire* operation on M

   E.g.: `ld.acquire [M];` or `atom.acquire [M];` or `mbarrier.test_wait.acquire [M];`

2. Or a *strong* read on M followed by an *acquire* operation on M in *program order*

   E.g.: `ld.relaxed [M]; ld.acquire [M];`

3. Or a *strong* read on M followed by an acquire *memory fence* in *program order*

   E.g.: `ld.relaxed [M]; fence.acquire;` or `atom.relaxed [M]; fence.acquire;`

Any *memory synchronization* established by an *acquire* pattern only affects operations occurring in *program order* after the last instruction in that pattern.

Note that while atomic reductions conceptually perform a strong read as part of its read-modify-write sequence, this strong read does not form an acquire pattern.

E.g.: `red.add [M], 1; fence.acquire;` is not an acquire pattern.

[1] For both *release* and *acquire* patterns, this effect is further extended to operations in other threads through the transitive nature of *causality order*.

8.9. Ordering of memory operations

The sequence of operations performed by each thread is captured as *program order* while *memory synchronization* across threads is captured as *causality order*. The visibility of the side-effects of memory operations to other memory operations is captured as *communication order*. The memory consistency model defines contradictions that are disallowed between communication order on the one hand, and *causality order* and *program order* on the other.

8.9.1. Program Order

The *program order* relates all operations performed by a thread to the order in which a sequential processor will execute instructions in the corresponding PTX source. It is a transitive relation that forms a total order over the operations performed by the thread, but does not relate operations from different threads.

8.9.1.1 Asynchronous Operations

Some PTX instructions (all variants of `cp.async`, `cp.async.bulk`, `cp.reduce.async.bulk`, `wgmma.mma_async`) perform operations that are asynchronous to the thread that executed the instruction. These asynchronous operations are ordered after prior instructions in the same thread (except in the case of `wgmma.mma_async`), but they are not part of the program order for that thread. Instead, they provide weaker ordering guarantees as documented in the instruction description.

For example, the loads and stores performed as part of a `cp.async` are ordered with respect to each other, but not to those of any other `cp.async` instructions initiated by the same thread, nor any other instruction subsequently issued by the thread with the exception of `cp.async.commit_group` or `cp.async.mbarrier.arrive`. The asynchronous mbarrier *arrive-on* operation performed by a `cp.async.mbarrier.arrive` instruction is ordered with respect to the memory operations performed by all prior `cp.async` operations initiated by the same thread, but not to those of any other instruction issued by the thread. The implicit mbarrier *complete-tx* operation that is part of all variants of `cp.async.bulk` and `cp.reduce.async.bulk` instructions is ordered only with respect to the memory operations performed by the same asynchronous instruction, and in particular it does not transitively establish ordering with respect to prior instructions from the issuing thread.

8.9.2. Observation Order

Observation order relates a write W to a read R through an optional sequence of atomic read-modify-write operations.

A write W precedes a read R in *observation order* if:

1. R and W are *morally strong* and R reads the value written by W, or
2. For some atomic operation Z, W precedes Z and Z precedes R in *observation order*.

8.9.3. Fence-SC Order

The *Fence-SC* order is an acyclic partial order, determined at runtime, that relates every pair of *morally strong fence.sc* operations.

8.9.4. Memory synchronization

Synchronizing operations performed by different threads synchronize with each other at runtime as described here. The effect of such synchronization is to establish *causality order* across threads.

1. A `fence.sc` operation X *synchronizes* with a `fence.sc` operation Y if X precedes Y in the *Fence-SC* order.
2. A `bar{.cta}.sync` or `bar{.cta}.red` or `bar{.cta}.arrive` operation *synchronizes* with a `bar{.cta}.sync` or `bar{.cta}.red` operation executed on the same barrier.
3. A `barrier.cluster.arrive` operation synchronizes with a `barrier.cluster.wait` operation.
4. A *release* pattern X *synchronizes* with an *acquire* pattern Y, if a *write* operation in X precedes a *read* operation in Y in *observation order*, and the first operation in X and the last operation in Y are *morally strong*.

API synchronization

A *synchronizes* relation can also be established by certain CUDA APIs.

1. Completion of a task enqueued in a CUDA stream *synchronizes* with the start of the following task in the same stream, if any.
2. For purposes of the above, recording or waiting on a CUDA event in a stream, or causing a cross-stream barrier to be inserted due to `cudaStreamLegacy`, enqueues tasks in the associated streams even if there are no direct side effects. An event record task *synchronizes* with matching event wait tasks, and a barrier arrival task *synchronizes* with matching barrier wait tasks.
3. Start of a CUDA kernel *synchronizes* with start of all threads in the kernel. End of all threads in a kernel *synchronize* with end of the kernel.
4. Start of a CUDA graph *synchronizes* with start of all source nodes in the graph. Completion of all sink nodes in a CUDA graph *synchronizes* with completion of the graph. Completion of a graph node *synchronizes* with start of all nodes with a direct dependency.
5. Start of a CUDA API call to enqueue a task *synchronizes* with start of the task.
6. Completion of the last task queued to a stream, if any, *synchronizes* with return from `cudaStreamSynchronize`. Completion of the most recently queued matching event record task, if any, *synchronizes* with return from `cudaEventSynchronize`. Synchronizing a CUDA device or context behaves as if synchronizing all streams in the context, including ones that have been destroyed.
7. Returning `cudaSuccess` from an API to query a CUDA handle, such as a stream or event, behaves the same as return from the matching synchronization API.

In addition to establishing a *synchronizes* relation, the CUDA API synchronization mechanisms above also participate in *proxy-preserved base causality order*.

8.9.5. Causality Order

Causality order captures how memory operations become visible across threads through synchronizing operations. The axiom “Causality” uses this order to constrain the set of write operations from which a read operation may read a value.

Relations in the *causality order* primarily consist of relations in *Base causality order*[1] , which is a transitive order, determined at runtime.

Base causality order

An operation X precedes an operation Y in *base causality order* if:

1. X precedes Y in *program order*, or
2. X *synchronizes* with Y, or
3. For some operation Z,
    a. X precedes Z in *program order* and Z precedes Y in *base causality order*, or
    b. X precedes Z in *base causality order* and Z precedes Y in *program order*, or
    c. X precedes Z in *base causality order* and Z precedes Y in *base causality order*.

Proxy-preserved base causality order

A memory operation X precedes a memory operation Y in *proxy-preserved base causality order* if X precedes Y in *base causality order*, and:

1. X and Y are performed to the same address, using the *generic proxy*, or
2. X and Y are performed to the same address, using the same *proxy*, and by the same thread block, or
3. X and Y are aliases and there is an alias *proxy fence* along the base causality path from X to Y.

Causality order

Causality order combines *base causality order* with some non-transitive relations as follows:

An operation X precedes an operation Y in *causality order* if:

1. X precedes Y in *proxy-preserved base causality order*, or
2. For some operation Z, X precedes Z in observation order, and Z precedes Y in *proxy-preserved base causality order*.

[1] The transitivity of *base causality order* accounts for the “cumulativity” of synchronizing operations.

8.9.6. Coherence Order

There exists a partial transitive order that relates *overlapping* write operations, determined at runtime, called the *coherence order*[1]. Two *overlapping* write operations are related in *coherence order* if they are *morally strong* or if they are related in *causality order*. Two *overlapping* writes are unrelated in *coherence order* if they are in a *data-race*, which gives rise to the partial nature of *coherence order*.

[1] *Coherence order* cannot be observed directly since it consists entirely of write operations. It may be observed indirectly by its use in constraining the set of candidate writes that a read operation may read from.

8.9.7. Communication Order

The *communication order* is a non-transitive order, determined at runtime, that relates write operations to other *overlapping* memory operations.

1. A write W precedes an *overlapping* read R in *communication order* if R returns the value of any byte that was written by W.
2. A write W precedes a write W' in *communication order* if W precedes W' in *coherence order*.
3. A read R precedes an *overlapping* write W in *communication order* if, for any byte accessed by both R and W, R returns the value written by a write W' that precedes W in *coherence order*.

Communication order captures the visibility of memory operations — when a memory operation X1 precedes a memory operation X2 in *communication order*, X1 is said to be visible to X2.

8.10. Axioms

8.10.1. Coherence

If a write W precedes an *overlapping* write W' in *causality order*, then W must precede W' in *coherence order*.

8.10.2. Fence-SC

Fence-SC order cannot contradict *causality order*. For a pair of *morally strong fence.sc* operations F1 and F2, if F1 precedes F2 in *causality order*, then F1 must precede F2 in *Fence-SC* order.

8.10.3. Atomicity

Single-Copy Atomicity

Conflicting *morally strong* operations are performed with *single-copy atomicity*. When a read R and a write W are *morally strong*, then the following two communications cannot both exist in the same execution, for the set of bytes accessed by both R and W:

1. R reads any byte from W.
2. R reads any byte from any write W' which precedes W in *coherence order*.

Atomicity of read-modify-write (RMW) operations

When an *atomic* operation A and a write W *overlap* and are *morally strong*, then the following two communications cannot both exist in the same execution, for the set of bytes accessed by both A and W:

1. A reads any byte from a write W' that precedes W in *coherence order*.
2. A follows W in *coherence order*.

Litmus Test 1

```
.global .u32 x = 0;
```

T1	T2
`A1: atom.sys.inc.u32 %r0, [x];`	`A2: atom.sys.inc.u32 %r0, [x];`

```
FINAL STATE: x == 2
```

Atomicity is guaranteed when the operations are *morally strong*.

Litmus Test 2

```
.global .u32 x = 0;
```

T1	T2 (In a different CTA)
`A1: atom.cta.inc.u32 %r0, [x];`	`A2: atom.gpu.inc.u32 %r0, [x];`

```
FINAL STATE: x == 1 OR x == 2
```

Atomicity is not guaranteed if the operations are not *morally strong*.

8.10.4. No Thin Air

Values may not appear “out of thin air”: an execution cannot speculatively produce a value in such a way that the speculation becomes self-satisfying through chains of instruction dependencies and inter-thread communication. This matches both programmer intuition and hardware reality, but is necessary to state explicitly when performing formal analysis.

Litmus Test: Load Buffering

```
.global .u32 x = 0;
.global .u32 y = 0;
```

T1	T2
`A1: ld.global.u32 %r0, [x];` `B1: st.global.u32 [y], %r0;`	`A2: ld.global.u32 %r1, [y];` `B2: st.global.u32 [x], %r1;`

```
FINAL STATE: x == 0 AND y == 0
```

The litmus test known as “LB” (Load Buffering) checks such forbidden values that may arise out of thin air. Two threads T1 and T2 each read from a first variable and copy the observed result into a second variable, with the first and second variable exchanged between the threads. If each variable is initially zero, the final result shall also be zero. If A1 reads from B2 and A2 reads from B1, then values passing through the memory operations in this example form a cycle: A1->B1->A2->B2->A1. Only the values x == 0 and y == 0 are allowed to satisfy this cycle. If any of the memory operations in this example were to speculatively associate a different value with the corresponding memory location, then such a speculation would become self-fulfilling, and hence forbidden.

8.10.5. Sequential Consistency Per Location

Within any set of *overlapping* memory operations that are pairwise *morally strong*, *communication order* cannot contradict *program order*, i.e., a concatenation of *program order* between *overlapping* operations and *morally strong* relations in *communication order* cannot result in a cycle. This ensures that each program slice of *overlapping* pairwise morally *strong operations* is strictly *sequentially-consistent*.

Litmus Test: CoRR

```
.global .u32 x = 0;
```

T1	T2
`W1: st.global.relaxed.sys.u32 [x], 1;`	`R1: ld.global.relaxed.sys.u32 %r0, [x];` `R2: ld.global.relaxed.sys.u32 %r1, [x];`

```
IF %r0 == 1 THEN %r1 == 1
```

The litmus test "CoRR" (Coherent Read-Read), demonstrates one consequence of this guarantee. A thread T1 executes a write W1 on a location x, and a thread T2 executes two (or an infinite sequence of) reads R1 and R2 on the same location x. No other writes are executed on x, except the one modelling the initial value. The operations W1, R1 and R2 are pairwise *morally strong*. If R1 reads from W1, then the subsequent read R2 must also observe the same value. If R2 observed the initial value of x instead, then this would form a sequence of *morally-strong* relations R2->W1->R1 in *communication order* that contradicts the *program order* R1->R2 in thread T2. Hence R2 cannot read the initial value of x in such an execution.

8.10.6. Causality

Relations in *communication order* cannot contradict *causality order*. This constrains the set of candidate write operations that a read operation may read from:

1. If a read R precedes an *overlapping* write W in *causality order*, then R cannot read from W.
2. If a write W precedes an *overlapping* read R in *causality order*, then for any byte accessed by both R and W, R cannot read from any write W' that precedes W in *coherence order*.

Litmus Test: Message Passing

```
.global .u32 data = 0;
.global .u32 flag = 0;
```

T1	T2

`W1: st.global.u32 [data], 1;`
`F1: fence.sys;`
`W2: st.global.relaxed.sys.u32 [flag], 1;`
	`R1: ld.global.relaxed.sys.u32 %r0,`
	`↪[flag];`
	`F2: fence.sys;`
	`R2: ld.global.u32 %r1, [data];`

```
IF %r0 == 1 THEN %r1 == 1
```

The litmus test known as “MP” (Message Passing) represents the essence of typical synchronization algorithms. A vast majority of useful programs can be reduced to sequenced applications of this pattern.

Thread T1 first writes to a data variable and then to a flag variable while a second thread T2 first reads from the flag variable and then from the data variable. The operations on the flag are *morally strong* and the memory operations in each thread are separated by a *fence*, and these *fences* are *morally strong*.

If R1 observes W2, then the release pattern “F1; W2” *synchronizes* with the *acquire pattern* “R1; F2”. This establishes the *causality order* W1 -> F1 -> W2 -> R1 -> F2 -> R2. Then axiom *causality* guarantees that R2 cannot read from any write that precedes W1 in *coherence order*. In the absence of any other writes in this example, R2 must read from W1.

Litmus Test: CoWR

```
// These addresses are aliases
.global .u32 data_alias_1;
.global .u32 data_alias_2;
```

T1

```
W1: st.global.u32 [data_alias_1], 1;
F1: fence.proxy.alias;
R1: ld.global.u32 %r1, [data_alias_2];
```

```
%r1 == 1
```

Virtual aliases require an alias *proxy fence* along the synchronization path.

Litmus Test: Store Buffering

The litmus test known as “SB” (Store Buffering) demonstrates the *sequential consistency* enforced by the `fence.sc`. A thread T1 writes to a first variable, and then reads the value of a second variable, while a second thread T2 writes to the second variable and then reads the value of the first variable. The memory operations in each thread are separated by `fence.sc` instructions, and these *fences* are *morally strong*.

```
.global .u32 x = 0;
.global .u32 y = 0;
```

T1	T2

`W1: st.global.u32 [x], 1;`
`F1: fence.sc.sys;`
`R1: ld.global.u32 %r0, [y];`
	`W2: st.global.u32 [y], 1;`
	`F2: fence.sc.sys;`
	`R2: ld.global.u32 %r1, [x];`

```
%r0 == 1 OR %r1 == 1
```

In any execution, either F1 precedes F2 in *Fence-SC* order, or vice versa. If F1 precedes F2 in *Fence-SC* order, then F1 *synchronizes* with F2. This establishes the *causality order* in W1 -> F1 -> F2 -> R2. Axiom *causality* ensures that R2 cannot read from any write that precedes W1 in *coherence order*. In the absence of any other write to that variable, R2 must read from W1. Similarly, in the case where F2 precedes F1 in *Fence-SC* order, R1 must read from W2. If each `fence.sc` in this example were replaced by a `fence.acq_rel` instruction, then this outcome is not guaranteed. There may be an execution where the write from each thread remains unobserved from the other thread, i.e., an execution is possible, where both R1 and R2 return the initial value “0” for variables y and x respectively.

8.11. Special Cases

8.11.1. Reductions do not form Acquire Patterns

Atomic reduction operations like `red` do not form acquire patterns with acquire fences.

Litmus Test: Message Passing with a Red Instruction

```
.global .u32 x = 0;
.global .u32 flag = 0;
```

T1	T2

`W1: st.u32 [x], 42;`
`W2: st.release.gpu.u32 [flag], 1;`
	`RMW1: red.sys.global.add.u32 [flag], 1;`
	`F2: fence.acquire.gpu;`
	`R2: ld.weak.u32 %r1, [x];`

```
%r1 == 0 AND flag == 2
```

The litmus test known as “MP” (Message Passing) demonstrates the consequence of reductions being excluded from acquire patterns. It is possible to observe the outcome where R2 reads the value `0` from `x` and `flag` has the final value of 2. This outcome is possible since the release pattern in T1 does not synchronize with any acquire pattern in T2. Using the `atom` instruction instead of `red` forbids this outcome.

Chapter 9. Instruction Set

9.1. Format and Semantics of Instruction Descriptions

This section describes each PTX instruction. In addition to the name and the format of the instruction, the semantics are described, followed by some examples that attempt to show several possible instantiations of the instruction.

9.2. PTX Instructions

PTX instructions generally have from zero to four operands, plus an optional guard predicate appearing after an `@` symbol to the left of the `opcode`:

- `@p opcode;`
- `@p opcode a;`
- `@p opcode d, a;`
- `@p opcode d, a, b;`
- `@p opcode d, a, b, c;`

For instructions that create a result value, the `d` operand is the destination operand, while `a`, `b`, and `c` are source operands.

The `setp` instruction writes two destination registers. We use a `|` symbol to separate multiple destination registers.

```
setp.lt.s32  p|q, a, b;  // p = (a < b); q = !(a < b);
```

For some instructions the destination operand is optional. A *bit bucket* operand denoted with an underscore (_) may be used in place of a destination register.

9.3. Predicated Execution

In PTX, predicate registers are virtual and have `.pred` as the type specifier. So, predicate registers can be declared as

```
.reg .pred p, q, r;
```

All instructions have an optional *guard predicate* which controls conditional execution of the instruction. The syntax to specify conditional execution is to prefix an instruction with `@{!}p`, where `p` is a predicate variable, optionally negated. Instructions without a guard predicate are executed unconditionally.

Predicates are most commonly set as the result of a comparison performed by the `setp` instruction.

As an example, consider the high-level code

```
if (i < n)
    j = j + 1;
```

This can be written in PTX as

```
      setp.lt.s32  p, i, n;    // p = (i < n)
@p    add.s32      j, j, 1;    // if i < n, add 1 to j
```

To get a conditional branch or conditional function call, use a predicate to control the execution of the branch or call instructions. To implement the above example as a true conditional branch, the following PTX instruction sequence might be used:

```
      setp.lt.s32  p, i, n;    // compare i to n
@!p   bra  L1;                 // if False, branch over
      add.s32      j, j, 1;
L1:     ...
```

9.3.1. Comparisons

9.3.1.1 Integer and Bit-Size Comparisons

The signed integer comparisons are the traditional `eq` (equal), `ne` (not-equal), `lt` (less-than), `le` (less-than-or-equal), `gt` (greater-than), and `ge` (greater-than-or-equal). The unsigned comparisons are `eq`, `ne`, `lo` (lower), `ls` (lower-or-same), `hi` (higher), and `hs` (higher-or-same). The bit-size comparisons are `eq` and `ne`; ordering comparisons are not defined for bit-size types.

Table 23 shows the operators for signed integer, unsigned integer, and bit-size types.

Table 23: Operators for Signed Integer, Unsigned Integer, and Bit-Size Types

Meaning	Signed Operator	Unsigned Operator	Bit-Size Operator
a == b	eq	eq	eq
a != b	ne	ne	ne
a < b	lt	lo	n/a
a <= b	le	ls	n/a
a > b	gt	hi	n/a
a >= b	ge	hs	n/a

9.3.1.2 Floating Point Comparisons

The ordered floating-point comparisons are `eq`, `ne`, `lt`, `le`, `gt`, and `ge`. If either operand is `NaN`, the result is `False`. Table 24 lists the floating-point comparison operators.

Table 24: Floating-Point Comparison Operators

Meaning	Floating-Point Operator
a == b && !isNaN(a) && !isNaN(b)	eq
a != b && !isNaN(a) && !isNaN(b)	ne
a < b && !isNaN(a) && !isNaN(b)	lt
a <= b && !isNaN(a) && !isNaN(b)	le
a > b && !isNaN(a) && !isNaN(b)	gt
a >= b && !isNaN(a) && !isNaN(b)	ge

To aid comparison operations in the presence of `NaN` values, unordered floating-point comparisons are provided: `equ`, `neu`, `ltu`, `leu`, `gtu`, and `geu`. If both operands are numeric values (not `NaN`), then the comparison has the same result as its ordered counterpart. If either operand is `NaN`, then the result of the comparison is `True`.

Table 25 lists the floating-point comparison operators accepting `NaN` values.

Table 25: Floating-Point Comparison Operators Accepting NaN

Meaning	Floating-Point Operator
a == b || isNaN(a) || isNaN(b)	equ
a != b || isNaN(a) || isNaN(b)	neu
a < b || isNaN(a) || isNaN(b)	ltu
a <= b || isNaN(a) || isNaN(b)	leu
a > b || isNaN(a) || isNaN(b)	gtu
a >= b || isNaN(a) || isNaN(b)	geu

To test for NaN values, two operators num (numeric) and nan (isNaN) are provided. num returns True if both operands are numeric values (not NaN), and nan returns True if either operand is NaN. Table 26 lists the floating-point comparison operators testing for NaN values.

Table 26: Floating-Point Comparison Operators Testing for NaN

Meaning	Floating-Point Operator
!isNaN(a) && !isNaN(b)	num
isNaN(a) || isNaN(b)	nan

9.3.2. Manipulating Predicates

Predicate values may be computed and manipulated using the following instructions: and, or, xor, not, and mov.

There is no direct conversion between predicates and integer values, and no direct way to load or store predicate register values. However, setp can be used to generate a predicate from an integer, and the predicate-based select (selp) instruction can be used to generate an integer value based on the value of a predicate; for example:

```
selp.u32 %r1,1,0,%p;    // convert predicate to 32-bit value
```

9.4. Type Information for Instructions and Operands

Typed instructions must have a type-size modifier. For example, the add instruction requires type and size information to properly perform the addition operation (signed, unsigned, float, different sizes), and this information must be specified as a suffix to the opcode.

Example

```
.reg .u16 d, a, b;

add.u16 d, a, b;    // perform a 16-bit unsigned add
```

Some instructions require multiple type-size modifiers, most notably the data conversion instruction cvt. It requires separate type-size modifiers for the result and source, and these are placed in the same order as the operands. For example:

```
.reg .u16 a;
.reg .f32 d;

cvt.f32.u16 d, a;   // convert 16-bit unsigned to 32-bit float
```

In general, an operand's type must agree with the corresponding instruction-type modifier. The rules for operand and instruction type conformance are as follows:

- Bit-size types agree with any type of the same size.
- Signed and unsigned integer types agree provided they have the same size, and integer operands are silently cast to the instruction type if needed. For example, an unsigned integer operand used in a signed integer instruction will be treated as a signed integer by the instruction.
- Floating-point types agree only if they have the same size; i.e., they must match exactly.

Table 27 summarizes these type checking rules.

Table 27: Type Checking Rules

		Operand Type			
		.bX	**.sX**	**.uX**	**.fX**
Instruction Type	**.bX**	okay	okay	okay	okay
	.sX	okay	okay	okay	invalid
	.uX	okay	okay	okay	invalid
	.fX	okay	invalid	invalid	okay

Note: Some operands have their type and size defined independently from the instruction type-size. For example, the shift amount operand for left and right shift instructions always has type `.u32`, while the remaining operands have their type and size determined by the instruction type.

Example

```
// 64-bit arithmetic right shift; shift amount 'b' is .u32
    shr.s64 d,a,b;
```

9.4.1. Operand Size Exceeding Instruction-Type Size

For convenience, `ld`, `st`, and `cvt` instructions permit source and destination data operands to be wider than the instruction-type size, so that narrow values may be loaded, stored, and converted using regular-width registers. For example, 8-bit or 16-bit values may be held directly in 32-bit or 64-bit registers when being loaded, stored, or converted to other types and sizes. The operand type checking rules are relaxed for bit-size and integer (signed and unsigned) instruction types; floating-point instruction types still require that the operand type-size matches exactly, unless the operand is of bit-size type.

When a source operand has a size that exceeds the instruction-type size, the source data is truncated (chopped) to the appropriate number of bits specified by the instruction type-size.

Table 28 summarizes the relaxed type-checking rules for source operands. Note that some combinations may still be invalid for a particular instruction; for example, the `cvt` instruction does not support `.bX` instruction types, so those rows are invalid for `cvt`.

Table 28: Relaxed Type-checking Rules for Source Operands

		Source Operand Type															
		b8	**b16**	**b32**	**b64**	**b128**	**s8**	**s16**	**s32**	**s64**	**u8**	**u16**	**u32**	**u64**	**f16**	**f32**	**f64**
Instruction Type	**b8**	–	chop	chop	chop	chop	–	chop	chop	chop	–	chop	chop	chop	chop	chop	chop
	b16	inv	–	chop	chop	chop	inv	–	chop	chop	inv	–	chop	chop	–	chop	chop
	b32	inv	inv	–	chop	chop	inv	inv	–	chop	inv	inv	–	chop	inv	–	chop
	b64	inv	inv	inv	–	chop	inv	inv	inv	–	inv	inv	inv	–	inv	inv	–
	b128	inv	inv	inv	inv	–	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv
	s8	–	chop	chop	chop	chop	–	chop	chop	chop	–	chop	chop	chop	inv	inv	inv
	s16	inv	–	chop	chop	chop	inv	–	chop	chop	inv	–	chop	chop	inv	inv	inv
	s32	inv	inv	–	chop	chop	inv	inv	–	chop	inv	inv	–	chop	inv	inv	inv
	s64	inv	inv	inv	–	chop	inv	inv	inv	–	inv	inv	inv	–	inv	inv	inv
	u8	–	chop	chop	chop	chop	–	chop	chop	chop	–	chop	chop	chop	inv	inv	inv
	u16	inv	–	chop	chop	chop	inv	–	chop	chop	inv	–	chop	chop	inv	inv	inv
	u32	inv	inv	–	chop	chop	inv	inv	–	chop	inv	inv	–	chop	inv	inv	inv
	u64	inv	inv	inv	–	chop	inv	inv	inv	–	inv	inv	inv	–	inv	inv	inv
	f16	inv	–	chop	chop	chop	inv	inv	inv	inv	inv	inv	inv	inv	–	inv	inv
	f32	inv	inv	–	chop	chop	inv	inv	inv	inv	inv	inv	inv	inv	inv	–	inv
	f64	inv	inv	inv	–	chop	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv	–
Notes		chop = keep only low bits that fit; "–" = allowed, but no conversion needed; inv = invalid, parse error. 1. Source register size must be of equal or greater size than the instruction-type size. 2. Bit-size source registers may be used with any appropriately-sized instruction type. The data are truncated ("chopped") to the instruction-type size and interpreted according to the instruction type. 3. Integer source registers may be used with any appropriately-sized bit-size or integer instruction type. The data are truncated to the instruction-type size and interpreted according to the instruction type. 4. Floating-point source registers can only be used with bit-size or floating-point instruction types. When used with a narrower bit-size instruction type, the data are truncated. When used with a floating-point instruction type, the size must match exactly.															

When a destination operand has a size that exceeds the instruction-type size, the destination data is zero- or sign-extended to the size of the destination register. If the corresponding instruction type is signed integer, the data is sign-extended; otherwise, the data is zero-extended.

Table 29 summarizes the relaxed type-checking rules for destination operands.

Table 29: Relaxed Type-checking Rules for Destination Operands

		Destination Operand Type															
		b8	**b16**	**b32**	**b64**	**b128**	**s8**	**s16**	**s32**	**s64**	**u8**	**u16**	**u32**	**u64**	**f16**	**f32**	**f64**
Instruction Type	**b8**	–	zext	zext	zext	zext	–	zext	zext	zext	–	zext	zext	zext	zext	zext	zext
	b16	inv	–	zext	zext	zext	inv	–	zext	zext	inv	–	zext	zext	–	zext	zext
	b32	inv	inv	–	zext	zext	inv	inv	–	zext	inv	inv	–	zext	inv	–	zext
	b64	inv	inv	inv	–	zext	inv	inv	inv	–	inv	inv	inv	–	inv	inv	–
	b128	inv	inv	inv	inv	–	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv
	s8	–	sext	sext	sext	sext	–	sext	sext	sext	–	sext	sext	sext	inv	inv	inv
	s16	inv	–	sext	sext	sext	inv	–	sext	sext	inv	–	sext	sext	inv	inv	inv
	s32	inv	inv	–	sext	sext	inv	inv	–	sext	inv	inv	–	sext	inv	inv	inv
	s64	inv	inv	inv	–	sext	inv	inv	inv	–	inv	inv	inv	–	inv	inv	inv
	u8	–	zext	zext	zext	zext	–	zext	zext	zext	–	zext	zext	zext	inv	inv	inv
	u16	inv	–	zext	zext	zext	inv	–	zext	zext	inv	–	zext	zext	inv	inv	inv
	u32	inv	inv	–	zext	zext	inv	inv	–	zext	inv	inv	–	zext	inv	inv	inv
	u64	inv	inv	inv	–	zext	inv	inv	inv	–	inv	inv	inv	–	inv	inv	inv
	f16	inv	–	zext	zext	zext	inv	inv	inv	inv	inv	inv	inv	inv	–	inv	inv
	f32	inv	inv	–	zext	zext	inv	inv	inv	inv	inv	inv	inv	inv	inv	–	inv
	f64	inv	inv	inv	–	zext	inv	inv	inv	inv	inv	inv	inv	inv	inv	inv	–
Notes		sext = sign-extend; zext = zero-extend; "–" = allowed, but no conversion needed; inv = invalid, parse error. 1. Destination register size must be of equal or greater size than the instruction-type size. 2. Bit-size destination registers may be used with any appropriately-sized instruction type. The data are sign-extended to the destination register width for signed integer instruction types, and are zero-extended to the destination register width otherwise. 3. Integer destination registers may be used with any appropriately-sized bit-size or integer instruction type. The data are sign-extended to the destination register width for signed integer instruction types, and are zero-extended to the destination register width for bit-size an d unsigned integer instruction types. 4. Floating-point destination registers can only be used with bit-size or floating-point instruction types. When used with a narrower bit-size instruction type, the data are zero-extended. When used with a floating-point instruction type, the size must match exactly.															

9.5. Divergence of Threads in Control Constructs

Threads in a CTA execute together, at least in appearance, until they come to a conditional control construct such as a conditional branch, conditional function call, or conditional return. If threads execute down different control flow paths, the threads are called *divergent*. If all of the threads act in unison and follow a single control flow path, the threads are called *uniform*. Both situations occur often in programs.

A CTA with divergent threads may have lower performance than a CTA with uniformly executing threads, so it is important to have divergent threads re-converge as soon as possible. All control constructs are assumed to be divergent points unless the control-flow instruction is marked as uniform, using the `.uni` suffix. For divergent control flow, the optimizing code generator automatically determines points of re-convergence. Therefore, a compiler or code author targeting PTX can ignore the issue of divergent threads, but has the opportunity to improve performance by marking branch points as uniform when the compiler or author can guarantee that the branch point is non-divergent.

9.6. Semantics

The goal of the semantic description of an instruction is to describe the results in all cases in as simple language as possible. The semantics are described using C, until C is not expressive enough.

9.6.1. Machine-Specific Semantics of 16-bit Code

A PTX program may execute on a GPU with either a 16-bit or a 32-bit data path. When executing on a 32-bit data path, 16-bit registers in PTX are mapped to 32-bit physical registers, and 16-bit computations are *promoted* to 32-bit computations. This can lead to computational differences between code run on a 16-bit machine versus the same code run on a 32-bit machine, since the promoted computation may have bits in the high-order half-word of registers that are not present in 16-bit physical registers. These extra precision bits can become visible at the application level, for example, by a right-shift instruction.

At the PTX language level, one solution would be to define semantics for 16-bit code that is consistent with execution on a 16-bit data path. This approach introduces a performance penalty for 16-bit code executing on a 32-bit data path, since the translated code would require many additional masking instructions to suppress extra precision bits in the high-order half-word of 32-bit registers.

Rather than introduce a performance penalty for 16-bit code running on 32-bit GPUs, the semantics of 16-bit instructions in PTX is machine-specific. A compiler or programmer may chose to enforce portable, machine-independent 16-bit semantics by adding explicit conversions to 16-bit values at appropriate points in the program to guarantee portability of the code. However, for many performance-critical applications, this is not desirable, and for many applications the difference in execution is preferable to limiting performance.

9.7. Instructions

All PTX instructions may be predicated. In the following descriptions, the optional guard predicate is omitted from the syntax.

9.7.1. Integer Arithmetic Instructions

Integer arithmetic instructions operate on the integer types in register and constant immediate forms. The integer arithmetic instructions are:

- `add`
- `sub`
- `mul`
- `mad`
- `mul24`
- `mad24`
- `sad`
- `div`
- `rem`
- `abs`
- `neg`
- `min`
- `max`
- `popc`
- `clz`
- `bfind`
- `fns`
- `brev`
- `bfe`
- `bfi`
- `bmsk`
- `szext`
- `dp4a`
- `dp2a`

9.7.1.1 Integer Arithmetic Instructions: add

add

Add two values.

Syntax

```
add.type       d, a, b;
add{.sat}.s32  d, a, b;     // .sat applies only to .s32

.type = { .u16, .u32, .u64,
          .s16, .s32, .s64,
          .u16x2, .s16x2 };
```

Description

Performs addition and writes the resulting value into a destination register.

For `.u16x2`, `.s16x2` instruction types, forms input vectors by half word values from source operands. Half-word operands are then added in parallel to produce `.u16x2`, `.s16x2` result in destination.

Operands d, a and b have type `.type`. For instruction types `.u16x2`, `.s16x2`, operands d, a and b have type `.b32`.

Semantics

```
if (type == u16x2 || type == s16x2) {
    iA[0] = a[0:15];
    iA[1] = a[16:31];
    iB[0] = b[0:15];
    iB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = iA[i] + iB[i];
    }
} else {
    d = a + b;
}
```

Notes

Saturation modifier:

.sat limits result to `MININT..MAXINT` (no overflow) for the size of the operation. Applies only to `.s32` type.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`add.u16x2` and `add.s16x2` introduced in PTX ISA version 8.0.

Target ISA Notes

Supported on all target architectures.

`add.u16x2` and `add.s16x2` require `sm_90` or higher.

Examples

```
@p  add.u32     x,y,z;
    add.sat.s32 c,c,1;
    add.u16x2   u,v,w;
```

9.7.1.2 Integer Arithmetic Instructions: sub

sub

Subtract one value from another.

Syntax

```
sub.type       d, a, b;
sub{.sat}.s32  d, a, b;     // .sat applies only to .s32

.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Performs subtraction and writes the resulting value into a destination register.

Semantics

```
d = a - b;
```

Notes

Saturation modifier:

.sat
limits result to MININT..MAXINT (no overflow) for the size of the operation. Applies only to .s32 type.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
sub.s32 c,a,b;
```

9.7.1.3 Integer Arithmetic Instructions: mul

mul

Multiply two values.

Syntax

```
mul.mode.type  d, a, b;

.mode = { .hi, .lo, .wide };
.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Compute the product of two values.

Semantics

```
t = a * b;
n = bitwidth of type;
d = t;            // for .wide
d = t<2n-1..n>;   // for .hi variant
d = t<n-1..0>;    // for .lo variant
```

Notes

The type of the operation represents the types of the a and b operands. If .hi or .lo is specified, then d is the same size as a and b, and either the upper or lower half of the result is written to the destination register. If .wide is specified, then d is twice as wide as a and b to receive the full result of the multiplication.

The .wide suffix is supported only for 16- and 32-bit integer types.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
mul.wide.s16 fa,fxs,fys;   // 16*16 bits yields 32 bits
mul.lo.s16 fa,fxs,fys;     // 16*16 bits, save only the low 16 bits
mul.wide.s32 z,x,y;        // 32*32 bits, creates 64 bit result
```

9.7.1.4 Integer Arithmetic Instructions: mad

mad

Multiply two values, optionally extract the high or low half of the intermediate result, and add a third value.

Syntax

```
mad.mode.type  d, a, b, c;
mad.hi.sat.s32 d, a, b, c;

.mode = { .hi, .lo, .wide };
.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Multiplies two values, optionally extracts the high or low half of the intermediate result, and adds a third value. Writes the result into a destination register.

Semantics

```
t = a * b;
n = bitwidth of type;
d = t + c;           // for .wide
d = t<2n-1..n> + c;  // for .hi variant
d = t<n-1..0> + c;   // for .lo variant
```

Notes

The type of the operation represents the types of the a and b operands. If .hi or .lo is specified, then d and c are the same size as a and b, and either the upper or lower half of the result is written to the destination register. If `.wide` is specified, then d and c are twice as wide as a and b to receive the result of the multiplication.

The `.wide` suffix is supported only for 16-bit and 32-bit integer types.

Saturation modifier:

`.sat`
limits result to `MININT..MAXINT` (no overflow) for the size of the operation.

Applies only to `.s32` type in `.hi` mode.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
@p  mad.lo.s32 d,a,b,c;
    mad.lo.s32 r,p,q,r;
```

9.7.1.5 Integer Arithmetic Instructions: mul24

mul24

Multiply two 24-bit integer values.

Syntax

```
mul24.mode.type  d, a, b;

.mode = { .hi, .lo };
.type = { .u32, .s32 };
```

Description

Compute the product of two 24-bit integer values held in 32-bit source registers, and return either the high or low 32-bits of the 48-bit result.

Semantics

```
t = a * b;
d = t<47..16>;    // for .hi variant
d = t<31..0>;     // for .lo variant
```

Notes

Integer multiplication yields a result that is twice the size of the input operands, i.e., 48-bits.

`mul24.hi` performs a 24x24-bit multiply and returns the high 32 bits of the 48-bit result.

`mul24.lo` performs a 24x24-bit multiply and returns the low 32 bits of the 48-bit result.

All operands are of the same type and size.

`mul24.hi` may be less efficient on machines without hardware support for 24-bit multiply.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
mul24.lo.s32 d,a,b;   // low 32-bits of 24x24-bit signed multiply.
```

9.7.1.6 Integer Arithmetic Instructions: mad24

mad24

Multiply two 24-bit integer values and add a third value.

Syntax

```
mad24.mode.type  d, a, b, c;
mad24.hi.sat.s32 d, a, b, c;

.mode = { .hi, .lo };
.type = { .u32, .s32 };
```

Description

Compute the product of two 24-bit integer values held in 32-bit source registers, and add a third, 32-bit value to either the high or low 32-bits of the 48-bit result. Return either the high or low 32-bits of the 48-bit result.

Semantics

```
t = a * b;
d = t<47..16> + c;   // for .hi variant
d = t<31..0> + c;    // for .lo variant
```

Notes

Integer multiplication yields a result that is twice the size of the input operands, i.e., 48-bits.

`mad24.hi` performs a 24x24-bit multiply and adds the high 32 bits of the 48-bit result to a third value.

`mad24.lo` performs a 24x24-bit multiply and adds the low 32 bits of the 48-bit result to a third value.

All operands are of the same type and size.

Saturation modifier:

`.sat`
limits result of 32-bit signed addition to `MININT..MAXINT` (no overflow). Applies only to `.s32` type in .hi mode.

`mad24.hi` may be less efficient on machines without hardware support for 24-bit multiply.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
mad24.lo.s32 d,a,b,c;   // low 32-bits of 24x24-bit signed multiply.
```

9.7.1.7 Integer Arithmetic Instructions: sad

sad

Sum of absolute differences.

Syntax

```
sad.type  d, a, b, c;

.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Adds the absolute value of `a-b` to `c` and writes the resulting value into `d`.

Semantics

```
d = c + ((a<b) ? b-a : a-b);
```

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
sad.s32  d,a,b,c;
sad.u32  d,a,b,d;  // running sum
```

9.7.1.8 Integer Arithmetic Instructions: div

div

Divide one value by another.

Syntax

```
div.type  d, a, b;

.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Divides a by b, stores result in d.

Semantics

```
d = a / b;
```

Notes

Division by zero yields an unspecified, machine-specific value.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
div.s32  b,n,i;
```

9.7.1.9 Integer Arithmetic Instructions: rem

rem

The remainder of integer division.

Syntax

```
rem.type  d, a, b;

.type = { .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Divides a by b, store the remainder in d.

Semantics

```
d = a % b;
```

Notes

The behavior for negative numbers is machine-dependent and depends on whether divide rounds towards zero or negative infinity.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
rem.s32  x,x,8;    // x = x%8;
```

9.7.1.10 Integer Arithmetic Instructions: abs

abs

Absolute value.

Syntax

```
abs.type  d, a;

.type = { .s16, .s32, .s64 };
```

Description

Take the absolute value of a and store it in d.

Semantics

```
d = |a|;
```

Notes

Only for signed integers.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
abs.s32  r0,a;
```

9.7.1.11 Integer Arithmetic Instructions: neg

neg

Arithmetic negate.

Syntax

```
neg.type  d, a;

.type = { .s16, .s32, .s64 };
```

Description

Negate the sign of **a** and store the result in **d**.

Semantics

```
d = -a;
```

Notes

Only for signed integers.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
neg.s32  r0,a;
```

9.7.1.12 Integer Arithmetic Instructions: min

min

Find the minimum of two values.

Syntax

```
min.atype         d, a, b;
min{.relu}.btype  d, a, b;

.atype = { .u16, .u32, .u64,
           .u16x2, .s16, .s64 };
.btype = { .s16x2, .s32 };
```

Description

Store the minimum of a and b in d.

For .u16x2, .s16x2 instruction types, forms input vectors by half word values from source operands. Half-word operands are then processed in parallel to produce .u16x2, .s16x2 result in destination.

Operands d, a and b have the same type as the instruction type. For instruction types .u16x2, .s16x2, operands d, a and b have type .b32.

Semantics

```
if (type == u16x2 || type == s16x2) {
    iA[0] = a[0:15];
    iA[1] = a[16:31];
    iB[0] = b[0:15];
    iB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = (iA[i] < iB[i]) ? iA[i] : iB[i];
    }
} else {
    d = (a < b) ? a : b; // Integer (signed and unsigned)
}
```

Notes

Signed and unsigned differ.

Saturation modifier:
`min.relu.{s16x2, s32}` clamps the result to 0 if negative.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`min.u16x2`, `min{.relu}.s16x2` and `min.relu.s32` introduced in PTX ISA version 8.0.

Target ISA Notes

Supported on all target architectures.

`min.u16x2`, `min{.relu}.s16x2` and `min.relu.s32` require `sm_90` or higher.

Examples

```
    min.s32  r0,a,b;
@p  min.u16  h,i,j;
    min.s16x2.relu u,v,w;
```

9.7.1.13 Integer Arithmetic Instructions: `max`

`max`

Find the maximum of two values.

Syntax

```
max.atype         d, a, b;
max{.relu}.btype  d, a, b;

.atype = { .u16, .u32, .u64,
           .u16x2, .s16, .s64 };
.btype = { .s16x2, .s32 };
```

Description

Store the maximum of a and b in d.

For `.u16x2`, `.s16x2` instruction types, forms input vectors by half word values from source operands. Half-word operands are then processed in parallel to produce `.u16x2`, `.s16x2` result in destination.

Operands d, a and b have the same type as the instruction type. For instruction types `.u16x2`, `.s16x2`, operands d, a and b have type `.b32`.

Semantics

```
if (type == u16x2 || type == s16x2) {
    iA[0] = a[0:15];
    iA[1] = a[16:31];
    iB[0] = b[0:15];
    iB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = (iA[i] > iB[i]) ? iA[i] : iB[i];
    }
} else {
    d = (a > b) ? a : b; // Integer (signed and unsigned)
}
```

Notes

Signed and unsigned differ.

Saturation modifier:
`max.relu.{s16x2, s32}` clamps the result to 0 if negative.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`max.u16x2`, `max{.relu}.s16x2` and `max.relu.s32` introduced in PTX ISA version 8.0.

Target ISA Notes

Supported on all target architectures.

`max.u16x2`, `max{.relu}.s16x2` and `max.relu.s32` require `sm_90` or higher.

Examples

```
max.u32  d,a,b;
max.s32  q,q,0;
max.relu.s16x2 t,t,u;
```

9.7.1.14 Integer Arithmetic Instructions: popc

popc

Population count.

Syntax

```
popc.type  d, a;

.type = { .b32, .b64 };
```

Description

Count the number of one bits in a and place the resulting *population count* in 32-bit destination register d. Operand a has the instruction type and destination d has type .u32.

Semantics

```
.u32  d = 0;
while (a != 0) {
   if (a & 0x1)  d++;
   a = a >> 1;
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

popc requires sm_20 or higher.

Examples

```
popc.b32  d, a;
popc.b64  cnt, X;  // cnt is .u32
```

9.7.1.15 Integer Arithmetic Instructions: clz

clz

Count leading zeros.

Syntax

```
clz.type  d, a;

.type = { .b32, .b64 };
```

Description

Count the number of leading zeros in a starting with the most-significant bit and place the result in 32-bit destination register d. Operand a has the instruction type, and destination d has type .u32. For .b32 type, the number of leading zeros is between 0 and 32, inclusively. For .b64 type, the number of leading zeros is between 0 and 64, inclusively.

Semantics

```
.u32  d = 0;
if (.type == .b32)   { max = 32; mask = 0x80000000; }
else                 { max = 64; mask = 0x8000000000000000; }

while (d < max && (a&mask == 0) ) {
    d++;
    a = a << 1;
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`clz` requires `sm_20` or higher.

Examples

```
clz.b32  d, a;
clz.b64  cnt, X;  // cnt is .u32
```

9.7.1.16 Integer Arithmetic Instructions: `bfind`

`bfind`

Find most significant non-sign bit.

Syntax

```
bfind.type           d, a;
bfind.shiftamt.type  d, a;

.type = { .u32, .u64,
          .s32, .s64 };
```

Description

Find the bit position of the most significant non-sign bit in `a` and place the result in `d`. Operand `a` has the instruction type, and destination `d` has type `.u32`. For unsigned integers, `bfind` returns the bit position of the most significant 1. For signed integers, `bfind` returns the bit position of the most significant `0` for negative inputs and the most significant 1 for non-negative inputs.

If `.shiftamt` is specified, `bfind` returns the shift amount needed to left-shift the found bit into the most-significant bit position.

`bfind` returns `0xffffffff` if no non-sign bit is found.

Semantics

```
msb = (.type==.u32 || .type==.s32) ? 31 : 63;
// negate negative signed inputs
if ( (.type==.s32 || .type==.s64) && (a & (1<<msb)) ) {
    a = ~a;
}
.u32  d = 0xffffffff;
for (.s32 i=msb; i>=0; i--) {
    if (a & (1<<i))  { d = i; break; }
}
if (.shiftamt && d != 0xffffffff)  { d = msb - d; }
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`bfind` requires `sm_20` or higher.

Examples

```
bfind.u32  d, a;
bfind.shiftamt.s64  cnt, X;  // cnt is .u32
```

9.7.1.17 Integer Arithmetic Instructions: fns

fns

Find the n-th set bit

Syntax

```
fns.b32 d, mask, base, offset;
```

Description

Given a 32-bit value `mask` and an integer value `base` (between 0 and 31), find the n-th (given by offset) set bit in `mask` from the `base` bit, and store the bit position in `d`. If not found, store 0xffffffff in `d`.

Operand `mask` has a 32-bit type. Operand `base` has `.b32`, `.u32` or `.s32` type. Operand offset has `.s32` type. Destination `d` has type `.b32`.

Operand `base` must be <= 31, otherwise behavior is undefined.

Semantics

```
d = 0xffffffff;
if (offset == 0) {
    if (mask[base] == 1) {
        d = base;
    }
} else {
    pos = base;
    count = |offset| - 1;
    inc = (offset > 0) ? 1 : -1;

    while ((pos >= 0) && (pos < 32)) {
        if (mask[pos] == 1) {
```

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```
            if (count == 0) {
              d = pos;
              break;
            } else {
               count = count - 1;
            }
        }
        pos = pos + inc;
    }
}
```

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

`fns` requires `sm_30` or higher.

Examples

```
fns.b32 d, 0xaaaaaaaa, 3, 1;   // d = 3
fns.b32 d, 0xaaaaaaaa, 3, -1;  // d = 3
fns.b32 d, 0xaaaaaaaa, 2, 1;   // d = 3
fns.b32 d, 0xaaaaaaaa, 2, -1;  // d = 1
```

9.7.1.18 Integer Arithmetic Instructions: `brev`

`brev`

Bit reverse.

Syntax

```
brev.type  d, a;

.type = { .b32, .b64 };
```

Description

Perform bitwise reversal of input.

Semantics

```
msb = (.type==.b32) ? 31 : 63;

for (i=0; i<=msb; i++) {
    d[i] = a[msb-i];
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`brev` requires `sm_20` or higher.

Examples

```
brev.b32  d, a;
```

9.7.1.19 Integer Arithmetic Instructions: bfe

bfe

Bit Field Extract.

Syntax

```
bfe.type  d, a, b, c;

.type = { .u32, .u64,
          .s32, .s64 };
```

Description

Extract bit field from a and place the zero or sign-extended result in d. Source b gives the bit field starting bit position, and source c gives the bit field length in bits.

Operands a and d have the same type as the instruction type. Operands b and c are type .u32, but are restricted to the 8-bit value range 0..255.

The sign bit of the extracted field is defined as:

.u32, .u64:
zero

.s32, .s64:
msb of input a if the extracted field extends beyond the msb of a msb of extracted field, otherwise

If the bit field length is zero, the result is zero.

The destination d is padded with the sign bit of the extracted field. If the start position is beyond the msb of the input, the destination d is filled with the replicated sign bit of the extracted field.

Semantics

```
msb = (.type==.u32 || .type==.s32) ? 31 : 63;
pos = b & 0xff;  // pos restricted to 0..255 range
len = c & 0xff;  // len restricted to 0..255 range

if (.type==.u32 || .type==.u64 || len==0)
    sbit = 0;
else
    sbit = a[min(pos+len-1,msb)];

d = 0;
for (i=0; i<=msb; i++) {
    d[i] = (i<len && pos+i<=msb) ? a[pos+i] : sbit;
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

bfe requires sm_20 or higher.

Examples

```
bfe.b32  d,a,start,len;
```

9.7.1.20 Integer Arithmetic Instructions: bfi

bfi

Bit Field Insert.

Syntax

```
bfi.type  f, a, b, c, d;

.type = { .b32, .b64 };
```

Description

Align and insert a bit field from a into b, and place the result in f. Source c gives the starting bit position for the insertion, and source d gives the bit field length in bits.

Operands a, b, and f have the same type as the instruction type. Operands c and d are type .u32, but are restricted to the 8-bit value range 0..255.

If the bit field length is zero, the result is b.

If the start position is beyond the msb of the input, the result is b.

Semantics

```
msb = (.type==.b32) ? 31 : 63;
pos = c & 0xff;  // pos restricted to 0..255 range
len = d & 0xff;  // len restricted to 0..255 range

f = b;
for (i=0; i<len && pos+i<=msb; i++) {
    f[pos+i] = a[i];
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`bfi` requires `sm_20` or higher.

Examples

```
bfi.b32  d,a,b,start,len;
```

9.7.1.21 Integer Arithmetic Instructions: szext

szext

Sign-extend or Zero-extend.

Syntax

```
szext.mode.type  d, a, b;

.mode = { .clamp, .wrap };
.type = { .u32, .s32 };
```

Description

Sign-extends or zero-extends an N-bit value from operand a where N is specified in operand b. The resulting value is stored in the destination operand d.

For the `.s32` instruction type, the value in a is treated as an N-bit signed value and the most significant bit of this N-bit value is replicated up to bit 31. For the `.u32` instruction type, the value in a is treated as an N-bit unsigned number and is zero-extended to 32 bits. Operand b is an unsigned 32-bit value.

If the value of N is 0, then the result of `szext` is 0. If the value of N is 32 or higher, then the result of `szext` depends upon the value of the `.mode` qualifier as follows:

- If `.mode` is `.clamp`, then the result is the same as the source operand a.
- If `.mode` is `.wrap`, then the result is computed using the wrapped value of N.

Semantics

```
b1        = b & 0x1f;
too_large = (b >= 32 && .mode == .clamp) ? true : false;
mask      = too_large ? 0 : (~0) << b1;
sign_pos  = (b1 - 1) & 0x1f;

if (b1 == 0 || too_large || .type != .s32) {
    sign_bit = false;
} else {
    sign_bit = (a >> sign_pos) & 1;
}
d = (a & ~mask) | (sign_bit ? mask | 0);
```

PTX ISA Notes

Introduced in PTX ISA version 7.6.

Target ISA Notes

`szext` requires `sm_70` or higher.

Examples

```
szext.clamp.s32 rd, ra, rb;
szext.wrap.u32  rd, 0xffffffff, 0; // Result is 0.
```

9.7.1.22 Integer Arithmetic Instructions: bmsk

bmsk

Bit Field Mask.

Syntax

```
bmsk.mode.b32  d, a, b;

.mode = { .clamp, .wrap };
```

Description

Generates a 32-bit mask starting from the bit position specified in operand a, and of the width specified in operand b. The generated bitmask is stored in the destination operand d.

The resulting bitmask is 0 in the following cases:

- When the value of a is 32 or higher and `.mode` is `.clamp`.
- When either the specified value of b or the wrapped value of b (when `.mode` is specified as `.wrap`) is 0.

Semantics

```
a1    = a & 0x1f;
mask0 = (~0) << a1;
b1    = b & 0x1f;
sum   = a1 + b1;
mask1 = (~0) << sum;

sum-overflow          = sum >= 32 ? true : false;
bit-position-overflow = false;
bit-width-overflow    = false;
```

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```
if (.mode == .clamp) {
    if (a >= 32) {
        bit-position-overflow = true;
        mask0 = 0;
    }
    if (b >= 32) {
        bit-width-overflow = true;
    }
}

if (sum-overflow || bit-position-overflow || bit-width-overflow) {
    mask1 = 0;
} else if (b1 == 0) {
    mask1 = ~0;
}
d = mask0 & ~mask1;
```

Notes

The bitmask width specified by operand `b` is limited to range `0..32` in `.clamp` mode and to range `0..31` in `.wrap` mode.

PTX ISA Notes

Introduced in PTX ISA version 7.6.

Target ISA Notes

`bmsk` requires `sm_70` or higher.

Examples

```
bmsk.clamp.b32  rd, ra, rb;
bmsk.wrap.b32   rd, 1, 2; // Creates a bitmask of 0x00000006.
```

9.7.1.23 Integer Arithmetic Instructions: dp4a

dp4a

Four-way byte dot product-accumulate.

Syntax

```
dp4a.atype.btype  d, a, b, c;

.atype = .btype = { .u32, .s32 };
```

Description

Four-way byte dot product which is accumulated in 32-bit result.

Operand a and b are 32-bit inputs which hold 4 byte inputs in packed form for dot product.

Operand c has type `.u32` if both `.atype` and `.btype` are `.u32` else operand c has type `.s32`.

Semantics

```
d = c;

// Extract 4 bytes from a 32bit input and sign or zero extend
// based on input type.
Va = extractAndSignOrZeroExt_4(a, .atype);
Vb = extractAndSignOrZeroExt_4(b, .btype);

for (i = 0; i < 4; ++i) {
    d += Va[i] * Vb[i];
}
```

PTX ISA Notes

Introduced in PTX ISA version 5.0.

Target ISA Notes

Requires `sm_61` or higher.

Examples

```
dp4a.u32.u32           d0, a0, b0, c0;
dp4a.u32.s32           d1, a1, b1, c1;
```

9.7.1.24 Integer Arithmetic Instructions: dp2a

dp2a

Two-way dot product-accumulate.

Syntax

```
dp2a.mode.atype.btype  d, a, b, c;

.atype = .btype = { .u32, .s32 };
.mode = { .lo, .hi };
```

Description

Two-way 16-bit to 8-bit dot product which is accumulated in 32-bit result.

Operand a and b are 32-bit inputs. Operand a holds two 16-bits inputs in packed form and operand b holds 4 byte inputs in packed form for dot product.

Depending on the `.mode` specified, either lower half or upper half of operand b will be used for dot product.

Operand c has type `.u32` if both `.atype` and `.btype` are `.u32` else operand c has type `.s32`.

Semantics

```
d = c;
// Extract two 16-bit values from a 32-bit input and sign or zero extend
// based on input type.
Va = extractAndSignOrZeroExt_2(a, .atype);

// Extract four 8-bit values from a 32-bit input and sign or zer extend
// based on input type.
Vb = extractAndSignOrZeroExt_4(b, .btype);

b_select = (.mode == .lo) ? 0 : 2;

for (i = 0; i < 2; ++i) {
    d += Va[i] * Vb[b_select + i];
}
```

PTX ISA Notes

Introduced in PTX ISA version 5.0.

Target ISA Notes

Requires `sm_61` or higher.

Examples

```
dp2a.lo.u32.u32           d0, a0, b0, c0;
dp2a.hi.u32.s32           d1, a1, b1, c1;
```

9.7.2. Extended-Precision Integer Arithmetic Instructions

Instructions `add.cc`, `addc`, `sub.cc`, `subc`, `mad.cc` and `madc` reference an implicitly specified condition code register (CC) having a single carry flag bit (`CC.CF`) holding carry-in/carry-out or borrow-in/borrow-out. These instructions support extended-precision integer addition, subtraction, and multiplication. No other instructions access the condition code, and there is no support for setting, clearing, or testing the condition code. The condition code register is not preserved across calls and is mainly intended for use in straight-line code sequences for computing extended-precision integer addition, subtraction, and multiplication.

The extended-precision arithmetic instructions are:

- `add.cc`, `addc`
- `sub.cc`, `subc`
- `mad.cc`, `madc`

9.7.2.1 Extended-Precision Arithmetic Instructions: `add.cc`

`add.cc`

Add two values with carry-out.

Syntax

```
add.cc.type  d, a, b;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Performs integer addition and writes the carry-out value into the condition code register.

Semantics

```
d = a + b;
```

carry-out written to `CC.CF`

Notes

No integer rounding modifiers.

No saturation.

Behavior is the same for unsigned and signed integers.

PTX ISA Notes

32-bit `add.cc` introduced in PTX ISA version 1.2.

64-bit `add.cc` introduced in PTX ISA version 4.3.

Target ISA Notes

32-bit `add.cc` is supported on all target architectures.

64-bit `add.cc` requires `sm_20` or higher.

Examples

```
@p  add.cc.u32   x1,y1,z1;   // extended-precision addition of
@p  addc.cc.u32  x2,y2,z2;   // two 128-bit values
@p  addc.cc.u32  x3,y3,z3;
@p  addc.u32     x4,y4,z4;
```

9.7.2.2 Extended-Precision Arithmetic Instructions: addc

addc

Add two values with carry-in and optional carry-out.

Syntax

```
addc{.cc}.type  d, a, b;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Performs integer addition with carry-in and optionally writes the carry-out value into the condition code register.

Semantics

```
d = a + b + CC.CF;
```

if `.cc` specified, carry-out written to `CC.CF`

Notes

No integer rounding modifiers.

No saturation.

Behavior is the same for unsigned and signed integers.

PTX ISA Notes

32-bit `addc` introduced in PTX ISA version 1.2.

64-bit `addc` introduced in PTX ISA version 4.3.

Target ISA Notes

32-bit `addc` is supported on all target architectures.

64-bit `addc` requires `sm_20` or higher.

Examples

```
@p  add.cc.u32   x1,y1,z1;   // extended-precision addition of
@p  addc.cc.u32  x2,y2,z2;   // two 128-bit values
@p  addc.cc.u32  x3,y3,z3;
@p  addc.u32     x4,y4,z4;
```

9.7.2.3 Extended-Precision Arithmetic Instructions: sub.cc

sub.cc

Subtract one value from another, with borrow-out.

Syntax

```
sub.cc.type  d, a, b;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Performs integer subtraction and writes the borrow-out value into the condition code register.

Semantics

```
d = a - b;
```

borrow-out written to CC.CF

Notes

No integer rounding modifiers.

No saturation.

Behavior is the same for unsigned and signed integers.

PTX ISA Notes

32-bit sub.cc introduced in PTX ISA version 1.2.

64-bit sub.cc introduced in PTX ISA version 4.3.

Target ISA Notes

32-bit sub.cc is supported on all target architectures.

64-bit sub.cc requires sm_20 or higher.

Examples

```
@p  sub.cc.u32   x1,y1,z1;   // extended-precision subtraction
@p  subc.cc.u32  x2,y2,z2;   // of two 128-bit values
@p  subc.cc.u32  x3,y3,z3;
@p  subc.u32     x4,y4,z4;
```

9.7.2.4 Extended-Precision Arithmetic Instructions: subc

subc

Subtract one value from another, with borrow-in and optional borrow-out.

Syntax

```
subc{.cc}.type  d, a, b;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Performs integer subtraction with borrow-in and optionally writes the borrow-out value into the condition code register.

Semantics

```
d = a  - (b + CC.CF);
```

if `.cc` specified, borrow-out written to `CC.CF`

Notes

No integer rounding modifiers.

No saturation.

Behavior is the same for unsigned and signed integers.

PTX ISA Notes

32-bit `subc` introduced in PTX ISA version 1.2.

64-bit `subc` introduced in PTX ISA version 4.3.

Target ISA Notes

32-bit subc is supported on all target architectures.

64-bit subc requires sm_20 or higher.

Examples

```
@p  sub.cc.u32   x1,y1,z1;   // extended-precision subtraction
@p  subc.cc.u32  x2,y2,z2;   // of two 128-bit values
@p  subc.cc.u32  x3,y3,z3;
@p  subc.u32     x4,y4,z4;
```

9.7.2.5 Extended-Precision Arithmetic Instructions: mad.cc

mad.cc

Multiply two values, extract high or low half of result, and add a third value with carry-out.

Syntax

```
mad{.hi,.lo}.cc.type  d, a, b, c;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Multiplies two values, extracts either the high or low part of the result, and adds a third value. Writes the result to the destination register and the carry-out from the addition into the condition code register.

Semantics

```
t = a * b;
d = t<63..32> + c;    // for .hi variant
d = t<31..0> + c;     // for .lo variant
```

carry-out from addition is written to CC.CF

Notes

Generally used in combination with `madc` and `addc` to implement extended-precision multi-word multiplication. See `madc` for an example.

PTX ISA Notes

32-bit `mad.cc` introduced in PTX ISA version 3.0.

64-bit `mad.cc` introduced in PTX ISA version 4.3.

Target ISA Notes

Requires target `sm_20` or higher.

Examples

```
@p  mad.lo.cc.u32 d,a,b,c;
    mad.lo.cc.u32 r,p,q,r;
```

9.7.2.6 Extended-Precision Arithmetic Instructions: `madc`

`madc`

Multiply two values, extract high or low half of result, and add a third value with carry-in and optional carry-out.

Syntax

```
madc{.hi,.lo}{.cc}.type  d, a, b, c;

.type = { .u32, .s32, .u64, .s64 };
```

Description

Multiplies two values, extracts either the high or low part of the result, and adds a third value along with carry-in. Writes the result to the destination register and optionally writes the carry-out from the addition into the condition code register.

Semantics

```
t = a * b;
d = t<63..32> + c + CC.CF;      // for .hi variant
d = t<31..0> + c + CC.CF;       // for .lo variant
```

if `.cc` specified, carry-out from addition is written to `CC.CF`

Notes

Generally used in combination with `mad.cc` and `addc` to implement extended-precision multi-word multiplication. See example below.

PTX ISA Notes

32-bit `madc` introduced in PTX ISA version 3.0.

64-bit `madc` introduced in PTX ISA version 4.3.

Target ISA Notes

Requires target `sm_20` or higher.

Examples

```
// extended-precision multiply:  [r3,r2,r1,r0] = [r5,r4] * [r7,r6]
mul.lo.u32     r0,r4,r6;      // r0=(r4*r6).[31:0], no carry-out
mul.hi.u32     r1,r4,r6;      // r1=(r4*r6).[63:32], no carry-out
mad.lo.cc.u32  r1,r5,r6,r1;   // r1+=(r5*r6).[31:0], may carry-out
madc.hi.u32    r2,r5,r6,0;    // r2 =(r5*r6).[63:32]+carry-in,
                              // no carry-out
mad.lo.cc.u32   r1,r4,r7,r1;  // r1+=(r4*r7).[31:0], may carry-out
madc.hi.cc.u32  r2,r4,r7,r2;  // r2+=(r4*r7).[63:32]+carry-in,
                              // may carry-out
addc.u32        r3,0,0;       // r3 = carry-in, no carry-out
mad.lo.cc.u32   r2,r5,r7,r2;  // r2+=(r5*r7).[31:0], may carry-out
madc.hi.u32     r3,r5,r7,r3;  // r3+=(r5*r7).[63:32]+carry-in
```

9.7.3. Floating-Point Instructions

Floating-point instructions operate on `.f32` and `.f64` register operands and constant immediate values. The floating-point instructions are:

- `testp`
- `copysign`
- `add`
- `sub`

- mul
- fma
- mad
- div
- abs
- neg
- min
- max
- rcp
- sqrt
- rsqrt
- sin
- cos
- lg2
- ex2
- tanh

Instructions that support rounding modifiers are IEEE-754 compliant. Double-precision instructions support subnormal inputs and results. Single-precision instructions support subnormal inputs and results by default for sm_20 and subsequent targets, and flush subnormal inputs and results to sign-preserving zero for sm_1x targets. The optional .ftz modifier on single-precision instructions provides backward compatibility with sm_1x targets by flushing subnormal inputs and results to sign-preserving zero regardless of the target architecture.

Single-precision add, sub, mul, and mad support saturation of results to the range [0.0, 1.0], with NaNs being flushed to positive zero. NaN payloads are supported for double-precision instructions (except for rcp.approx.ftz.f64 and rsqrt.approx.ftz.f64, which maps input NaNs to a canonical NaN). Single-precision instructions return an unspecified NaN. Note that future implementations may support NaN payloads for single-precision instructions, so PTX programs should not rely on the specific single-precision NaNs being generated.

Table 30 summarizes floating-point instructions in PTX.

Table 30: Summary of Floating-Point Instructions

Instruction	.rn	.rz	.rm	.rp	.ftz	.sat	Notes
{add,sub, mul}.rnd.f32	x	x	x	x	x	x	If no rounding modifier is specified, default is .rn and instructions may be folded into a multiply-add.
{add,sub, mul}.rnd.f64	x	x	x	x	n/a	n/a	If no rounding modifier is specified, default is .rn and instructions may be folded into a multiply-add.
mad.f32	n/a	n/a	n/a	n/a	x	x	.target sm_1x No rounding modifier.
{mad,fma}. rnd.f32	x	x	x	x	x	x	.target sm_20 or higher mad.f32 and fma.f32 are the same.
{mad,fma}. rnd.f64	x	x	x	x	n/a	n/a	mad.f64 and fma.f64 are the same.
div.full.f32	n/a	n/a	n/a	n/a	x	n/a	No rounding modifier.
{div,rcp, sqrt}.approx. f32	n/a	n/a	n/a	n/a	x	n/a	n/a
rcp.approx. ftz.f64	n/a	n/a	n/a	n/a	x	n/a	.target sm_20 or higher
{div,rcp, sqrt}.rnd.f32	x	x	x	x	x	n/a	.target sm_20 or higher
{div,rcp, sqrt}.rnd.f64	x	x	x	x	n/a	n/a	.target sm_20 or higher
{abs,neg,min, max}.f32	n/a	n/a	n/a	n/a	x	n/a	
{abs,neg,min, max}.f64	n/a	n/a	n/a	n/a	n/a	n/a	
rsqrt.approx. f32	n/a	n/a	n/a	n/a	x	n/a	
rsqrt.approx. f64	n/a	n/a	n/a	n/a	n/a	n/a	
rsqrt.approx. ftz.f64	n/a	n/a	n/a	n/a	x	n/a	.target sm_20 or higher
{sin,cos,lg2, ex2}.approx. f32	n/a	n/a	n/a	n/a	x	n/a	
tanh.approx. f32	n/a	n/a	n/a	n/a	n/a	n/a	.target sm_75 or higher

9.7.3.1 Floating Point Instructions: testp

testp

Test floating-point property.

Syntax

```
testp.op.type  p, a;  // result is .pred

.op   = { .finite, .infinite,
          .number, .notanumber,
          .normal, .subnormal };
.type = { .f32, .f64 };
```

Description

`testp` tests common properties of floating-point numbers and returns a predicate value of 1 if `True` and `0` if `False`.

testp.finite
`True` if the input is not infinite or `NaN`

testp.infinite
`True` if the input is positive or negative infinity

testp.number
`True` if the input is not `NaN`

testp.notanumber
`True` if the input is `NaN`

testp.normal
`True` if the input is a normal number (not `NaN`, not infinity)

testp.subnormal
`True` if the input is a subnormal number (not `NaN`, not infinity)

As a special case, positive and negative zero are considered normal numbers.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

Requires sm_20 or higher.

Examples

```
testp.notanumber.f32  isnan, f0;
testp.infinite.f64    p, X;
```

9.7.3.2 Floating Point Instructions: copysign

copysign

Copy sign of one input to another.

Syntax

```
copysign.type  d, a, b;

.type = { .f32, .f64 };
```

Description

Copy sign bit of a into value of b, and return the result as d.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

Requires sm_20 or higher.

Examples

```
copysign.f32  x, y, z;
copysign.f64  A, B, C;
```

9.7.3.3 Floating Point Instructions: add

add

Add two values.

Syntax

```
add{.rnd}{.ftz}{.sat}.f32  d, a, b;
add{.rnd}{.ftz}.f32x2      d, a, b;
add{.rnd}.f64              d, a, b;

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Performs addition and writes the resulting value into a destination register.

For `.f32x2` instruction type, forms input vectors of single precision (`.f32`) values from source operands. Single precision (`.f32`) operands are then added in parallel to produce `.f32x2` result in destination.

For `.f32x2` instruction type, operands `d`, `a` and `b` have `.b64` type.

Semantics

```
if (type == f32 || type == f64) {
    d = a + b;
} else if (type == f32x2) {
    fA[0] = a[0:31];
    fA[1] = a[32:63];
    fB[0] = b[0:31];
    fB[1] = b[32:63];
    for (i = 0; i < 2; i++) {
        d[i] = fA[i] + fB[i];
    }
}
```

Notes

Rounding modifiers:

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

The default value of rounding modifier is `.rn`. Note that an `add` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. An `add` instruction with no rounding modifier

defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul`/`add` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:

`sm_20+`
By default, subnormal numbers are supported.

`add.ftz.f32`, `add.ftz.f32x2` flushes subnormal inputs and results to sign-preserving zero.

`sm_1x`
`add.f64` supports subnormal numbers.

`add.f32` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:

`add.sat.f32` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`add.f32x2` introduced in PTX ISA version 8.6.

Target ISA Notes

`add.f32` supported on all target architectures.

`add.f64` requires `sm_13` or higher.

Rounding modifiers have the following target requirements:

`.rn`, `.rz`
available for all targets

`.rm`, `.rp`
for `add.f64`, requires `sm_13` or higher.

for `add.f32`, requires `sm_20` or higher.

`add.f32x2` requires `sm_100` or higher.

Examples

```
@p  add.rz.ftz.f32  f1,f2,f3;
add.rp.ftz.f32x2    d, a, b;
```

9.7.3.4 Floating Point Instructions: sub

sub

Subtract one value from another.

Syntax

```
sub{.rnd}{.ftz}{.sat}.f32  d, a, b;
sub{.rnd}{.ftz}.f32x2      d, a, b;
sub{.rnd}.f64              d, a, b;

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Performs subtraction and writes the resulting value into a destination register.

For `.f32x2` instruction type, forms input vectors of single precision (`.f32`) values from source operands. Single precision (`.f32`) operands are then subtracted in parallel to produce `.f32x2` result in destination.

For `.f32x2` instruction type, operands `d`, `a` and `b` have `.b64` type.

Semantics

```
if (type == f32 || type == f64) {
    d = a - b;
} else if (type == f32x2) {
    fA[0] = a[0:31];
    fA[1] = a[32:63];
    fB[0] = b[0:31];
    fB[1] = b[32:63];
    for (i = 0; i < 2; i++) {
        d[i] = fA[i] - fB[i];
    }
}
```

Notes

Rounding modifiers:

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

The default value of rounding modifier is `.rn`. Note that a `sub` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. A `sub` instruction with no rounding modifier

defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul`/`sub` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:

`sm_20+`
By default, subnormal numbers are supported.

`sub.ftz.f32`, `sub.ftz.f32x2` flushes subnormal inputs and results to sign-preserving zero.

`sm_1x`
`sub.f64` supports subnormal numbers.

`sub.f32` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:

`sub.sat.f32` clamps the result to [0.0, 1.0]. NaN results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`sub.f32x2` introduced in PTX ISA version 8.6.

Target ISA Notes

`sub.f32` supported on all target architectures.

`sub.f64` requires `sm_13` or higher.

Rounding modifiers have the following target requirements:

`.rn`, `.rz`
available for all targets

`.rm`, `.rp`
for `sub.f64`, requires `sm_13` or higher.

for `sub.f32`, requires `sm_20` or higher.

`sub.f32x2` requires `sm_100` or higher.

Examples

```
sub.f32 c,a,b;
sub.rn.ftz.f32  f1,f2,f3;
```

9.7.3.5 Floating Point Instructions: mul

mul

Multiply two values.

Syntax

```
mul{.rnd}{.ftz}{.sat}.f32  d, a, b;
mul{.rnd}{.ftz}.f32x2      d, a, b;
mul{.rnd}.f64              d, a, b;

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Compute the product of two values.

For `.f32x2` instruction type, forms input vectors of single precision (`.f32`) values from source operands. Single precision (`.f32`) operands are then multiplied in parallel to produce `.f32x2` result in destination.

For `.f32x2` instruction type, operands d, a and b have `.b64` type.

Semantics

```
if (type == f32 || type == f64) {
    d = a * b;
} else if (type == f32x2) {
    fA[0] = a[0:31];
    fA[1] = a[32:63];
    fB[0] = b[0:31];
    fB[1] = b[32:63];
    for (i = 0; i < 2; i++) {
        d[i] = fA[i] * fB[i];
    }
}
```

Notes

For floating-point multiplication, all operands must be the same size.

Rounding modifiers:

.rn mantissa LSB rounds to nearest even

.rz mantissa LSB rounds towards zero

.rm mantissa LSB rounds towards negative infinity

.rp mantissa LSB rounds towards positive infinity

The default value of rounding modifier is `.rn`. Note that a `mul` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. A `mul` instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul/add` and `mul/sub` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `mul.ftz.f32`, `mul.ftz.f32x2` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
: `mul.f64` supports subnormal numbers.

  `mul.f32` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:

`mul.sat.f32` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`mul.f32x2` introduced in PTX ISA version 8.6.

Target ISA Notes

`mul.f32` supported on all target architectures.

`mul.f64` requires `sm_13` or higher.

Rounding modifiers have the following target requirements:

.rn, .rz
: available for all targets

.rm, .rp
: for `mul.f64`, requires `sm_13` or higher.

  for `mul.f32`, requires `sm_20` or higher.

`mul.f32x2` requires `sm_100` or higher.

Examples

```
mul.ftz.f32 circumf,radius,pi  // a single-precision multiply
```

9.7.3.6 Floating Point Instructions: fma

fma

Fused multiply-add.

Syntax

```
fma.rnd{.ftz}{.sat}.f32  d, a, b, c;
fma.rnd{.ftz}.f32x2      d, a, b, c;
fma.rnd.f64              d, a, b, c;

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Performs a fused multiply-add with no loss of precision in the intermediate product and addition.

For `.f32x2` instruction type, forms input vectors of single precision (`.f32`) values from source operands. Single precision (`.f32`) operands are then operated in parallel to produce `.f32x2` result in destination.

For `.f32x2` instruction type, operands d, a, b and c have `.b64` type.

Semantics

```
if (type == f32 || type == f64) {
    d = a * b + c;
} else if (type == f32x2) {
    fA[0] = a[0:31];
    fA[1] = a[32:63];
    fB[0] = b[0:31];
    fB[1] = b[32:63];
    fC[0] = c[0:31];
    fC[1] = c[32:63];
    for (i = 0; i < 2; i++) {
        d[i] = fA[i] * fB[i] + fC[i];
    }
}
```

Notes

`fma.f32` computes the product of a and b to infinite precision and then adds c to this product, again in infinite precision. The resulting value is then rounded to single precision using the rounding mode specified by `.rnd`.

`fma.f64` computes the product of a and b to infinite precision and then adds c to this product, again in infinite precision. The resulting value is then rounded to double precision using the rounding mode specified by `.rnd`.

`fma.f64` is the same as `mad.f64`.

Rounding modifiers (no default):

.rn mantissa LSB rounds to nearest even

.rz mantissa LSB rounds towards zero

.rm mantissa LSB rounds towards negative infinity

.rp mantissa LSB rounds towards positive infinity

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`fma.ftz.f32`, `fma.ftz.f32x2` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`fma.f64` supports subnormal numbers.

`fma.f32` is unimplemented for `sm_1x` targets.

Saturation:

`fma.sat.f32` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

`fma.f64` introduced in PTX ISA version 1.4.

`fma.f32` introduced in PTX ISA version 2.0.

`fma.f32x2` introduced in PTX ISA version 8.6.

Target ISA Notes

`fma.f32` requires `sm_20` or higher.

`fma.f64` requires `sm_13` or higher.

`fma.f32x2` requires `sm_100` or higher.

Examples

```
    fma.rn.ftz.f32  w,x,y,z;
@p  fma.rn.f64      d,a,b,c;
    fma.rp.ftz.f32x2 p,q,r,s;
```

9.7.3.7 Floating Point Instructions: mad

mad

Multiply two values and add a third value.

Syntax

```
mad{.ftz}{.sat}.f32      d, a, b, c;    // .target sm_1x
mad.rnd{.ftz}{.sat}.f32  d, a, b, c;    // .target sm_20
mad.rnd.f64              d, a, b, c;    // .target sm_13 and higher

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Multiplies two values and adds a third, and then writes the resulting value into a destination register.

Semantics

```
d = a*b + c;
```

Notes

For `.target sm_20` and higher:

- `mad.f32` computes the product of `a` and `b` to infinite precision and then adds `c` to this product, again in infinite precision. The resulting value is then rounded to single precision using the rounding mode specified by `.rnd`.
- `mad.f64` computes the product of `a` and `b` to infinite precision and then adds `c` to this product, again in infinite precision. The resulting value is then rounded to double precision using the rounding mode specified by `.rnd`.
- `mad.{f32,f64}` is the same as `fma.{f32,f64}`.

For `.target sm_1x`:

- `mad.f32` computes the product of `a` and `b` at double precision, and then the mantissa is truncated to 23 bits, but the exponent is preserved. Note that this is different from computing the product with `mul`, where the mantissa can be rounded and the exponent will be clamped. The exception for `mad.f32` is when `c = +/-0.0`, `mad.f32` is identical to the result computed using separate mul and add instructions. When JIT-compiled for SM 2.0 devices, `mad.f32` is implemented as a fused multiply-add (i.e., `fma.rn.ftz.f32`). In this case, `mad.f32` can produce slightly different numeric results and backward compatibility is not guaranteed in this case.
- `mad.f64` computes the product of `a` and `b` to infinite precision and then adds `c` to this product, again in infinite precision. The resulting value is then rounded to double precision using the rounding mode specified by `.rnd`. Unlike `mad.f32`, the treatment of subnormal inputs and output follows IEEE 754 standard.
- `mad.f64` is the same as `fma.f64`.

Rounding modifiers (no default):

.rn mantissa LSB rounds to nearest even

.rz mantissa LSB rounds towards zero

.rm mantissa LSB rounds towards negative infinity

.rp mantissa LSB rounds towards positive infinity

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`mad.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`mad.f64` supports subnormal numbers.

`mad.f32` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:

`mad.sat.f32` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

In PTX ISA versions 1.4 and later, a rounding modifier is required for `mad.f64`.

Legacy `mad.f64` instructions having no rounding modifier will map to `mad.rn.f64`.

In PTX ISA versions 2.0 and later, a rounding modifier is required for `mad.f32` for `sm_20` and higher targets.

Errata

`mad.f32` requires a rounding modifier for `sm_20` and higher targets. However for PTX ISA version 3.0 and earlier, ptxas does not enforce this requirement and `mad.f32` silently defaults to `mad.rn.f32`. For PTX ISA version 3.1, ptxas generates a warning and defaults to `mad.rn.f32`, and in subsequent releases ptxas will enforce the requirement for PTX ISA version 3.2 and later.

Target ISA Notes

`mad.f32` supported on all target architectures.

`mad.f64` requires `sm_13` or higher.

Rounding modifiers have the following target requirements:

- `.rn`, `.rz`, `.rm`, `.rp` for `mad.f64`, requires `sm_13` or higher.
- `.rn`, `.rz`, `.rm`, `.rp` for `mad.f32`, requires `sm_20` or higher.

Examples

```
@p  mad.f32  d,a,b,c;
```

9.7.3.8 Floating Point Instructions: div

div

Divide one value by another.

Syntax

```
div.approx{.ftz}.f32  d, a, b;  // fast, approximate divide
div.full{.ftz}.f32    d, a, b;  // full-range approximate divide
div.rnd{.ftz}.f32     d, a, b;  // IEEE 754 compliant rounding
div.rnd.f64           d, a, b;  // IEEE 754 compliant rounding

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Divides a by b, stores result in d.

Semantics

```
d = a / b;
```

Notes

Fast, approximate single-precision divides:

- `div.approx.f32` implements a fast approximation to divide, computed as `d = a * (1/b)`. For `|b|` in $[2^{-126}, 2^{126}]$, the maximum `ulp` error is 2. For $2^{126} < |b| < 2^{128}$, if a is infinity, `div.approx.f32` returns NaN, otherwise it returns 0.
- `div.full.f32` implements a relatively fast, full-range approximation that scales operands to achieve better accuracy, but is not fully IEEE 754 compliant and does not support rounding modifiers. The maximum `ulp` error is 2 across the full range of inputs.
- Subnormal inputs and results are flushed to sign-preserving zero. Fast, approximate division by zero creates a value of infinity (with same sign as a).

Divide with IEEE 754 compliant rounding:

Rounding modifiers (no default):

.rn mantissa LSB rounds to nearest even

.rz mantissa LSB rounds towards zero

.rm mantissa LSB rounds towards negative infinity

.rp mantissa LSB rounds towards positive infinity

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`div.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`div.f64` supports subnormal numbers.

`div.f32` flushes subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`div.f32` and `div.f64` introduced in PTX ISA version 1.0.

Explicit modifiers `.approx`, `.full`, `.ftz`, and rounding introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, one of `.approx`, `.full`, or `.rnd` is required.

For PTX ISA versions 1.0 through 1.3, `div.f32` defaults to `div.approx.ftz.f32`, and `div.f64` defaults to `div.rn.f64`.

Target ISA Notes

`div.approx.f32` and `div.full.f32` supported on all target architectures.

`div.rnd.f32` requires `sm_20` or higher.

`div.rn.f64` requires `sm_13` or higher, or `.target map_f64_to_f32`.

`div.{rz,rm,rp}.f64` requires `sm_20` or higher.

Examples

```
div.approx.ftz.f32  diam,circum,3.14159;
div.full.ftz.f32    x, y, z;
div.rn.f64          xd, yd, zd;
```

9.7.3.9 Floating Point Instructions: abs

abs

Absolute value.

Syntax

```
abs{.ftz}.f32  d, a;
abs.f64        d, a;
```

Description

Take the absolute value of a and store the result in d.

Semantics

```
d = |a|;
```

Notes

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`abs.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`abs.f64` supports subnormal numbers.

`abs.f32` flushes subnormal inputs and results to sign-preserving zero.

For `abs.f32`, `NaN` input yields unspecified `NaN`. For `abs.f64`, `NaN` input is passed through unchanged. Future implementations may comply with the IEEE 754 standard by preserving payload and modifying only the sign bit.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`abs.f32` supported on all target architectures.

`abs.f64` requires `sm_13` or higher.

Examples

```
abs.ftz.f32  x,f0;
```

9.7.3.10 Floating Point Instructions: neg

neg

Arithmetic negate.

Syntax

```
neg{.ftz}.f32  d, a;
neg.f64        d, a;
```

Description

Negate the sign of `a` and store the result in `d`.

Semantics

```
d = -a;
```

Notes

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `neg.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
: `neg.f64` supports subnormal numbers.

  `neg.f32` flushes subnormal inputs and results to sign-preserving zero.

`NaN` inputs yield an unspecified `NaN`. Future implementations may comply with the IEEE 754 standard by preserving payload and modifying only the sign bit.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`neg.f32` supported on all target architectures.

`neg.f64` requires `sm_13` or higher.

Examples

```
neg.ftz.f32  x,f0;
```

9.7.3.11 Floating Point Instructions: `min`

`min`

Find the minimum of given values.

Syntax

```
min{.ftz}{.NaN}{.xorsign.abs}.f32  d, a, b;
min{.ftz}{.NaN}{.abs}.f32          d, a, b, c;
min.f64                            d, a, b;
```

Description

Store the minimum of `a`, `b` and optionally `c` in `d`.

If `.NaN` modifier is specified, then the result is canonical `NaN` if any of the inputs is `NaN`.

If `.abs` modifier is specified, the magnitude of destination operand `d` is the minimum of absolute values of both input arguments.

If `.xorsign` modifier is specified, the sign bit of destination `d` is equal to the XOR of the sign bits of both inputs `a` and `b`. The `.xorsign` qualifier cannot be specified for three inputs operation.

Qualifier `.xorsign` requires qualifier `.abs` to be specified. In such cases, `.xorsign` considers the sign bit of both inputs before applying `.abs` operation.

If the result of `min` is `NaN` then the `.xorsign` and `.abs` modifiers will be ignored.

Semantics

```
def min_num (z, x, y) {
    if (isNaN(x) && isNaN(y))
        z = NaN;
    else if (isNaN(x))
        z = y;
    else if (isNaN(y))
        z = x;
    else
        // note: -0.0 < +0.0 here
        z = (x < y) ? x : y;
    return z;
}

def min_nan (z, x, y) {
    if (isNaN(x) || isNaN(y))
        z = NaN;
    else
        // note: -0.0 < +0.0 here
        z = (x < y) ? x : y;
    return z;
}

def two_inputs_min (z, x, y) {
    if (.NaN)
        z = min_nan(z, x, y);
    else
        z = min_num(z, x, y);
    return z;
}

if (.xorsign && !isPresent(c)) {
    xorsign = getSignBit(a) ^ getSignBit(b);
}
if (.abs) {
    a = |a|;
    b = |b|;
    if (isPresent(c)) {
        c = |c|;
    }
}

d = two_inputs_min(d, a, b)
if (isPresent(c)) {
    d = two_inputs_min(d, d, c)
}
if (.xorsign && !isPresent(c) && !isNaN(d)) {
    setSignBit(d, xorsign);
}
```

Notes

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`min.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`min.f64` supports subnormal numbers.

`min.f32` flushes subnormal inputs and results to sign-preserving zero.

If values of both inputs are 0.0, then +0.0 > -0.0.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`min.NaN` introduced in PTX ISA version 7.0.

`min.xorsign.abs` introduced in PTX ISA version 7.2.

`min` with three input arguments introduced in PTX ISA version 8.8.

Target ISA Notes

`min.f32` supported on all target architectures.

`min.f64` requires `sm_13` or higher.

`min.NaN` requires `sm_80` or higher.

`min.xorsign.abs` requires `sm_86` or higher.

`min` with three input arguments requires `sm_100` or higher.

Examples

```
@p  min.ftz.f32  z,z,x;
    min.f64      a,b,c;
    // fp32 min with .NaN
    min.NaN.f32  f0,f1,f2;
    // fp32 min with .xorsign.abs
    min.xorsign.abs.f32 Rd, Ra, Rb;
```

9.7.3.12 Floating Point Instructions: max

max

Find the maximum of given values.

Syntax

```
max{.ftz}{.NaN}{.xorsign.abs}.f32  d, a, b;
max{.ftz}{.NaN}{.abs}.f32          d, a, b, c;
max.f64                            d, a, b;
```

Description

Store the maximum of a, b and optionally c in d.

If .NaN modifier is specified, the result is canonical NaN if any of the inputs is NaN.

If .abs modifier is specified, the magnitude of destination operand d is the maximum of absolute values of the input arguments.

If .xorsign modifier is specified, the sign bit of destination d is equal to the XOR of the sign bits of the inputs: a and b. The .xorsign qualifier cannot be specified for three inputs operation.

Qualifier .xorsign requires qualifier .abs to be specified. In such cases, .xorsign considers the sign bit of both inputs before applying .abs operation.

If the result of max is NaN then the .xorsign and .abs modifiers will be ignored.

Semantics

```
def max_num (z, x, y) {
    if (isNaN(x) && isNaN(y))
        z = NaN;
    else if (isNaN(x))
        z = y;
    else if (isNaN(y))
        z = x;
    else
        // note: +0.0 > -0.0 here
        z = (x > y) ? x : y;
    return z;
}

def max_nan (z, x, y) {
    if (isNaN(x) || isNaN(y))
        z = NaN;
    else
        // note: +0.0 > -0.0 here
        z = (x > y) ? x : y;
    return z;
}
```

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```
def two_inputs_max (z, x, y) {
    if (.NaN)
        z = max_nan(z, x, y);
    else
        z = max_num(z, x, y);
    return z;
}

if (.xorsign && !isPresent(c)) {
    xorsign = getSignBit(a) ^ getSignBit(b);
}
if (.abs) {
    a = |a|;
    b = |b|;
    if (isPresent(c)) {
        c = |c|;
    }
}

d = two_inputs_max (d, a, b)
if (isPresent(c)) {
    d = two_inputs_max (d, d, c)
}

if (.xorsign && !isPresent(c) !isNaN(d)) {
    setSignBit(d, xorsign);
}
```

Notes

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`max.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
`max.f64` supports subnormal numbers.

`max.f32` flushes subnormal inputs and results to sign-preserving zero.

If values of both inputs are 0.0, then +0.0 > -0.0.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`max.NaN` introduced in PTX ISA version 7.0.

`max.xorsign.abs` introduced in PTX ISA version 7.2.

`max` with three input arguments introduced in PTX ISA version 8.8.

Target ISA Notes

`max.f32` supported on all target architectures.

`max.f64` requires `sm_13` or higher.

`max.NaN` requires `sm_80` or higher.

`max.xorsign.abs` requires `sm_86` or higher.

`max` with three input arguments requires `sm_100` or higher.

Examples

```
max.ftz.f32  f0,f1,f2;
max.f64      a,b,c;
// fp32 max with .NaN
max.NaN.f32  f0,f1,f2;
// fp32 max with .xorsign.abs
max.xorsign.abs.f32 Rd, Ra, Rb;
```

9.7.3.13 Floating Point Instructions: `rcp`

`rcp`

Take the reciprocal of a value.

Syntax

```
rcp.approx{.ftz}.f32  d, a;  // fast, approximate reciprocal
rcp.rnd{.ftz}.f32     d, a;  // IEEE 754 compliant rounding
rcp.rnd.f64           d, a;  // IEEE 754 compliant rounding

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Compute 1/a, store result in d.

Semantics

```
d = 1 / a;
```

Notes

Fast, approximate single-precision reciprocal:

`rcp.approx.f32` implements a fast approximation to reciprocal. The maximum ulp error is 1 across the full range of inputs.

Input	Result
-Inf	-0.0
-0.0	-Inf
+0.0	+Inf
+Inf	+0.0
NaN	NaN

Reciprocal with IEEE 754 compliant rounding:

Rounding modifiers (no default):

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

Subnormal numbers:

`sm_20+`
By default, subnormal numbers are supported.

`rcp.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

`sm_1x`
`rcp.f64` supports subnormal numbers.

`rcp.f32` flushes subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`rcp.f32` and `rcp.f64` introduced in PTX ISA version 1.0. `rcp.rn.f64` and explicit modifiers `.approx` and `.ftz` were introduced in PTX ISA version 1.4. General rounding modifiers were added in PTX ISA version 2.0.

For PTX ISA version 1.4 and later, one of `.approx` or `.rnd` is required.

For PTX ISA versions 1.0 through 1.3, `rcp.f32` defaults to `rcp.approx.ftz.f32`, and `rcp.f64` defaults to `rcp.rn.f64`.

Target ISA Notes

`rcp.approx.f32` supported on all target architectures.

`rcp.rnd.f32` requires `sm_20` or higher.

`rcp.rn.f64` requires `sm_13` or higher, or `.target map_f64_to_f32.`

`rcp.{rz,rm,rp}.f64` requires `sm_20` or higher.

Examples

```
rcp.approx.ftz.f32  ri,r;
rcp.rn.ftz.f32      xi,x;
rcp.rn.f64          xi,x;
```

9.7.3.14 Floating Point Instructions: `rcp.approx.ftz.f64`

`rcp.approx.ftz.f64`

Compute a fast, gross approximation to the reciprocal of a value.

Syntax

```
rcp.approx.ftz.f64  d, a;
```

Description

Compute a fast, gross approximation to the reciprocal as follows:

1. extract the most-significant 32 bits of `.f64` operand a in 1.11.20 IEEE floating-point format (i.e., ignore the least-significant 32 bits of a),
2. compute an approximate `.f64` reciprocal of this value using the most-significant 20 bits of the mantissa of operand a,
3. place the resulting 32-bits in 1.11.20 IEEE floating-point format in the most-significant 32-bits of destination d,and
4. zero the least significant 32 mantissa bits of `.f64` destination d.

Semantics

```
tmp = a[63:32]; // upper word of a, 1.11.20 format
d[63:32] = 1.0 / tmp;
d[31:0] = 0x00000000;
```

Notes

`rcp.approx.ftz.f64` implements a fast, gross approximation to reciprocal.

Input a[63:32]	Result d[63:32]
-Inf	-0.0
-subnormal	-Inf
-0.0	-Inf
+0.0	+Inf
+subnormal	+Inf
+Inf	+0.0
NaN	NaN

Input `NaN`s map to a canonical `NaN` with encoding `0x7fffffff00000000`.

Subnormal inputs and results are flushed to sign-preserving zero.

PTX ISA Notes

`rcp.approx.ftz.f64` introduced in PTX ISA version 2.1.

Target ISA Notes

`rcp.approx.ftz.f64` requires `sm_20` or higher.

Examples

```
rcp.approx.ftz.f64  xi,x;
```

9.7.3.15 Floating Point Instructions: `sqrt`

`sqrt`

Take the square root of a value.

Syntax

```
sqrt.approx{.ftz}.f32  d, a; // fast, approximate square root
sqrt.rnd{.ftz}.f32     d, a; // IEEE 754 compliant rounding
sqrt.rnd.f64           d, a; // IEEE 754 compliant rounding

.rnd = { .rn, .rz, .rm, .rp };
```

Description

Compute sqrt(a) and store the result in d.

Semantics

```
d = sqrt(a);
```

Notes

`sqrt.approx.f32` implements a fast approximation to square root. The maximum relative error over the entire positive finite floating-point range is 2^{-23}.

For various corner-case inputs, results of `sqrt` instruction are shown in below table:

Input	Result
-Inf	NaN
-normal	NaN
-0.0	-0.0
+0.0	+0.0
+Inf	+Inf
NaN	NaN

Square root with IEEE 754 compliant rounding:

Rounding modifiers (no default):

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

Subnormal numbers:

`sm_20+`
By default, subnormal numbers are supported.

`sqrt.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x

`sqrt.f64` supports subnormal numbers.

`sqrt.f32` flushes subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`sqrt.f32` and `sqrt.f64` introduced in PTX ISA version 1.0. `sqrt.rn.f64` and explicit modifiers `.approx` and `.ftz` were introduced in PTX ISA version 1.4. General rounding modifiers were added in PTX ISA version 2.0.

For PTX ISA version 1.4 and later, one of `.approx` or `.rnd` is required.

For PTX ISA versions 1.0 through 1.3, `sqrt.f32` defaults to `sqrt.approx.ftz.f32`, and `sqrt.f64` defaults to `sqrt.rn.f64`.

Target ISA Notes

`sqrt.approx.f32` supported on all target architectures.

`sqrt.rnd.f32` requires `sm_20` or higher.

`sqrt.rn.f64` requires `sm_13` or higher, or `.target map_f64_to_f32`.

`sqrt.{rz,rm,rp}.f64` requires `sm_20` or higher.

Examples

```
sqrt.approx.ftz.f32  r,x;
sqrt.rn.ftz.f32      r,x;
sqrt.rn.f64          r,x;
```

9.7.3.16 Floating Point Instructions: `rsqrt`

`rsqrt`

Take the reciprocal of the square root of a value.

Syntax

```
rsqrt.approx{.ftz}.f32  d, a;
rsqrt.approx.f64        d, a;
```

Description

Compute `1/sqrt(a)` and store the result in `d`.

Semantics

```
d = 1/sqrt(a);
```

Notes

`rsqrt.approx` implements an approximation to the reciprocal square root.

Input	Result
-Inf	NaN
-normal	NaN
-0.0	-Inf
+0.0	+Inf
+Inf	+0.0
NaN	NaN

The maximum relative error for `rsqrt.f32` over the entire positive finite floating-point range is $2^{-22.9}$.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `rsqrt.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
: `rsqrt.f64` supports subnormal numbers.

  `rsqrt.f32` flushes subnormal inputs and results to sign-preserving zero.

Note that `rsqrt.approx.f64` is emulated in software and are relatively slow.

PTX ISA Notes

`rsqrt.f32` and `rsqrt.f64` were introduced in PTX ISA version 1.0. Explicit modifiers `.approx` and `.ftz` were introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, the `.approx` modifier is required.

For PTX ISA versions 1.0 through 1.3, `rsqrt.f32` defaults to `rsqrt.approx.ftz.f32`, and `rsqrt.f64` defaults to `rsqrt.approx.f64`.

Target ISA Notes

`rsqrt.f32` supported on all target architectures.

`rsqrt.f64` requires `sm_13` or higher.

Examples

```
rsqrt.approx.ftz.f32  isr, x;
rsqrt.approx.f64      ISR, X;
```

9.7.3.17 Floating Point Instructions: `rsqrt.approx.ftz.f64`

`rsqrt.approx.ftz.f64`

Compute an approximation of the square root reciprocal of a value.

Syntax

```
rsqrt.approx.ftz.f64 d, a;
```

Description

Compute a double-precision (`.f64`) approximation of the square root reciprocal of a value. The least significant 32 bits of the double-precision (`.f64`) destination `d` are all zeros.

Semantics

```
tmp = a[63:32]; // upper word of a, 1.11.20 format
d[63:32] = 1.0 / sqrt(tmp);
d[31:0] = 0x00000000;
```

Notes

`rsqrt.approx.ftz.f64` implements a fast approximation of the square root reciprocal of a value.

Input	Result
-Inf	NaN
-subnormal	-Inf
-0.0	-Inf
+0.0	+Inf
+subnormal	+Inf
+Inf	+0.0
NaN	NaN

Input NaNs map to a canonical NaN with encoding `0x7fffffff00000000`.

Subnormal inputs and results are flushed to sign-preserving zero.

PTX ISA Notes

`rsqrt.approx.ftz.f64` introduced in PTX ISA version 4.0.

Target ISA Notes

`rsqrt.approx.ftz.f64` requires `sm_20` or higher.

Examples

```
rsqrt.approx.ftz.f64 xi,x;
```

9.7.3.18 Floating Point Instructions: `sin`

`sin`

Find the sine of a value.

Syntax

```
sin.approx{.ftz}.f32  d, a;
```

Description

Find the sine of the angle a (in radians).

Semantics

```
d = sin(a);
```

Notes

`sin.approx.f32` implements a fast approximation to sine.

Input	Result
-Inf	NaN
-0.0	-0.0
+0.0	+0.0
+Inf	NaN
NaN	NaN

The maximum absolute error over input range is as follows:

Range	[-2pi .. 2pi]	[-100pi .. +100pi]
Error	$2^{-20.5}$	$2^{-14.7}$

Outside of the range [-100pi .. +100pi], only best effort is provided. There are no defined error guarantees.

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`sin.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
Subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`sin.f32` introduced in PTX ISA version 1.0. Explicit modifiers `.approx` and `.ftz` introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, the .approx modifier is required.

For PTX ISA versions 1.0 through 1.3, `sin.f32` defaults to `sin.approx.ftz.f32`.

Target ISA Notes

Supported on all target architectures.

Examples

```
sin.approx.ftz.f32  sa, a;
```

9.7.3.19 Floating Point Instructions: cos

cos

Find the cosine of a value.

Syntax

```
cos.approx{.ftz}.f32  d, a;
```

Description

Find the cosine of the angle a (in radians).

Semantics

```
d = cos(a);
```

Notes

`cos.approx.f32` implements a fast approximation to cosine.

Input	Result
-Inf	NaN
-0.0	+1.0
+0.0	+1.0
+Inf	NaN
NaN	NaN

The maximum absolute error over input range is as follows:

Range	[-2pi .. 2pi]	[-100pi .. +100pi]
Error	$2^{-20.5}$	$2^{-14.7}$

Outside of the range [-100pi .. +100pi], only best effort is provided. There are no defined error guarantees.

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported.

`cos.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
Subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`cos.f32` introduced in PTX ISA version 1.0. Explicit modifiers `.approx` and `.ftz` introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, the `.approx` modifier is required.

For PTX ISA versions 1.0 through 1.3, `cos.f32` defaults to `cos.approx.ftz.f32`.

Target ISA Notes

Supported on all target architectures.

Examples

```
cos.approx.ftz.f32  ca, a;
```

9.7.3.20 Floating Point Instructions: lg2

lg2

Find the base-2 logarithm of a value.

Syntax

```
lg2.approx{.ftz}.f32  d, a;
```

Description

Determine the $\log_2$ of a.

Semantics

```
d = log(a) / log(2);
```

Notes

`lg2.approx.f32` implements a fast approximation to $\log_2(a)$.

Input	Result
-Inf	NaN
-normal	NaN
-0.0	-Inf
+0.0	-Inf
+Inf	+Inf
NaN	NaN

The maximum absolute error is 2^{-22} when the input operand is in the range (0.5, 2). For positive finite inputs outside of this interval, maximum relative error is 2^{-22}.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `lg2.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
: Subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`lg2.f32` introduced in PTX ISA version 1.0. Explicit modifiers `.approx` and `.ftz` introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, the `.approx` modifier is required.

For PTX ISA versions 1.0 through 1.3, `lg2.f32` defaults to `lg2.approx.ftz.f32`.

Target ISA Notes

Supported on all target architectures.

Examples

```
lg2.approx.ftz.f32  la, a;
```

9.7.3.21 Floating Point Instructions: ex2

ex2

Find the base-2 exponential of a value.

Syntax

```
ex2.approx{.ftz}.f32  d, a;
```

Description

Raise 2 to the power a.

Semantics

```
d = 2 ^ a;
```

Notes

`ex2.approx.f32` implements a fast approximation to 2^a.

Input	Result
-Inf	+0.0
-0.0	+1.0
+0.0	+1.0
+Inf	+Inf
NaN	NaN

The maximum ulp error is 2 ulp from correctly rounded result across the full range of inputs.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `ex2.ftz.f32` flushes subnormal inputs and results to sign-preserving zero.

sm_1x
: Subnormal inputs and results to sign-preserving zero.

PTX ISA Notes

`ex2.f32` introduced in PTX ISA version 1.0. Explicit modifiers `.approx` and `.ftz` introduced in PTX ISA version 1.4.

For PTX ISA version 1.4 and later, the `.approx` modifier is required.

For PTX ISA versions 1.0 through 1.3, `ex2.f32` defaults to `ex2.approx.ftz.f32`.

Target ISA Notes

Supported on all target architectures.

Examples

```
ex2.approx.ftz.f32  xa, a;
```

9.7.3.22 Floating Point Instructions: tanh

tanh

Find the hyperbolic tangent of a value (in radians)

Syntax

```
tanh.approx.f32 d, a;
```

Description

Take hyperbolic tangent value of a.

The operands d and a are of type `.f32`.

Semantics

```
d = tanh(a);
```

Notes

`tanh.approx.f32` implements a fast approximation to FP32 hyperbolic-tangent.

Results of `tanh` for various corner-case inputs are as follows:

Input	Result
-Inf	-1.0
-0.0	-0.0
+0.0	+0.0
+Inf	1.0
NaN	NaN

The maximum relative error over the entire floating point range is 2^{-11}. The subnormal numbers are supported.

Note: The subnormal inputs gets passed through to the output since the value of `tanh(x)` for small values of `x` is approximately the same as `x`.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Target ISA Notes

Requires `sm_75` or higher.

Examples

```
tanh.approx.f32 ta, a;
```

9.7.4. Half Precision Floating-Point Instructions

Half precision floating-point instructions operate on `.f16` and `.f16x2` register operands. The half precision floating-point instructions are:

- `add`
- `sub`
- `mul`
- `fma`
- `neg`
- `abs`
- `min`
- `max`
- `tanh`

- ex2

Half-precision `add`, `sub`, `mul`, and `fma` support saturation of results to the range [0.0, 1.0], with NaNs being flushed to positive zero. Half-precision instructions return an unspecified NaN.

9.7.4.1 Half Precision Floating Point Instructions: add

add

Add two values.

Syntax

```
add{.rnd}{.ftz}{.sat}.f16   d, a, b;
add{.rnd}{.ftz}{.sat}.f16x2 d, a, b;

add{.rnd}.bf16   d, a, b;
add{.rnd}.bf16x2 d, a, b;

.rnd = { .rn };
```

Description

Performs addition and writes the resulting value into a destination register.

For `.f16x2` and `.bf16x2` instruction type, forms input vectors by half word values from source operands. Half-word operands are then added in parallel to produce `.f16x2` or `.bf16x2` result in destination.

For `.f16` instruction type, operands d, a and b have `.f16` or `.b16` type. For `.f16x2` instruction type, operands d, a and b have `.b32` type. For `.bf16` instruction type, operands d, a, b have `.b16` type. For `.bf16x2` instruction type, operands d, a, b have `.b32` type.

Semantics

```
if (type == f16 || type == bf16) {
    d = a + b;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = fA[i] + fB[i];
    }
}
```

Notes

Rounding modifiers:

.rn mantissa LSB rounds to nearest even

The default value of rounding modifier is .rn. Note that an add instruction with an explicit rounding modifier is treated conservatively by the code optimizer. An add instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, mul/add sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:
By default, subnormal numbers are supported. add.ftz.{f16, f16x2} flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:
add.sat.{f16, f16x2} clamps the result to [0.0, 1.0]. NaN results are flushed to +0.0f.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

add{.rnd}.bf16 and add{.rnd}.bf16x2 introduced in PTX ISA version 7.8.

Target ISA Notes

Requires sm_53 or higher.

add{.rnd}.bf16 and add{.rnd}.bf16x2 requires sm_90 or higher.

Examples

```
// scalar f16 additions
add.f16         d0, a0, b0;
add.rn.f16      d1, a1, b1;
add.bf16        bd0, ba0, bb0;
add.rn.bf16     bd1, ba1, bb1;

// SIMD f16 addition
cvt.rn.f16.f32 h0, f0;
cvt.rn.f16.f32 h1, f1;
cvt.rn.f16.f32 h2, f2;
cvt.rn.f16.f32 h3, f3;
mov.b32  p1, {h0, h1};   // pack two f16 to 32bit f16x2
mov.b32  p2, {h2, h3};   // pack two f16 to 32bit f16x2
add.f16x2  p3, p1, p2;   // SIMD f16x2 addition

// SIMD bf16 addition
cvt.rn.bf16x2.f32 p4, f4, f5; // Convert two f32 into packed bf16x2
cvt.rn.bf16x2.f32 p5, f6, f7; // Convert two f32 into packed bf16x2
add.bf16x2  p6, p4, p5;       // SIMD bf16x2 addition

// SIMD fp16 addition
```

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```
ld.global.b32   f0, [addr];     // load 32 bit which hold packed f16x2
ld.global.b32   f1, [addr + 4]; // load 32 bit which hold packed f16x2
add.f16x2       f2, f0, f1;     // SIMD f16x2 addition

ld.global.b32   f3, [addr + 8];  // load 32 bit which hold packed bf16x2
ld.global.b32   f4, [addr + 12]; // load 32 bit which hold packed bf16x2
add.bf16x2      f5, f3, f4;      // SIMD bf16x2 addition
```

9.7.4.2 Half Precision Floating Point Instructions: sub

sub

Subtract two values.

Syntax

```
sub{.rnd}{.ftz}{.sat}.f16   d, a, b;
sub{.rnd}{.ftz}{.sat}.f16x2 d, a, b;

sub{.rnd}.bf16   d, a, b;
sub{.rnd}.bf16x2 d, a, b;

.rnd = { .rn };
```

Description

Performs subtraction and writes the resulting value into a destination register.

For `.f16x2` and `.bf16x2` instruction type, forms input vectors by half word values from source operands. Half-word operands are then subtracted in parallel to produce `.f16x2` or `.bf16x2` result in destination.

For `.f16` instruction type, operands d, a and b have `.f16` or `.b16` type. For `.f16x2` instruction type, operands d, a and b have `.b32` type. For `.bf16` instruction type, operands d, a, b have `.b16` type. For `.bf16x2` instruction type, operands d, a, b have `.b32` type.

Semantics

```
if (type == f16 || type == bf16) {
    d = a - b;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = fA[i] - fB[i];
    }
}
```

Notes

Rounding modifiers:

.rn mantissa LSB rounds to nearest even

The default value of rounding modifier is `.rn`. Note that a `sub` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. A `sub` instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul`/`sub` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:
By default, subnormal numbers are supported. `sub.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:
`sub.sat.{f16, f16x2}` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

`sub{.rnd}.bf16` and `sub{.rnd}.bf16x2` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_53` or higher.

`sub{.rnd}.bf16` and `sub{.rnd}.bf16x2` requires `sm_90` or higher.

Examples

```
// scalar f16 subtractions
sub.f16        d0, a0, b0;
sub.rn.f16     d1, a1, b1;
sub.bf16       bd0, ba0, bb0;
sub.rn.bf16    bd1, ba1, bb1;

// SIMD f16 subtraction
cvt.rn.f16.f32 h0, f0;
cvt.rn.f16.f32 h1, f1;
cvt.rn.f16.f32 h2, f2;
cvt.rn.f16.f32 h3, f3;
mov.b32  p1, {h0, h1};   // pack two f16 to 32bit f16x2
mov.b32  p2, {h2, h3};   // pack two f16 to 32bit f16x2
sub.f16x2  p3, p1, p2;   // SIMD f16x2 subtraction

// SIMD bf16 subtraction
cvt.rn.bf16x2.f32 p4, f4, f5; // Convert two f32 into packed bf16x2
cvt.rn.bf16x2.f32 p5, f6, f7; // Convert two f32 into packed bf16x2
sub.bf16x2  p6, p4, p5;       // SIMD bf16x2 subtraction

// SIMD fp16 subtraction
```

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```
ld.global.b32   f0, [addr];     // load 32 bit which hold packed f16x2
ld.global.b32   f1, [addr + 4]; // load 32 bit which hold packed f16x2
sub.f16x2       f2, f0, f1;     // SIMD f16x2 subtraction

// SIMD bf16 subtraction
ld.global.b32   f3, [addr + 8];  // load 32 bit which hold packed bf16x2
ld.global.b32   f4, [addr + 12]; // load 32 bit which hold packed bf16x2
sub.bf16x2      f5, f3, f4;      // SIMD bf16x2 subtraction
```

9.7.4.3 Half Precision Floating Point Instructions: mul

mul

Multiply two values.

Syntax

```
mul{.rnd}{.ftz}{.sat}.f16   d, a, b;
mul{.rnd}{.ftz}{.sat}.f16x2 d, a, b;

mul{.rnd}.bf16   d, a, b;
mul{.rnd}.bf16x2 d, a, b;

.rnd = { .rn };
```

Description

Performs multiplication and writes the resulting value into a destination register.

For `.f16x2` and `.bf16x2` instruction type, forms input vectors by half word values from source operands. Half-word operands are then multiplied in parallel to produce `.f16x2` or `.bf16x2` result in destination.

For `.f16` instruction type, operands d, a and b have `.f16` or `.b16` type. For `.f16x2` instruction type, operands d, a and b have `.b32` type. For `.bf16` instruction type, operands d, a, b have `.b16` type. For `.bf16x2` instruction type, operands d, a, b have `.b32` type.

Semantics

```
if (type == f16 || type == bf16) {
    d = a * b;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = fA[i] * fB[i];
    }
}
```

Notes

Rounding modifiers:

.rn mantissa LSB rounds to nearest even

The default value of rounding modifier is `.rn`. Note that a `mul` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. A `mul` instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul/add` and `mul/sub` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:
By default, subnormal numbers are supported. `mul.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:
`mul.sat.{f16, f16x2}` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

`mul{.rnd}.bf16` and `mul{.rnd}.bf16x2` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_53` or higher.

`mul{.rnd}.bf16` and `mul{.rnd}.bf16x2` requires `sm_90` or higher.

Examples

```
// scalar f16 multiplications
mul.f16        d0, a0, b0;
mul.rn.f16     d1, a1, b1;
mul.bf16       bd0, ba0, bb0;
mul.rn.bf16    bd1, ba1, bb1;

// SIMD f16 multiplication
cvt.rn.f16.f32 h0, f0;
cvt.rn.f16.f32 h1, f1;
cvt.rn.f16.f32 h2, f2;
cvt.rn.f16.f32 h3, f3;
mov.b32  p1, {h0, h1};   // pack two f16 to 32bit f16x2
mov.b32  p2, {h2, h3};   // pack two f16 to 32bit f16x2
mul.f16x2  p3, p1, p2;   // SIMD f16x2 multiplication

// SIMD bf16 multiplication
cvt.rn.bf16x2.f32 p4, f4, f5; // Convert two f32 into packed bf16x2
cvt.rn.bf16x2.f32 p5, f6, f7; // Convert two f32 into packed bf16x2
mul.bf16x2  p6, p4, p5;       // SIMD bf16x2 multiplication

// SIMD fp16 multiplication
```

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```
ld.global.b32   f0, [addr];     // load 32 bit which hold packed f16x2
ld.global.b32   f1, [addr + 4]; // load 32 bit which hold packed f16x2
mul.f16x2       f2, f0, f1;     // SIMD f16x2 multiplication

// SIMD bf16 multiplication
ld.global.b32   f3, [addr + 8];  // load 32 bit which hold packed bf16x2
ld.global.b32   f4, [addr + 12]; // load 32 bit which hold packed bf16x2
mul.bf16x2      f5, f3, f4;      // SIMD bf16x2 multiplication
```

9.7.4.4 Half Precision Floating Point Instructions: fma

fma

Fused multiply-add

Syntax

```
fma.rnd{.ftz}{.sat}.f16     d, a, b, c;
fma.rnd{.ftz}{.sat}.f16x2   d, a, b, c;
fma.rnd{.ftz}.relu.f16      d, a, b, c;
fma.rnd{.ftz}.relu.f16x2    d, a, b, c;
fma.rnd{.relu}.bf16         d, a, b, c;
fma.rnd{.relu}.bf16x2       d, a, b, c;
fma.rnd.oob.{relu}.type     d, a, b, c;

.rnd = { .rn };
```

Description

Performs a fused multiply-add with no loss of precision in the intermediate product and addition.

For `.f16x2` and `.bf16x2` instruction type, forms input vectors by half word values from source operands. Half-word operands are then operated in parallel to produce `.f16x2` or `.bf16x2` result in destination.

For `.f16` instruction type, operands d, a, b and c have `.f16` or `.b16` type. For `.f16x2` instruction type, operands d, a, b and c have `.b32` type. For `.bf16` instruction type, operands d, a, b and c have `.b16` type. For `.bf16x2` instruction type, operands d, a, b and c have `.b32` type.

Semantics

```
if (type == f16 || type == bf16) {
    d = a * b + c;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    fC[0] = c[0:15];
```

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```
    fC[1] = c[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = fA[i] * fB[i] + fC[i];
    }
}
```

Notes

Rounding modifiers (default is `.rn`):

`.rn` mantissa LSB rounds to nearest even

Subnormal numbers:
By default, subnormal numbers are supported. `fma.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

Saturation modifier:
`fma.sat.{f16, f16x2}` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`. `fma.relu.{f16, f16x2, bf16, bf16x2}` clamps the result to 0 if negative. `NaN` result is converted to canonical `NaN`.

Out Of Bounds modifier:
`fma.oob.{f16, f16x2, bf16, bf16x2}` clamps the result to 0 if either of the operands is `OOB NaN` (defined under *Tensors*) value. The test for the special `NaN` value and resultant forcing of the result to +0.0 is performed independently for each of the two SIMD operations.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

`fma.relu.{f16, f16x2}` and `fma{.relu}.{bf16, bf16x2}` introduced in PTX ISA version 7.0.

Support for modifier `.oob` introduced in PTX ISA version 8.1.

Target ISA Notes

Requires `sm_53` or higher.

`fma.relu.{f16, f16x2}` and `fma{.relu}.{bf16, bf16x2}` require `sm_80` or higher.

`fma{.oob}.{f16, f16x2, bf16, bf16x2}` requires `sm_90` or higher.

Examples

```
// scalar f16 fused multiply-add
fma.rn.f16         d0, a0, b0, c0;
fma.rn.f16         d1, a1, b1, c1;
fma.rn.relu.f16    d1, a1, b1, c1;
fma.rn.oob.f16      d1, a1, b1, c1;
fma.rn.oob.relu.f16 d1, a1, b1, c1;

// scalar bf16 fused multiply-add
```

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```
fma.rn.bf16        d1, a1, b1, c1;
fma.rn.relu.bf16   d1, a1, b1, c1;
fma.rn.oob.bf16       d1, a1, b1, c1;
fma.rn.oob.relu.bf16  d1, a1, b1, c1;

// SIMD f16 fused multiply-add
cvt.rn.f16.f32 h0, f0;
cvt.rn.f16.f32 h1, f1;
cvt.rn.f16.f32 h2, f2;
cvt.rn.f16.f32 h3, f3;
mov.b32  p1, {h0, h1}; // pack two f16 to 32bit f16x2
mov.b32  p2, {h2, h3}; // pack two f16 to 32bit f16x2
fma.rn.f16x2  p3, p1, p2, p2;   // SIMD f16x2 fused multiply-add
fma.rn.relu.f16x2  p3, p1, p2, p2; // SIMD f16x2 fused multiply-add with relu
↪saturation mode
fma.rn.oob.f16x2  p3, p1, p2, p2; // SIMD f16x2 fused multiply-add with oob modifier
fma.rn.oob.relu.f16x2 p3, p1, p2, p2; // SIMD f16x2 fused multiply-add with oob
↪modifier and relu saturation mode

// SIMD fp16 fused multiply-add
ld.global.b32   f0, [addr];     // load 32 bit which hold packed f16x2
ld.global.b32   f1, [addr + 4]; // load 32 bit which hold packed f16x2
fma.rn.f16x2    f2, f0, f1, f1; // SIMD f16x2 fused multiply-add

// SIMD bf16 fused multiply-add
fma.rn.bf16x2       f2, f0, f1, f1; // SIMD bf16x2 fused multiply-add
fma.rn.relu.bf16x2  f2, f0, f1, f1; // SIMD bf16x2 fused multiply-add with relu
↪saturation mode
fma.rn.oob.bf16x2  f2, f0, f1, f1; // SIMD bf16x2 fused multiply-add with oob modifier
fma.rn.oob.relu.bf16x2  f2, f0, f1, f1; // SIMD bf16x2 fused multiply-add with oob
↪modifier and relu saturation mode
```

9.7.4.5 Half Precision Floating Point Instructions: neg

neg

Arithmetic negate.

Syntax

```
neg{.ftz}.f16    d, a;
neg{.ftz}.f16x2  d, a;
neg.bf16         d, a;
neg.bf16x2       d, a;
```

Description

Negate the sign of a and store the result in d.

For .f16x2 and .bf16x2 instruction type, forms input vector by extracting half word values from the source operand. Half-word operands are then negated in parallel to produce .f16x2 or .bf16x2 result in destination.

For .f16 instruction type, operands d and a have .f16 or .b16 type. For .f16x2 instruction type, operands d and a have .b32 type. For .bf16 instruction type, operands d and a have .b16 type. For .bf16x2 instruction type, operands d and a have .b32 type.

Semantics

```
if (type == f16 || type == bf16) {
    d = -a;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = -fA[i];
    }
}
```

Notes

Subnormal numbers:
By default, subnormal numbers are supported. neg.ftz.{f16, f16x2} flushes subnormal inputs and results to sign-preserving zero.

NaN inputs yield an unspecified NaN. Future implementations may comply with the IEEE 754 standard by preserving payload and modifying only the sign bit.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

neg.bf16 and neg.bf16x2 introduced in PTX ISA 7.0.

Target ISA Notes

Requires sm_53 or higher.

neg.bf16 and neg.bf16x2 requires architecture sm_80 or higher.

Examples

```
neg.ftz.f16  x,f0;
neg.bf16     x,b0;
neg.bf16x2   x1,b1;
```

9.7.4.6 Half Precision Floating Point Instructions: abs

abs

Absolute value

Syntax

```
abs{.ftz}.f16    d, a;
abs{.ftz}.f16x2  d, a;
abs.bf16         d, a;
abs.bf16x2       d, a;
```

Description

Take absolute value of a and store the result in d.

For .f16x2 and .bf16x2 instruction type, forms input vector by extracting half word values from the source operand. Absolute values of half-word operands are then computed in parallel to produce .f16x2 or .bf16x2 result in destination.

For .f16 instruction type, operands d and a have .f16 or .b16 type. For .f16x2 instruction type, operands d and a have .f16x2 or .b32 type. For .bf16 instruction type, operands d and a have .b16 type. For .bf16x2 instruction type, operands d and a have .b32 type.

Semantics

```
if (type == f16 || type == bf16) {
    d = |a|;
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    for (i = 0; i < 2; i++) {
         d[i] = |fA[i]|;
    }
}
```

Notes

Subnormal numbers:
By default, subnormal numbers are supported. `abs.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

NaN inputs yield an unspecified NaN. Future implementations may comply with the IEEE 754 standard by preserving payload and modifying only the sign bit.

PTX ISA Notes

Introduced in PTX ISA version 6.5.

`abs.bf16` and `abs.bf16x2` introduced in PTX ISA 7.0.

Target ISA Notes

Requires `sm_53` or higher.

`abs.bf16` and `abs.bf16x2` requires architecture `sm_80` or higher.

Examples

```
abs.ftz.f16  x,f0;
abs.bf16     x,b0;
abs.bf16x2   x1,b1;
```

9.7.4.7 Half Precision Floating Point Instructions: `min`

`min`

Find the minimum of two values.

Syntax

```
min{.ftz}{.NaN}{.xorsign.abs}.f16      d, a, b;
min{.ftz}{.NaN}{.xorsign.abs}.f16x2    d, a, b;
min{.NaN}{.xorsign.abs}.bf16           d, a, b;
min{.NaN}{.xorsign.abs}.bf16x2         d, a, b;
```

Description

Store the minimum of a and b in d.

For .f16x2 and .bf16x2 instruction types, input vectors are formed with half-word values from source operands. Half-word operands are then processed in parallel to store .f16x2 or .bf16x2 result in destination.

For .f16 instruction type, operands d and a have .f16 or .b16 type. For .f16x2 instruction type, operands d and a have .f16x2 or .b32 type. For .bf16 instruction type, operands d and a have .b16 type. For .bf16x2 instruction type, operands d and a have .b32 type.

If .NaN modifier is specified, then the result is canonical NaN if either of the inputs is NaN.

If .abs modifier is specified, the magnitude of destination operand d is the minimum of absolute values of both the input arguments.

If .xorsign modifier is specified, the sign bit of destination d is equal to the XOR of the sign bits of both the inputs.

Modifiers .abs and .xorsign must be specified together and .xorsign considers the sign bit of both inputs before applying .abs operation.

If the result of min is NaN then the .xorsign and .abs modifiers will be ignored.

Semantics

```
if (type == f16 || type == bf16) {
    if (.xorsign) {
        xorsign = getSignBit(a) ^ getSignBit(b);
        if (.abs) {
            a = |a|;
            b = |b|;
        }
    }
    if (isNaN(a) && isNaN(b))              d = NaN;
    if (.NaN && (isNaN(a) || isNaN(b)))    d = NaN;
    else if (isNaN(a))                     d = b;
    else if (isNaN(b))                     d = a;
    else                                   d = (a < b) ? a : b;
    if (.xorsign && !isNaN(d)) {
         setSignBit(d, xorsign);
    }
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
        if (.xorsign) {
            xorsign = getSignBit(fA[i]) ^ getSignBit(fB[i]);
            if (.abs) {
               fA[i] = |fA[i]|;
               fB[i] = |fB[i]|;
           }
        }
        if (isNaN(fA[i]) && isNaN(fB[i]))              d[i] = NaN;
        if (.NaN && (isNaN(fA[i]) || isNaN(fB[i])))    d[i] = NaN;
```

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```
        else if (isNaN(fA[i]))                          d[i] = fB[i];
        else if (isNaN(fB[i]))                          d[i] = fA[i];
        else                                            d[i] = (fA[i] < fB[i]) ? fA[i]
↪: fB[i];
        if (.xorsign && !isNaN(d[i])) {
            setSignBit(d[i], xorsign);
        }
    }
}
```

Notes

Subnormal numbers:
By default, subnormal numbers are supported. `min.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

If values of both inputs are 0.0, then +0.0 > -0.0.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

`min.xorsign` introduced in PTX ISA version 7.2.

Target ISA Notes

Requires `sm_80` or higher.

`min.xorsign.abs` support requires `sm_86` or higher.

Examples

```
min.ftz.f16       h0,h1,h2;
min.f16x2         b0,b1,b2;
// SIMD fp16 min with .NaN
min.NaN.f16x2     b0,b1,b2;
min.bf16          h0, h1, h2;
// SIMD bf16 min with NaN
min.NaN.bf16x2    b0, b1, b2;
// scalar bf16 min with xorsign.abs
min.xorsign.abs.bf16 Rd, Ra, Rb
```

9.7.4.8 Half Precision Floating Point Instructions: max

max

Find the maximum of two values.

Syntax

```
max{.ftz}{.NaN}{.xorsign.abs}.f16      d, a, b;
max{.ftz}{.NaN}{.xorsign.abs}.f16x2    d, a, b;
max{.NaN}{.xorsign.abs}.bf16           d, a, b;
max{.NaN}{.xorsign.abs}.bf16x2         d, a, b;
```

Description

Store the maximum of a and b in d.

For .f16x2 and .bf16x2 instruction types, input vectors are formed with half-word values from source operands. Half-word operands are then processed in parallel to store .f16x2 or .bf16x2 result in destination.

For .f16 instruction type, operands d and a have .f16 or .b16 type. For .f16x2 instruction type, operands d and a have .f16x2 or .b32 type. For .bf16 instruction type, operands d and a have .b16 type. For .bf16x2 instruction type, operands d and a have .b32 type.

If .NaN modifier is specified, the result is canonical NaN if either of the inputs is NaN.

If .abs modifier is specified, the magnitude of destination operand d is the maximum of absolute values of both the input arguments.

If .xorsign modifier is specified, the sign bit of destination d is equal to the XOR of the sign bits of both the inputs.

Modifiers .abs and .xorsign must be specified together and .xorsign considers the sign bit of both inputs before applying .abs operation.

If the result of max is NaN then the .xorsign and .abs modifiers will be ignored.

Semantics

```
if (type == f16 || type == bf16) {
    if (.xorsign) {
        xorsign = getSignBit(a) ^ getSignBit(b);
        if (.abs) {
            a = |a|;
            b = |b|;
        }
    }
    if (isNaN(a) && isNaN(b))              d = NaN;
    if (.NaN && (isNaN(a) || isNaN(b)))    d = NaN;
    else if (isNaN(a))                     d = b;
    else if (isNaN(b))                     d = a;
    else                                   d = (a > b) ? a : b;
    if (.xorsign && !isNaN(d)) {
```

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```
        setSignBit(d, xorsign);
    }
} else if (type == f16x2 || type == bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    for (i = 0; i < 2; i++) {
        if (.xorsign) {
            xorsign = getSignBit(fA[i]) ^ getSignBit(fB[i]);
            if (.abs) {
                fA[i] = |fA[i]|;
                fB[i] = |fB[i]|;
            }
        }
        if (isNaN(fA[i]) && isNaN(fB[i]))              d[i] = NaN;
        if (.NaN && (isNaN(fA[i]) || isNaN(fB[i])))    d[i] = NaN;
        else if (isNaN(fA[i]))                         d[i] = fB[i];
        else if (isNaN(fB[i]))                         d[i] = fA[i];
        else                                           d[i] = (fA[i] > fB[i]) ? fA[i]
↪: fB[i];
        if (.xorsign && !isNaN(fA[i])) {
            setSignBit(d[i], xorsign);
        }
    }
}
```

Notes

Subnormal numbers:
By default, subnormal numbers are supported. `max.ftz.{f16, f16x2}` flushes subnormal inputs and results to sign-preserving zero.

If values of both inputs are 0.0, then +0.0 > -0.0.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

`max.xorsign.abs` introduced in PTX ISA version 7.2.

Target ISA Notes

Requires `sm_80` or higher.

`max.xorsign.abs` support requires `sm_86` or higher.

Examples

```
max.ftz.f16       h0,h1,h2;
max.f16x2         b0,b1,b2;
// SIMD fp16 max with NaN
max.NaN.f16x2     b0,b1,b2;
// scalar f16 max with xorsign.abs
max.xorsign.abs.f16 Rd, Ra, Rb;
max.bf16          h0, h1, h2;
// scalar bf16 max and NaN
max.NaN.bf16x2    b0, b1, b2;
// SIMD bf16 max with xorsign.abs
max.xorsign.abs.bf16x2 Rd, Ra, Rb;
```

9.7.4.9 Half Precision Floating Point Instructions: tanh

tanh

Find the hyperbolic tangent of a value (in radians)

Syntax

```
tanh.approx.type d, a;

.type = {.f16, .f16x2, .bf16, .bf16x2}
```

Description

Take hyperbolic tangent value of a.

The type of operands d and a are as specified by `.type`.

For `.f16x2` or `.bf16x2` instruction type, each of the half-word operands are operated in parallel and the results are packed appropriately into a `.f16x2` or `.bf16x2`.

Semantics

```
if (.type == .f16 || .type == .bf16) {
  d = tanh(a)
} else if (.type == .f16x2 || .type == .bf16x2) {
  fA[0] = a[0:15];
  fA[1] = a[16:31];
  d[0] = tanh(fA[0])
  d[1] = tanh(fA[1])
}
```

Notes

`tanh.approx.{f16, f16x2, bf16, bf16x2}` implements an approximate hyperbolic tangent in the target format.

Results of `tanh` for various corner-case inputs are as follows:

Input	Result
-Inf	-1.0
-0.0	-0.0
+0.0	+0.0
+Inf	1.0
NaN	NaN

The maximum absolute error for `.f16` type is 2-10.987. The maximum absolute error for `.bf16` type is 2-8.

The subnormal numbers are supported.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

`tanh.approx.{bf16/bf16x2}` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_75` or higher.

`tanh.approx.{bf16/bf16x2}` requires `sm_90` or higher.

Examples

```
tanh.approx.f16    h1, h0;
tanh.approx.f16x2  hd1, hd0;
tanh.approx.bf16   b1, b0;
tanh.approx.bf16x2 hb1, hb0;
```

9.7.4.10 Half Precision Floating Point Instructions: ex2

ex2

Find the base-2 exponent of input.

Syntax

```
ex2.approx.atype     d, a;
ex2.approx.ftz.btype d, a;

.atype = { .f16,  .f16x2}
.btype = { .bf16, .bf16x2}
```

Description

Raise 2 to the power a.

The type of operands d and a are as specified by `.type`.

For `.f16x2` or `.bf16x2` instruction type, each of the half-word operands are operated in parallel and the results are packed appropriately into a `.f16x2` or `.bf16x2`.

Semantics

```
if (.type == .f16 || .type == .bf16) {
  d = 2 ^ a
} else if (.type == .f16x2 || .type == .bf16x2) {
  fA[0] = a[0:15];
  fA[1] = a[16:31];
  d[0] = 2 ^ fA[0]
  d[1] = 2 ^ fA[1]
}
```

Notes

`ex2.approx.{f16, f16x2, bf16, bf16x2}` implement a fast approximation to 2^a.

For the `.f16` type, subnormal inputs are supported. `ex2.approx.ftz.bf16` flushes subnormal inputs and results to sign-preserving zero.

Results of `ex2.approx.ftz.bf16` for various corner-case inputs are as follows:

Input	Result
-Inf	+0.0
-subnormal	+1.0
-0.0	+1.0
+0.0	+1.0
+subnormal	+1.0
+Inf	+Inf
NaN	NaN

Results of `ex2.approx.f16` for various corner-case inputs are as follows:

Input	Result
-Inf	+0.0
-0.0	+1.0
+0.0	+1.0
+Inf	+Inf
NaN	NaN

The maximum relative error for `.f16` type is 2-9.9. The maximum relative error for `.bf16` type is 2-7.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

`ex2.approx.ftz.{bf16/bf16x2}` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_75` or higher.

`ex2.approx.ftz.{bf16/bf16x2}` requires `sm_90` or higher.

Examples

```
ex2.approx.f16          h1, h0;
ex2.approx.f16x2        hd1, hd0;
ex2.approx.ftz.bf16     b1, b2;
ex2.approx.ftz.bf16x2   hb1, hb2;
```

9.7.5. Mixed Precision Floating-Point Instructions

Mixed precision floating-point instructions operate on data with varied floating point precision. Before executing the specified operation, operands with different precision needs to be converted such that all the instruction operands can be represented with a consistent floating-point precision. The register variable to be used for holding a particular operand depends upon the combination of the instruction types. Refer *Fundamental Types* and *Alternate Floating-Point Data Formats* for more details around exact register operand to be used for a given data type.

The mixed precision floating point instructions are:

- `add`
- `sub`
- `fma`

Mixed precision `add`, `sub`, `fma` support saturation of results to the range [0.0, 1.0], with `NaN` being flushed to positive zero.

9.7.5.1 Mixed Precision Floating Point Instructions: add

add

Add 2 values.

Syntax

```
add{.rnd}{.sat}.f32.atype  d, a, c;

.atype = { .f16, .bf16};
.rnd   = { .rn, .rz, .rm, .rp };
```

Description

Converts input operand `a` from `.atype` into `.f32` type. The converted value is then used for the addition. The resulting value is stored in the destination operand `d`.

Semantics

```
d = convert(a) + c;
```

Notes

Rounding modifiers:

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

The default value of rounding modifier is `.rn`. Note that an `add` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. An `add` instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul`/`add` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:
By default, subnormal numbers are supported.

Saturation modifier:
`add.sat` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

`add.f32.{f16/bf16}` introduced in PTX ISA version 8.6.

Target ISA Notes

`add.f32.{f16/bf16}` requires `sm_100` or higher.

Examples

```
.reg .f32 fc, fd;
.reg .b16 ba;
add.rz.f32.bf16.sat   fd, fa, fc;
```

9.7.5.2 Mixed Precision Floating Point Instructions: sub

sub

Subtract one value from another.

Syntax

```
sub{.rnd}{.sat}.f32.atype  d, a, c;

.atype = { .f16, .bf16};
.rnd   = { .rn, .rz, .rm, .rp };
```

Description

Converts input operand `a` from `.atype` into `.f32` type. The converted value is then used for the subtraction. The resulting value is stored in the destination operand `d`.

Semantics

```
d = convert(a) - c;
```

Notes

Rounding modifiers:

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

The default value of rounding modifier is `.rn`. Note that an `sub` instruction with an explicit rounding modifier is treated conservatively by the code optimizer. An `sub` instruction with no rounding modifier defaults to round-to-nearest-even and may be optimized aggressively by the code optimizer. In particular, `mul`/`sub` sequences with no rounding modifiers may be optimized to use fused-multiply-add instructions on the target device.

Subnormal numbers:
By default, subnormal numbers are supported.

Saturation modifier:
`sub.sat` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

`sub.f32.{f16/bf16}` introduced in PTX ISA version 8.6.

Target ISA Notes

`sub.f32.{f16/bf16}` requires `sm_100` or higher.

Examples

```
.reg .f32 fc, fd;
.reg .f16 ha;
sub.rz.f32.f16.sat   fd, ha, fc;
```

9.7.5.3 Mixed Precision Floating Point Instructions: `fma`

`fma`

Fused multiply-add.

Syntax

```
fma.rnd{.ftz}{.sat}.f32.abtype  d, a, b, c;

.abtype = { .f16, .bf16};
.rnd    = { .rn, .rz, .rm, .rp };
```

Description

Converts input operands `a` and `b` from `.atype` into `.f32` type. The converted values are then used to perform fused multiply-add operation with no loss of precision in the intermediate product and addition. The resulting value is stored in the destination operand `d`.

Semantics

```
d = convert(a) * convert(b) + c;
```

Notes

`fma.f32.{f16/bf16}` computes the product of `a` and `b` to infinite precision and then adds `c` to this product, again in infinite precision. The resulting value is then rounded to single precision using the rounding mode specified by `.rnd`.

Rounding modifiers(no default):

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

`.rp` mantissa LSB rounds towards positive infinity

Subnormal numbers:
By default, subnormal numbers are supported.

Saturation modifier:
`fma.sat` clamps the result to [0.0, 1.0]. `NaN` results are flushed to `+0.0f`.

PTX ISA Notes

`fma.f32.{f16/bf16}` introduced in PTX ISA version 8.6.

Target ISA Notes

`fma.f32.{f16/bf16}` requires `sm_100` or higher.

Examples

```
.reg .f32 fc, fd;
.reg .f16 ha, hb;
fma.rz.sat.f32.f16.sat   fd, ha, hb, fc;
```

9.7.6. Comparison and Selection Instructions

The comparison select instructions are:

- `set`
- `setp`
- `selp`
- `slct`

As with single-precision floating-point instructions, the `set`, `setp`, and `slct` instructions support subnormal numbers for `sm_20` and higher targets and flush single-precision subnormal inputs to sign-preserving zero for `sm_1x` targets. The optional `.ftz` modifier provides backward compatibility with `sm_1x` targets by flushing subnormal inputs and results to sign-preserving zero regardless of the target architecture.

9.7.6.1 Comparison and Selection Instructions: `set`

`set`

Compare two numeric values with a relational operator, and optionally combine this result with a predicate value by applying a Boolean operator.

Syntax

```
set.CmpOp{.ftz}.dtype.stype         d, a, b;
set.CmpOp.BoolOp{.ftz}.dtype.stype  d, a, b, {!}c;

.CmpOp  = { eq, ne, lt, le, gt, ge, lo, ls, hi, hs,
            equ, neu, ltu, leu, gtu, geu, num, nan };
.BoolOp = { and, or, xor };
.dtype  = { .u32, .s32, .f32 };
.stype  = { .b16, .b32, .b64,
            .u16, .u32, .u64,
            .s16, .s32, .s64,
                  .f32, .f64 };
```

Description

Compares two numeric values and optionally combines the result with another predicate value by applying a Boolean operator. If this result is `True`, `1.0f` is written for floating-point destination types, and `0xffffffff` is written for integer destination types. Otherwise, `0x00000000` is written.

Operand `d` has type `.dtype`; operands `a` and `b` have type `.stype`; operand `c` has type `.pred`.

Semantics

```
t = (a CmpOp b) ? 1 : 0;
if (isFloat(dtype))
    d = BoolOp(t, c) ? 1.0f : 0x00000000;
else
    d = BoolOp(t, c) ? 0xffffffff : 0x00000000;
```

Integer Notes

The signed and unsigned comparison operators are `eq`, `ne`, `lt`, `le`, `gt`, `ge`.

For unsigned values, the comparison operators `lo`, `ls`, `hi`, and `hs` for lower, lower-or-same, higher, and higher-or-same may be used instead of `lt`, `le`, `gt`, `ge`, respectively.

The untyped, bit-size comparisons are `eq` and `ne`.

Floating Point Notes

The ordered comparisons are `eq`, `ne`, `lt`, `le`, `gt`, `ge`. If either operand is `NaN`, the result is `False`.

To aid comparison operations in the presence of `NaN` values, unordered versions are included: `equ`, `neu`, `ltu`, `leu`, `gtu`, `geu`. If both operands are numeric values (not `NaN`), then these comparisons have the same result as their ordered counterparts. If either operand is `NaN`, then the result of these comparisons is `True`.

`num` returns `True` if both operands are numeric values (not `NaN`), and `nan` returns `True` if either operand is `NaN`.

Subnormal numbers:

`sm_20+`
: By default, subnormal numbers are supported.

  `set.ftz.dtype.f32` flushes subnormal inputs to sign-preserving zero.

`sm_1x`
: `set.dtype.f64` supports subnormal numbers.

  `set.dtype.f32` flushes subnormal inputs to sign-preserving zero.

Modifier `.ftz` applies only to `.f32` comparisons.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`set` with `.f64` source type requires `sm_13` or higher.

Examples

```
@p  set.lt.and.f32.s32  d,a,b,r;
    set.eq.u32.u32      d,i,n;
```

9.7.6.2 Comparison and Selection Instructions: `setp`

`setp`

Compare two numeric values with a relational operator, and (optionally) combine this result with a predicate value by applying a Boolean operator.

Syntax

```
setp.CmpOp{.ftz}.type         p[|q], a, b;
setp.CmpOp.BoolOp{.ftz}.type  p[|q], a, b, {!}c;

.CmpOp  = { eq, ne, lt, le, gt, ge, lo, ls, hi, hs,
            equ, neu, ltu, leu, gtu, geu, num, nan };
.BoolOp = { and, or, xor };
.type   = { .b16, .b32, .b64,
            .u16, .u32, .u64,
            .s16, .s32, .s64,
                  .f32, .f64 };
```

Description

Compares two values and combines the result with another predicate value by applying a Boolean operator. This result is written to the first destination operand. A related value computed using the complement of the compare result is written to the second destination operand.

Applies to all numeric types. Operands `a` and `b` have type `.type`; operands `p`, `q`, and `c` have type `.pred`. The sink symbol '_' may be used in place of any one of the destination operands.

Semantics

```
t = (a CmpOp b) ? 1 : 0;
p = BoolOp(t, c);
q = BoolOp(!t, c);
```

Integer Notes

The signed and unsigned comparison operators are `eq`, `ne`, `lt`, `le`, `gt`, `ge`.

For unsigned values, the comparison operators `lo`, `ls`, `hi`, and `hs` for lower, lower-or-same, higher, and higher-or-same may be used instead of `lt`, `le`, `gt`, `ge`, respectively.

The untyped, bit-size comparisons are `eq` and `ne`.

Floating Point Notes

The ordered comparisons are `eq`, `ne`, `lt`, `le`, `gt`, `ge`. If either operand is `NaN`, the result is `False`.

To aid comparison operations in the presence of `NaN` values, unordered versions are included: `equ`, `neu`, `ltu`, `leu`, `gtu`, `geu`. If both operands are numeric values (not `NaN`), then these comparisons have the same result as their ordered counterparts. If either operand is `NaN`, then the result of these comparisons is `True`.

`num` returns `True` if both operands are numeric values (not `NaN`), and `nan` returns `True` if either operand is `NaN`.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `setp.ftz.dtype.f32` flushes subnormal inputs to sign-preserving zero.

sm_1x
: `setp.dtype.f64` supports subnormal numbers.

  `setp.dtype.f32` flushes subnormal inputs to sign-preserving zero.

Modifier `.ftz` applies only to `.f32` comparisons.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`setp` with `.f64` source type requires `sm_13` or higher.

Examples

```
    setp.lt.and.s32  p|q,a,b,r;
@q  setp.eq.u32      p,i,n;
```

9.7.6.3 Comparison and Selection Instructions: selp

selp

Select between source operands, based on the value of the predicate source operand.

Syntax

```
selp.type d, a, b, c;

.type = { .b16, .b32, .b64,
          .u16, .u32, .u64,
          .s16, .s32, .s64,
                .f32, .f64 };
```

Description

Conditional selection. If c is True, a is stored in d, b otherwise. Operands d, a, and b must be of the same type. Operand c is a predicate.

Semantics

```
d = (c == 1) ? a : b;
```

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

selp.f64 requires sm_13 or higher.

Examples

```
    selp.s32  r0,r,g,p;
@q  selp.f32  f0,t,x,xp;
```

9.7.6.4 Comparison and Selection Instructions: `slct`

`slct`

Select one source operand, based on the sign of the third operand.

Syntax

```
slct.dtype.s32         d, a, b, c;
slct{.ftz}.dtype.f32   d, a, b, c;

.dtype = { .b16, .b32, .b64,
           .u16, .u32, .u64,
           .s16, .s32, .s64,
                 .f32, .f64 };
```

Description

Conditional selection. If c >= 0, a is stored in d, otherwise b is stored in d. Operands d, a, and b are treated as a bitsize type of the same width as the first instruction type; operand c must match the second instruction type (`.s32` or `.f32`). The selected input is copied to the output without modification.

Semantics

```
d = (c >= 0) ? a : b;
```

Floating Point Notes

For `.f32` comparisons, negative zero equals zero.

Subnormal numbers:

sm_20+
: By default, subnormal numbers are supported.

  `slct.ftz.dtype.f32` flushes subnormal values of operand c to sign-preserving zero, and operand a is selected.

sm_1x
: `slct.dtype.f32` flushes subnormal values of operand c to sign-preserving zero, and operand a is selected.

Modifier `.ftz` applies only to `.f32` comparisons.

If operand c is NaN, the comparison is unordered and operand b is selected.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`slct.f64` requires `sm_13` or higher.

Examples

```
slct.u32.s32  x, y, z, val;
slct.ftz.u64.f32  A, B, C, fval;
```

9.7.7. Half Precision Comparison Instructions

The comparison instructions are:

- `set`
- `setp`

9.7.7.1 Half Precision Comparison Instructions: `set`

`set`

Compare two numeric values with a relational operator, and optionally combine this result with a predicate value by applying a Boolean operator.

Syntax

```
set.CmpOp{.ftz}.f16.stype            d, a, b;
set.CmpOp.BoolOp{.ftz}.f16.stype     d, a, b, {!}c;

set.CmpOp.bf16.stype                 d, a, b;
set.CmpOp.BoolOp.bf16.stype          d, a, b, {!}c;

set.CmpOp{.ftz}.dtype.f16            d, a, b;
set.CmpOp.BoolOp{.ftz}.dtype.f16     d, a, b, {!}c;
.dtype  = { .u16, .s16, .u32, .s32}

set.CmpOp.dtype.bf16                 d, a, b;
set.CmpOp.BoolOp.dtype.bf16          d, a, b, {!}c;
.dtype  = { .u16, .s16, .u32, .s32}

set.CmpOp{.ftz}.dtype.f16x2          d, a, b;
set.CmpOp.BoolOp{.ftz}.dtype.f16x2   d, a, b, {!}c;
.dtype  = { .f16x2, .u32, .s32}
```

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```
set.CmpOp.dtype.bf16x2               d, a, b;
set.CmpOp.BoolOp.dtype.bf16x2        d, a, b, {!}c;
.dtype  = { .bf16x2, .u32, .s32}

.CmpOp  = { eq, ne, lt, le, gt, ge,
            equ, neu, ltu, leu, gtu, geu, num, nan };
.BoolOp = { and, or, xor };
.stype  = { .b16, .b32, .b64,
            .u16, .u32, .u64,
            .s16, .s32, .s64,
            .f16, .f32, .f64};
```

Description

Compares two numeric values and optionally combines the result with another predicate value by applying a Boolean operator.

Result of this computation is written in destination register in the following way:

- If result is `True`,
  - `0xffffffff` is written for destination types `.u32`/`.s32`.
  - `0xffff` is written for destination types `.u16`/`.s16`.
  - `1.0` in target precision floating point format is written for destination type `.f16`, `.bf16`.
- If result is `False`,
  - `0x0` is written for all integer destination types.
  - `0.0` in target precision floating point format is written for destination type `.f16`, `.bf16`.

If the source type is `.f16x2` or `.bf16x2` then result of individual operations are packed in the 32-bit destination operand.

Operand `c` has type `.pred`.

Semantics

```
if (stype == .f16x2 || stype == .bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    t[0]   = (fA[0] CmpOp fB[0]) ? 1 : 0;
    t[1]   = (fA[1] CmpOp fB[1]) ? 1 : 0;
    if (dtype == .f16x2 || stype == .bf16x2) {
        for (i = 0; i < 2; i++) {
            d[i] = BoolOp(t[i], c) ? 1.0 : 0.0;
        }
    } else {
        for (i = 0; i < 2; i++) {
            d[i] = BoolOp(t[i], c) ? 0xffff : 0;
        }
    }
```

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```
} else if (dtype == .f16 || stype == .bf16) {
    t = (a CmpOp b) ? 1 : 0;
    d = BoolOp(t, c) ? 1.0 : 0.0;
} else  { // Integer destination type
    trueVal = (isU16(dtype) || isS16(dtype)) ?  0xffff : 0xffffffff;
    t = (a CmpOp b) ? 1 : 0;
    d = BoolOp(t, c) ? trueVal : 0;
}
```

Floating Point Notes

The ordered comparisons are `eq`, `ne`, `lt`, `le`, `gt`, `ge`. If either operand is `NaN`, the result is `False`.

To aid comparison operations in the presence of `NaN` values, unordered versions are included: `equ`, `neu`, `ltu`, `leu`, `gtu`, `geu`. If both operands are numeric values (not `NaN`), then these comparisons have the same result as their ordered counterparts. If either operand is `NaN`, then the result of these comparisons is `True`.

`num` returns `True` if both operands are numeric values (not `NaN`), and `nan` returns `True` if either operand is `NaN`.

Subnormal numbers:

By default, subnormal numbers are supported.

When `.ftz` modifier is specified then subnormal inputs and results are flushed to sign preserving zero.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

`set.{u16, u32, s16, s32}.f16` and `set.{u32, s32}.f16x2` are introduced in PTX ISA version 6.5.

`set.{u16, u32, s16, s32}.bf16`, `set.{u32, s32, bf16x2}.bf16x2`, `set.bf16.{s16,u16, f16,b16,s32,u32,f32,b32,s64,u64,f64,b64}` are introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_53` or higher.

`set.{u16, u32, s16, s32}.bf16`, `set.{u32, s32, bf16x2}.bf16x2`, `set.bf16.{s16,u16, f16,b16,s32,u32,f32,b32,s64,u64,f64,b64}` require `sm_90` or higher.

Examples

```
set.lt.and.f16.f16  d,a,b,r;
set.eq.f16x2.f16x2  d,i,n;
set.eq.u32.f16x2    d,i,n;
set.lt.and.u16.f16  d,a,b,r;
set.ltu.or.bf16.f16    d,u,v,s;
set.equ.bf16x2.bf16x2  d,j,m;
set.geu.s32.bf16x2     d,j,m;
set.num.xor.s32.bf16   d,u,v,s;
```

9.7.7.2 Half Precision Comparison Instructions: `setp`

`setp`

Compare two numeric values with a relational operator, and optionally combine this result with a predicate value by applying a Boolean operator.

Syntax

```
setp.CmpOp{.ftz}.f16           p, a, b;
setp.CmpOp.BoolOp{.ftz}.f16    p, a, b, {!}c;

setp.CmpOp{.ftz}.f16x2         p|q, a, b;
setp.CmpOp.BoolOp{.ftz}.f16x2  p|q, a, b, {!}c;

setp.CmpOp.bf16                p, a, b;
setp.CmpOp.BoolOp.bf16         p, a, b, {!}c;

setp.CmpOp.bf16x2              p|q, a, b;
setp.CmpOp.BoolOp.bf16x2       p|q, a, b, {!}c;

.CmpOp  = { eq, ne, lt, le, gt, ge,
            equ, neu, ltu, leu, gtu, geu, num, nan };
.BoolOp = { and, or, xor };
```

Description

Compares two values and combines the result with another predicate value by applying a Boolean operator. This result is written to the destination operand.

Operand c, p and q has type `.pred`.

For instruction type `.f16`, operands a and b have type `.b16` or `.f16`.

For instruction type `.f16x2`, operands a and b have type `.b32`.

For instruction type `.bf16`, operands a and b have type `.b16`.

For instruction type `.bf16x2`, operands a and b have type `.b32`.

Semantics

```
if (type == .f16 || type == .bf16) {
     t = (a CmpOp b) ? 1 : 0;
     p = BoolOp(t, c);
} else if (type == .f16x2 || type == .bf16x2) {
    fA[0] = a[0:15];
    fA[1] = a[16:31];
    fB[0] = b[0:15];
    fB[1] = b[16:31];
    t[0] = (fA[0] CmpOp fB[0]) ? 1 : 0;
    t[1] = (fA[1] CmpOp fB[1]) ? 1 : 0;
    p = BoolOp(t[0], c);
    q = BoolOp(t[1], c);
}
```

Floating Point Notes

The ordered comparisons are `eq`, `ne`, `lt`, `le`, `gt`, `ge`. If either operand is `NaN`, the result is `False`.

To aid comparison operations in the presence of `NaN` values, unordered versions are included: `equ`, `neu`, `ltu`, `leu`, `gtu`, `geu`. If both operands are numeric values (not `NaN`), then these comparisons have the same result as their ordered counterparts. If either operand is `NaN`, then the result of these comparisons is `True`.

`num` returns `True` if both operands are numeric values (not `NaN`), and `nan` returns `True` if either operand is `NaN`.

Subnormal numbers:

By default, subnormal numbers are supported.

`setp.ftz.{f16,f16x2}` flushes subnormal inputs to sign-preserving zero.

PTX ISA Notes

Introduced in PTX ISA version 4.2.

`setp.{bf16/bf16x2}` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_53` or higher.

`setp.{bf16/bf16x2}` requires `sm_90` or higher.

Examples

```
setp.lt.and.f16x2  p|q,a,b,r;
@q  setp.eq.f16    p,i,n;

setp.gt.or.bf16x2  u|v,c,d,s;
@q  setp.eq.bf16   u,j,m;
```

9.7.8. Logic and Shift Instructions

The logic and shift instructions are fundamentally untyped, performing bit-wise operations on operands of any type, provided the operands are of the same size. This permits bit-wise operations on floating point values without having to define a union to access the bits. Instructions `and`, `or`, `xor`, and `not` also operate on predicates.

The logical shift instructions are:

- `and`
- `or`
- `xor`
- `not`
- `cnot`
- `lop3`
- `shf`
- `shl`
- `shr`

9.7.8.1 Logic and Shift Instructions: and

and

Bitwise AND.

Syntax

```
and.type d, a, b;

.type = { .pred, .b16, .b32, .b64 };
```

Description

Compute the bit-wise and operation for the bits in a and b.

Semantics

```
d = a & b;
```

Notes

The size of the operands must match, but not necessarily the type.

Allowed types include predicate registers.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
and.b32  x,q,r;
and.b32  sign,fpvalue,0x80000000;
```

9.7.8.2 Logic and Shift Instructions: or

or

Biwise OR.

Syntax

```
or.type d, a, b;

.type = { .pred, .b16, .b32, .b64 };
```

Description

Compute the bit-wise or operation for the bits in a and b.

Semantics

```
d = a | b;
```

Notes

The size of the operands must match, but not necessarily the type.

Allowed types include predicate registers.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
or.b32  mask mask,0x00010001
or.pred  p,q,r;
```

9.7.8.3 Logic and Shift Instructions: xor

xor

Bitwise exclusive-OR (inequality).

Syntax

```
xor.type d, a, b;

.type = { .pred, .b16, .b32, .b64 };
```

Description

Compute the bit-wise exclusive-or operation for the bits in a and b.

Semantics

```
d = a ^ b;
```

Notes

The size of the operands must match, but not necessarily the type.

Allowed types include predicate registers.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
xor.b32  d,q,r;
xor.b16  d,x,0x0001;
```

9.7.8.4 Logic and Shift Instructions: not

not

Bitwise negation; one's complement.

Syntax

```
not.type d, a;

.type = { .pred, .b16, .b32, .b64 };
```

Description

Invert the bits in a.

Semantics

```
d = ~a;
```

Notes

The size of the operands must match, but not necessarily the type.

Allowed types include predicates.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
not.b32  mask,mask;
not.pred  p,q;
```

9.7.8.5 Logic and Shift Instructions: cnot

cnot

C/C++ style logical negation.

Syntax

```
cnot.type d, a;

.type = { .b16, .b32, .b64 };
```

Description

Compute the logical negation using C/C++ semantics.

Semantics

```
d = (a==0) ? 1 : 0;
```

Notes

The size of the operands must match, but not necessarily the type.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
cnot.b32 d,a;
```

9.7.8.6 Logic and Shift Instructions: lop3

lop3

Arbitrary logical operation on 3 inputs.

Syntax

```
lop3.b32 d, a, b, c, immLut;
lop3.BoolOp.b32 d|p, a, b, c, immLut, q;

.BoolOp   = { .or , .and };
```

Description

Compute bitwise logical operation on inputs a, b, c and store the result in destination d.

Optionally, `.BoolOp` can be specified to compute the predicate result p by performing a Boolean operation on the destination operand d with the predicate q in the following manner:

```
p = (d != 0) BoolOp q;
```

The sink symbol '_' may be used in place of the destination operand d when `.BoolOp` qualifier is specified.

The logical operation is defined by a look-up table which, for 3 inputs, can be represented as an 8-bit value specified by operand `immLut` as described below. `immLut` is an integer constant that can take values from 0 to 255, thereby allowing up to 256 distinct logical operations on inputs a, b, c.

For a logical operation `F(a, b, c)` the value of `immLut` can be computed by applying the same operation to three predefined constant values as follows:

```
ta = 0xF0;
tb = 0xCC;
tc = 0xAA;

immLut = F(ta, tb, tc);
```

Examples:

```
If F = (a & b & c);
immLut = 0xF0 & 0xCC & 0xAA = 0x80

If F = (a | b | c);
immLut = 0xF0 | 0xCC | 0xAA = 0xFE

If F = (a & b & ~c);
immLut = 0xF0 & 0xCC & (~0xAA) = 0x40

If F = ((a & b | c) ^ a);
immLut = (0xF0 & 0xCC | 0xAA) ^ 0xF0 = 0x1A
```

The following table illustrates computation of `immLut` for various logical operations:

ta	tb	tc	Oper 0 (False)	Oper 1 (ta & tb & tc)	Oper 2 (ta & tb & ~tc)	...	Oper 254 (ta | tb | tc)	Oper 255 (True)
0	0	0	0	0	0	...	0	1
0	0	1	0	0	0		1	1
0	1	0	0	0	0		1	1
0	1	1	0	0	0		1	1
1	0	0	0	0	0		1	1
1	0	1	0	0	0		1	1
1	1	0	0	0	1		1	1
1	1	1	0	1	0		1	1
immLut			**0x0**	**0x80**	**0x40**	**...**	**0xFE**	**0xFF**

Semantics

```
F = GetFunctionFromTable(immLut); // returns the function corresponding to immLut
↪value
d = F(a, b, c);
if (BoolOp specified) {
    p = (d != 0) BoolOp q;
}
```

PTX ISA Notes

Introduced in PTX ISA version 4.3.

Support for `.BoolOp` qualifier introduced in PTX ISA version 8.2.

Target ISA Notes

Requires `sm_50` or higher.

Qualifier `.BoolOp` requires `sm_70` or higher.

Examples

```
lop3.b32       d, a, b, c, 0x40;
lop3.or.b32  d|p, a, b, c, 0x3f, q;
lop3.and.b32 _|p, a, b, c, 0x3f, q;
```

9.7.8.7 Logic and Shift Instructions: shf

shf

Funnel shift.

Syntax

```
shf.l.mode.b32  d, a, b, c;  // left shift
shf.r.mode.b32  d, a, b, c;  // right shift

.mode = { .clamp, .wrap };
```

Description

Shift the 64-bit value formed by concatenating operands a and b left or right by the amount specified by the unsigned 32-bit value in c. Operand b holds bits 63:32 and operand a holds bits 31:0 of the 64-bit source value. The source is shifted left or right by the clamped or wrapped value in c. For shf.l, the most-significant 32-bits of the result are written into d; for shf.r, the least-significant 32-bits of the result are written into d.

Semantics

```
u32  n = (.mode == .clamp) ? min(c, 32) : c & 0x1f;
switch (shf.dir) {  // shift concatenation of [b, a]
    case shf.l:     // extract 32 msbs
           u32  d = (b << n)      | (a >> (32-n));
    case shf.r:     // extract 32 lsbs
           u32  d = (b << (32-n)) | (a >> n);
}
```

Notes

Use funnel shift for multi-word shift operations and for rotate operations. The shift amount is limited to the range 0..32 in clamp mode and 0..31 in wrap mode, so shifting multi-word values by distances greater than 32 requires first moving 32-bit words, then using shf to shift the remaining 0..31 distance.

To shift data sizes greater than 64 bits to the right, use repeated shf.r instructions applied to adjacent words, operating from least-significant word towards most-significant word. At each step, a single word of the shifted result is computed. The most-significant word of the result is computed using a shr.{u32,s32} instruction, which zero or sign fills based on the instruction type.

To shift data sizes greater than 64 bits to the left, use repeated shf.l instructions applied to adjacent words, operating from most-significant word towards least-significant word. At each step, a single word of the shifted result is computed. The least-significant word of the result is computed using a shl instruction.

Use funnel shift to perform 32-bit left or right rotate by supplying the same value for source arguments a and b.

PTX ISA Notes

Introduced in PTX ISA version 3.1.

Target ISA Notes

Requires sm_32 or higher.

Example

```
shf.l.clamp.b32  r3,r1,r0,16;

// 128-bit left shift; n < 32
// [r7,r6,r5,r4] = [r3,r2,r1,r0] << n
shf.l.clamp.b32  r7,r2,r3,n;
shf.l.clamp.b32  r6,r1,r2,n;
shf.l.clamp.b32  r5,r0,r1,n;
shl.b32          r4,r0,n;

// 128-bit right shift, arithmetic; n < 32
// [r7,r6,r5,r4] = [r3,r2,r1,r0] >> n
shf.r.clamp.b32  r4,r0,r1,n;
shf.r.clamp.b32  r5,r1,r2,n;
shf.r.clamp.b32  r6,r2,r3,n;
shr.s32          r7,r3,n;     // result is sign-extended

shf.r.clamp.b32  r1,r0,r0,n;  // rotate right by n; n < 32
shf.l.clamp.b32  r1,r0,r0,n;  // rotate left by n; n < 32

// extract 32-bits from [r1,r0] starting at position n < 32
shf.r.clamp.b32  r0,r0,r1,n;
```

9.7.8.8 Logic and Shift Instructions: shl

shl

Shift bits left, zero-fill on right.

Syntax

```
shl.type d, a, b;

.type = { .b16, .b32, .b64 };
```

Description

Shift a left by the amount specified by unsigned 32-bit value in b.

Semantics

```
d = a << b;
```

Notes

Shift amounts greater than the register width *N* are clamped to *N*.

The sizes of the destination and first source operand must match, but not necessarily the type. The b operand must be a 32-bit value, regardless of the instruction type.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Example

```
shl.b32  q,a,2;
```

9.7.8.9 Logic and Shift Instructions: shr

shr

Shift bits right, sign or zero-fill on left.

Syntax

```
shr.type d, a, b;

.type = { .b16, .b32, .b64,
          .u16, .u32, .u64,
          .s16, .s32, .s64 };
```

Description

Shift a right by the amount specified by unsigned 32-bit value in b. Signed shifts fill with the sign bit, unsigned and untyped shifts fill with 0.

Semantics

```
d = a >> b;
```

Notes

Shift amounts greater than the register width *N* are clamped to *N*.

The sizes of the destination and first source operand must match, but not necessarily the type. The b operand must be a 32-bit value, regardless of the instruction type.

Bit-size types are included for symmetry with shl.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Example

```
shr.u16  c,a,2;
shr.s32  i,i,1;
shr.b16  k,i,j;
```

9.7.9. Data Movement and Conversion Instructions

These instructions copy data from place to place, and from state space to state space, possibly converting it from one format to another. mov, ld, ldu, and st operate on both scalar and vector types. The isspacep instruction is provided to query whether a generic address falls within a particular state space window. The cvta instruction converts addresses between generic and const, global, local, or shared state spaces.

Instructions ld, st, suld, and sust support optional cache operations.

The Data Movement and Conversion Instructions are:

- mov
- shfl.sync
- prmt

- ld
- ldu
- st
- st.async
- st.bulk
- multimem.ld_reduce, multimem.st, multimem.red
- prefetch, prefetchu
- isspacep
- cvta
- cvt
- cvt.pack
- cp.async
- cp.async.commit_group
- cp.async.wait_group, cp.async.wait_all
- cp.async.bulk
- cp.reduce.async.bulk
- cp.async.bulk.prefetch
- cp.async.bulk.tensor
- cp.reduce.async.bulk.tensor
- cp.async.bulk.prefetch.tensor
- cp.async.bulk.commit_group
- cp.async.bulk.wait_group
- tensormap.replace

9.7.9.1 Cache Operators

PTX ISA version 2.0 introduced optional cache operators on load and store instructions. The cache operators require a target architecture of sm_20 or higher.

Cache operators on load or store instructions are treated as performance hints only. The use of a cache operator on an ld or st instruction does not change the memory consistency behavior of the program.

For sm_20 and higher, the cache operators have the following definitions and behavior.

Table 31: Cache Operators for Memory Load Instructions

Operator	Meaning
.ca	Cache at all levels, likely to be accessed again. The default load instruction cache operation is ld.ca, which allocates cache lines in all levels (L1 and L2) with normal eviction policy. Global data is coherent at the L2 level, but multiple L1 caches are not coherent for global data. If one thread stores to global memory via one L1 cache, and a second thread loads that address via a second L1 cache with ld.ca, the second thread may get stale L1 cache data, rather than the data stored by the first thread. The driver must invalidate global L1 cache lines between dependent grids of parallel threads. Stores by the first grid program are then correctly fetched by the second grid program issuing default ld.ca loads cached in L1.
.cg	Cache at global level (cache in L2 and below, not L1). Use ld.cg to cache loads only globally, bypassing the L1 cache, and cache only in the L2 cache.
.cs	Cache streaming, likely to be accessed once. The ld.cs load cached streaming operation allocates global lines with evict-first policy in L1 and L2 to limit cache pollution by temporary streaming data that may be accessed once or twice. When ld.cs is applied to a Local window address, it performs the ld.lu operation.
.lu	Last use. The compiler/programmer may use ld.lu when restoring spilled registers and popping function stack frames to avoid needless write-backs of lines that will not be used again. The ld.lu instruction performs a load cached streaming operation (ld.cs) on global addresses.
.cv	Don't cache and fetch again (consider cached system memory lines stale, fetch again). The ld.cv load operation applied to a global System Memory address invalidates (discards) a matching L2 line and re-fetches the line on each new load.

Table 32: Cache Operators for Memory Store Instructions

Operator	Meaning
.wb	Cache write-back all coherent levels. The default store instruction cache operation is st.wb, which writes back cache lines of coherent cache levels with normal eviction policy. If one thread stores to global memory, bypassing its L1 cache, and a second thread in a different SM later loads from that address via a different L1 cache with ld.ca, the second thread may get a hit on stale L1 cache data, rather than get the data from L2 or memory stored by the first thread. The driver must invalidate global L1 cache lines between dependent grids of thread arrays. Stores by the first grid program are then correctly missed in L1 and fetched by the second grid program issuing default ld.ca loads.
.cg	Cache at global level (cache in L2 and below, not L1). Use st.cg to cache global store data only globally, bypassing the L1 cache, and cache only in the L2 cache.
.cs	Cache streaming, likely to be accessed once. The st.cs store cached-streaming operation allocates cache lines with evict-first policy to limit cache pollution by streaming output data.
.wt	Cache write-through (to system memory). The st.wt store write-through operation applied to a global System Memory address writes through the L2 cache.

9.7.9.2 Cache Eviction Priority Hints

PTX ISA version 7.4 adds optional cache eviction priority hints on load and store instructions. Cache eviction priority requires target architecture sm_70 or higher.

Cache eviction priority on load or store instructions is treated as a performance hint. It is supported for .global state space and generic addresses where the address points to .global state space.

Table 33: Cache Eviction Priority Hints for Memory Load and Store Instructions

Cache Eviction Priority	Meaning
evict_normal	Cache data with normal eviction priority. This is the default eviction priority.
evict_first	Data cached with this priority will be first in the eviction priority order and will likely be evicted when cache eviction is required. This priority is suitable for streaming data.
evict_last	Data cached with this priority will be last in the eviction priority order and will likely be evicted only after other data with evict_normal or evict_first eviction priotity is already evicted. This priority is suitable for data that should remain persistent in cache.
evict_unchanged	Do not change eviction priority order as part of this operation.
no_allocate	Do not allocate data to cache. This priority is suitable for streaming data.

9.7.9.3 Data Movement and Conversion Instructions: mov

mov

Set a register variable with the value of a register variable or an immediate value. Take the non-generic address of a variable in global, local, or shared state space.

Syntax

```
mov.type  d, a;
mov.type  d, sreg;
mov.type  d, avar;       // get address of variable
mov.type  d, avar+imm;   // get address of variable with offset
mov.u32   d, fname;      // get address of device function
mov.u64   d, fname;      // get address of device function
mov.u32   d, kernel;     // get address of entry function
mov.u64   d, kernel;     // get address of entry function

.type = { .pred,
          .b16, .b32, .b64,
          .u16, .u32, .u64,
          .s16, .s32, .s64,
                .f32, .f64 };
```

Description

Write register d with the value of a.

Operand a may be a register, special register, variable with optional offset in an addressable memory space, or function name.

For variables declared in .const, .global, .local, and .shared state spaces, mov places the non-generic address of the variable (i.e., the address of the variable in its state space) into the destination register. The generic address of a variable in const, global, local, or shared state space may be generated by first taking the address within the state space with mov and then converting it to a generic address using the cvta instruction; alternately, the generic address of a variable declared in const, global, local, or shared state space may be taken directly using the cvta instruction.

Note that if the address of a device function parameter is moved to a register, the parameter will be copied onto the stack and the address will be in the local state space.

Semantics

```
d = a;
d = sreg;
d = &avar;        // address is non-generic; i.e., within the variable's declared
↪state space
d = &avar+imm;
```

Notes

- Although only predicate and bit-size types are required, we include the arithmetic types for the programmer's convenience: their use enhances program readability and allows additional type checking.
- When moving address of a kernel or a device function, only `.u32` or `.u64` instruction types are allowed. However, if a signed type is used, it is not treated as a compilation error. The compiler issues a warning in this case.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Taking the address of kernel entry functions requires PTX ISA version 3.1 or later. Kernel function addresses should only be used in the context of CUDA Dynamic Parallelism system calls. See the *CUDA Dynamic Parallelism Programming Guide* for details.

Target ISA Notes

`mov.f64` requires `sm_13` or higher.

Taking the address of kernel entry functions requires `sm_35` or higher.

Examples

```
mov.f32  d,a;
mov.u16  u,v;
mov.f32  k,0.1;
mov.u32  ptr, A;        // move address of A into ptr
mov.u32  ptr, A[5];     // move address of A[5] into ptr
mov.u32  ptr, A+20;     // move address with offset into ptr
mov.u32  addr, myFunc;  // get address of device function 'myFunc'
mov.u64  kptr, main;    // get address of entry function 'main'
```

9.7.9.4 Data Movement and Conversion Instructions: `mov`

`mov`

Move vector-to-scalar (pack) or scalar-to-vector (unpack).

Syntax

```
mov.type  d, a;

.type = { .b16, .b32, .b64, .b128 };
```

Description

Write scalar register d with the packed value of vector register a, or write vector register d with the unpacked values from scalar register a.

When destination operand d is a vector register, the sink symbol '_' may be used for one or more elements provided that at least one element is a scalar register.

For bit-size types, mov may be used to pack vector elements into a scalar register or unpack sub-fields of a scalar register into a vector. Both the overall size of the vector and the size of the scalar must match the size of the instruction type.

Semantics

```
// pack two 8-bit elements into .b16
d = a.x | (a.y << 8)
// pack four 8-bit elements into .b32
d = a.x | (a.y << 8)  | (a.z << 16) | (a.w << 24)
// pack two 16-bit elements into .b32
d = a.x | (a.y << 16)
// pack four 16-bit elements into .b64
d = a.x | (a.y << 16)  | (a.z << 32) | (a.w << 48)
// pack two 32-bit elements into .b64
d = a.x | (a.y << 32)
// pack four 32-bit elements into .b128
d = a.x | (a.y << 32)  | (a.z << 64) | (a.w << 96)
// pack two 64-bit elements into .b128
d = a.x | (a.y << 64)

// unpack 8-bit elements from .b16
{ d.x, d.y } = { a[0..7], a[8..15] }
// unpack 8-bit elements from .b32
{ d.x, d.y, d.z, d.w }
        { a[0..7], a[8..15], a[16..23], a[24..31] }

// unpack 16-bit elements from .b32
{ d.x, d.y }  = { a[0..15], a[16..31] }
// unpack 16-bit elements from .b64
{ d.x, d.y, d.z, d.w } =
        { a[0..15], a[16..31], a[32..47], a[48..63] }

// unpack 32-bit elements from .b64
{ d.x, d.y } = { a[0..31], a[32..63] }

// unpack 32-bit elements from .b128
{ d.x, d.y, d.z, d.w } =
        { a[0..31], a[32..63], a[64..95], a[96..127] }
// unpack 64-bit elements from .b128
{ d.x, d.y } = { a[0..63], a[64..127] }
```

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Support for `.b128` type introduced in PTX ISA version 8.3.

Target ISA Notes

Supported on all target architectures.

Support for `.b128` type requires `sm_70` or higher.

Examples

```
mov.b32 %r1,{a,b};      // a,b have type .u16
mov.b64 {lo,hi}, %x;    // %x is a double; lo,hi are .u32
mov.b32 %r1,{x,y,z,w};  // x,y,z,w have type .b8
mov.b32 {r,g,b,a},%r1;  // r,g,b,a have type .u8
mov.b64 {%r1, _}, %x;   // %x is.b64, %r1 is .b32
mov.b128 {%b1, %b2}, %y;   // %y is.b128, %b1 and % b2 are .b64
mov.b128 %y, {%b1, %b2};   // %y is.b128, %b1 and % b2 are .b64
```

9.7.9.5 Data Movement and Conversion Instructions: `shfl` (deprecated)

`shfl` (deprecated)

Register data shuffle within threads of a warp.

Syntax

```
shfl.mode.b32  d[|p], a, b, c;

.mode = { .up, .down, .bfly, .idx };
```

Deprecation Note

The `shfl` instruction without a `.sync` qualifier is deprecated in PTX ISA version 6.0.

- Support for this instruction with `.target` lower than `sm_70` may be removed in a future PTX ISA version.

Removal Note

Support for `shfl` instruction without a `.sync` qualifier is removed in PTX ISA version 6.4 for `.target sm_70` or higher.

Description

Exchange register data between threads of a warp.

Each thread in the currently executing warp will compute a source lane index *j* based on input operands `b` and `c` and the *mode*. If the computed source lane index *j* is in range, the thread will copy the input operand `a` from lane *j* into its own destination register `d`; otherwise, the thread will simply copy its own input `a` to destination `d`. The optional destination predicate `p` is set to `True` if the computed source lane is in range, and otherwise set to `False`.

Note that an out of range value of `b` may still result in a valid computed source lane index *j*. In this case, a data transfer occurs and the destination predicate `p` is True.

Note that results are undefined in divergent control flow within a warp, if an active thread sources a register from an inactive thread.

Operand `b` specifies a source lane or source lane offset, depending on the mode.

Operand `c` contains two packed values specifying a mask for logically splitting warps into sub-segments and an upper bound for clamping the source lane index.

Semantics

```
lane[4:0]  = [Thread].laneid;  // position of thread in warp
bval[4:0] = b[4:0];            // source lane or lane offset (0..31)
cval[4:0] = c[4:0];            // clamp value
mask[4:0] = c[12:8];

// get value of source register a if thread is active and
// guard predicate true, else unpredictable
if (isActive(Thread) && isGuardPredicateTrue(Thread)) {
    SourceA[lane] = a;
} else {
    // Value of SourceA[lane] is unpredictable for
    // inactive/predicated-off threads in warp
}
maxLane = (lane[4:0] & mask[4:0]) | (cval[4:0] & ~mask[4:0]);
minLane = (lane[4:0] & mask[4:0]);

switch (.mode) {
    case .up:    j = lane - bval; pval = (j >= maxLane); break;
    case .down:  j = lane + bval; pval = (j <= maxLane); break;
    case .bfly:  j = lane ^ bval; pval = (j <= maxLane); break;
    case .idx:   j = minLane  | (bval[4:0] & ~mask[4:0]);
                                  pval = (j <= maxLane); break;
}
if (!pval) j = lane;  // copy from own lane
d = SourceA[j];       // copy input a from lane j
if (dest predicate selected)
    p = pval;
```

PTX ISA Notes

Introduced in PTX ISA version 3.0.

Deprecated in PTX ISA version 6.0 in favor of `shfl.sync`.

Not supported in PTX ISA version 6.4 for .target `sm_70` or higher.

Target ISA Notes

`shfl` requires `sm_30` or higher.

`shfl` is not supported on `sm_70` or higher starting PTX ISA version 6.4.

Examples

```
    // Warp-level INCLUSIVE PLUS SCAN:
    //
    // Assumes input in following registers:
    //     - Rx  = sequence value for this thread
    //
    shfl.up.b32  Ry|p, Rx, 0x1,  0x0;
@p  add.f32      Rx, Ry, Rx;
    shfl.up.b32  Ry|p, Rx, 0x2,  0x0;
@p  add.f32      Rx, Ry, Rx;
    shfl.up.b32  Ry|p, Rx, 0x4,  0x0;
@p  add.f32      Rx, Ry, Rx;
    shfl.up.b32  Ry|p, Rx, 0x8,  0x0;
@p  add.f32      Rx, Ry, Rx;
    shfl.up.b32  Ry|p, Rx, 0x10, 0x0;
@p  add.f32      Rx, Ry, Rx;


    // Warp-level INCLUSIVE PLUS REVERSE-SCAN:
    //
    // Assumes input in following registers:
    //     - Rx  = sequence value for this thread
    //
    shfl.down.b32  Ry|p, Rx, 0x1,  0x1f;
@p  add.f32        Rx, Ry, Rx;
    shfl.down.b32  Ry|p, Rx, 0x2,  0x1f;
@p  add.f32        Rx, Ry, Rx;
    shfl.down.b32  Ry|p, Rx, 0x4,  0x1f;
@p  add.f32        Rx, Ry, Rx;
    shfl.down.b32  Ry|p, Rx, 0x8,  0x1f;
@p  add.f32        Rx, Ry, Rx;
    shfl.down.b32  Ry|p, Rx, 0x10, 0x1f;
@p  add.f32        Rx, Ry, Rx;


    // BUTTERFLY REDUCTION:
    //
    // Assumes input in following registers:
    //     - Rx  = sequence value for this thread
    //
```

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```
    shfl.bfly.b32  Ry, Rx, 0x10, 0x1f;   // no predicate dest
    add.f32        Rx, Ry, Rx;
    shfl.bfly.b32  Ry, Rx, 0x8,  0x1f;
    add.f32        Rx, Ry, Rx;
    shfl.bfly.b32  Ry, Rx, 0x4,  0x1f;
    add.f32        Rx, Ry, Rx;
    shfl.bfly.b32  Ry, Rx, 0x2,  0x1f;
    add.f32        Rx, Ry, Rx;
    shfl.bfly.b32  Ry, Rx, 0x1,  0x1f;
    add.f32        Rx, Ry, Rx;
    //
    // All threads now hold sum in Rx
```

9.7.9.6 Data Movement and Conversion Instructions: shfl.sync

shfl.sync

Register data shuffle within threads of a warp.

Syntax

```
shfl.sync.mode.b32  d[|p], a, b, c, membermask;

.mode = { .up, .down, .bfly, .idx };
```

Description

Exchange register data between threads of a warp.

`shfl.sync` will cause executing thread to wait until all non-exited threads corresponding to `membermask` have executed `shfl.sync` with the same qualifiers and same `membermask` value before resuming execution.

Operand `membermask` specifies a 32-bit integer which is a mask indicating threads participating in barrier where the bit position corresponds to thread's `laneid`.

`shfl.sync` exchanges register data between threads in `membermask`.

Each thread in the currently executing warp will compute a source lane index *j* based on input operands `b` and `c` and the *mode*. If the computed source lane index *j* is in range, the thread will copy the input operand `a` from lane *j* into its own destination register `d`; otherwise, the thread will simply copy its own input `a` to destination `d`. The optional destination predicate `p` is set to `True` if the computed source lane is in range, and otherwise set to `False`.

Note that an out of range value of `b` may still result in a valid computed source lane index *j*. In this case, a data transfer occurs and the destination predicate `p` is True.

Note that results are undefined if a thread sources a register from an inactive thread or a thread that is not in `membermask`.

Operand `b` specifies a source lane or source lane offset, depending on the mode.

Operand `c` contains two packed values specifying a mask for logically splitting warps into sub-segments and an upper bound for clamping the source lane index.

The behavior of `shfl.sync` is undefined if the executing thread is not in the `membermask`.

Note: For .target `sm_6x` or below, all threads in `membermask` must execute the same `shfl.sync` instruction in convergence, and only threads belonging to some `membermask` can be active when the `shfl.sync` instruction is executed. Otherwise, the behavior is undefined.

Semantics

```
// wait for all threads in membermask to arrive
wait_for_specified_threads(membermask);

lane[4:0]  = [Thread].laneid;  // position of thread in warp
bval[4:0] = b[4:0];            // source lane or lane offset (0..31)
cval[4:0] = c[4:0];            // clamp value
segmask[4:0] = c[12:8];

// get value of source register a if thread is active and
// guard predicate true, else unpredictable
if (isActive(Thread) && isGuardPredicateTrue(Thread)) {
    SourceA[lane] = a;
} else {
    // Value of SourceA[lane] is unpredictable for
    // inactive/predicated-off threads in warp
}
maxLane = (lane[4:0] & segmask[4:0]) | (cval[4:0] & ~segmask[4:0]);
minLane = (lane[4:0] & segmask[4:0]);

switch (.mode) {
    case .up:    j = lane - bval; pval = (j >= maxLane); break;
    case .down:  j = lane + bval; pval = (j <= maxLane); break;
    case .bfly:  j = lane ^ bval; pval = (j <= maxLane); break;
    case .idx:   j = minLane  | (bval[4:0] & ~segmask[4:0]);
                                  pval = (j <= maxLane); break;
}
if (!pval) j = lane;  // copy from own lane
d = SourceA[j];       // copy input a from lane j
if (dest predicate selected)
    p = pval;
```

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
shfl.sync.up.b32  Ry|p, Rx, 0x1,  0x0, 0xffffffff;
```

9.7.9.7 Data Movement and Conversion Instructions: `prmt`

`prmt`

Permute bytes from register pair.

Syntax

```
prmt.b32{.mode}  d, a, b, c;

.mode = { .f4e, .b4e, .rc8, .ecl, .ecr, .rc16 };
```

Description

Pick four arbitrary bytes from two 32-bit registers, and reassemble them into a 32-bit destination register.

In the generic form (no mode specified), the permute control consists of four 4-bit selection values. The bytes in the two source registers are numbered from 0 to 7: `{b, a} = {{b7, b6, b5, b4}, {b3, b2, b1, b0}}`. For each byte in the target register, a 4-bit selection value is defined.

The 3 lsbs of the selection value specify which of the 8 source bytes should be moved into the target position. The msb defines if the byte value should be copied, or if the sign (msb of the byte) should be replicated over all 8 bits of the target position (sign extend of the byte value); `msb=0` means copy the literal value; `msb=1` means replicate the sign. Note that the sign extension is only performed as part of generic form.

Thus, the four 4-bit values fully specify an arbitrary byte permute, as a `16b` permute code.

default mode	**`d.b3` source select**	**`d.b2` source select**	**`d.b1` source select**	**`d.b0` source select**
index	`c[15:12]`	`c[11:8]`	`c[7:4]`	`c[3:0]`

The more specialized form of the permute control uses the two lsb's of operand `c` (which is typically an address pointer) to control the byte extraction.

mode	selector c[1:0]	d.b3 source	d.b2 source	d.b1 source	d.b0 source
f4e (forward 4 extract)	0	3	2	1	0
	1	4	3	2	1
	2	5	4	3	2
	3	6	5	4	3
b4e (backward 4 extract)	0	5	6	7	0
	1	6	7	0	1
	2	7	0	1	2
	3	0	1	2	3
rc8 (replicate 8)	0	0	0	0	0
	1	1	1	1	1
	2	2	2	2	2
	3	3	3	3	3
ecl (edge clamp left)	0	3	2	1	0
	1	3	2	1	1
	2	3	2	2	2
	3	3	3	3	3
ecr (edge clamp right)	0	0	0	0	0
	1	1	1	1	0
	2	2	2	1	0
	3	3	2	1	0
rc16 (replicate 16)	0	1	0	1	0
	1	3	2	3	2
	2	1	0	1	0
	3	3	2	3	2

Semantics

```
tmp64 = (b<<32) | a;  // create 8 byte source

if ( ! mode ) {
   ctl[0] = (c >>  0) & 0xf;
   ctl[1] = (c >>  4) & 0xf;
   ctl[2] = (c >>  8) & 0xf;
   ctl[3] = (c >> 12) & 0xf;
} else {
```

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```
   ctl[0] = ctl[1] = ctl[2] = ctl[3] = (c >>  0) & 0x3;
}

tmp[07:00] = ReadByte( mode, ctl[0], tmp64 );
tmp[15:08] = ReadByte( mode, ctl[1], tmp64 );
tmp[23:16] = ReadByte( mode, ctl[2], tmp64 );
tmp[31:24] = ReadByte( mode, ctl[3], tmp64 );
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`prmt` requires `sm_20` or higher.

Examples

```
prmt.b32      r1, r2, r3, r4;
prmt.b32.f4e  r1, r2, r3, r4;
```

9.7.9.8 Data Movement and Conversion Instructions: `ld`

`ld`

Load a register variable from an addressable state space variable.

Syntax

```
ld{.weak}{.ss}{.cop}{.level::cache_hint}{.level::prefetch_size}{.vec}.type  d, [a]{.
↪unified}{, cache-policy};

ld{.weak}{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.level::cache_
↪hint}{.level::prefetch_size}{.vec}.type  d, [a]{.unified}{, cache-policy};

ld.volatile{.ss}{.level::prefetch_size}{.vec}.type  d, [a];

ld.relaxed.scope{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.
↪level::cache_hint}{.level::prefetch_size}{.vec}.type  d, [a]{, cache-policy};

ld.acquire.scope{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.
↪level::cache_hint}{.level::prefetch_size}{.vec}.type  d, [a]{, cache-policy};

ld.mmio.relaxed.sys{.global}.type  d, [a];

.ss =                       { .const, .global, .local, .param{::entry, ::func}, .
↪shared{::cta, ::cluster} };
.cop =                      { .ca, .cg, .cs, .lu, .cv };
```

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```
.level1::eviction_priority = { .L1::evict_normal, .L1::evict_unchanged,
                               .L1::evict_first, .L1::evict_last, .L1::no_allocate };
.level2::eviction_priority = {.L2::evict_normal, .L2::evict_first, .L2::evict_last};
.level::cache_hint =        { .L2::cache_hint };
.level::prefetch_size =     { .L2::64B, .L2::128B, .L2::256B }
.scope =                    { .cta, .cluster, .gpu, .sys };
.vec =                      { .v2, .v4, .v8 };
.type =                     { .b8, .b16, .b32, .b64, .b128,
                              .u8, .u16, .u32, .u64,
                              .s8, .s16, .s32, .s64,
                              .f32, .f64 };
```

Description

Load register variable d from the location specified by the source address operand a in specified state space. If no state space is given, perform the load using *Generic Addressing*.

If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*

If no sub-qualifier is specified with `.param` state space, then:

- `::func` is assumed when access is inside a device function.
- `::entry` is assumed when accessing kernel function parameters from entry function. Otherwise, when accessing device function parameters or any other `.param` variables from entry function `::func` is assumed by default.

For `ld.param::entry` instruction, operand a must be a kernel parameter address, otherwise behavior is undefined. For `ld.param::func` instruction, operand a must be a device function parameter address, otherwise behavior is undefined.

Instruction `ld.param{::func}` used for reading value returned from device function call cannot be predicated. See *Parameter State Space* and *Function Declarations and Definitions* for descriptions of the proper use of `ld.param`.

The `.relaxed` and `.acquire` qualifiers indicate memory synchronization as described in the *Memory Consistency Model*. The `.scope` qualifier indicates the set of threads with which an `ld.relaxed` or `ld.acquire` instruction can directly synchronize[1]. The `.weak` qualifier indicates a memory instruction with no synchronization. The effects of this instruction become visible to other threads only when synchronization is established by other means.

The semantic details of `.mmio` qualifier are described in the *Memory Consistency Model*. Only `.sys` thread scope is valid for `ld.mmio` operation. The qualifiers `.mmio` and `.relaxed` must be specified together.

The semantic details of `.volatile` qualifier are described in the *Memory Consistency Model*.

The `.weak`, `.volatile`, `.relaxed` and `.acquire` qualifiers are mutually exclusive. When none of these is specified, the `.weak` qualifier is assumed by default.

The qualifiers `.volatile`, `.relaxed` and `.acquire` may be used only with `.global` and `.shared` spaces and with generic addressing, where the address points to `.global` or `.shared` space. Cache operations are not permitted with these qualifiers. The qualifier `.mmio` may be used only with `.global` space and with generic addressing, where the address points to `.global` space.

The optional qualifier `.unified` must be specified on operand a if a is the address of a variable declared with `.unified` attribute as described in *Variable and Function Attribute Directive: .attribute*.

The `.v8` (`.vec`) qualifier is supported if:

- `.type` is `.b32` or `.s32` or `.u32` or `.f32` AND
- State space is `.global` or with generic addressing where address points to `.global` state space

The `.v4` (`.vec`) qualifier with type `.b64` or `.s64` or `.u64` or `.f64` is supported if:

- State space is `.global` or with generic addressing where address points to `.global` state space

Qualifiers `.level1::eviction_priority` and `.level2::eviction_priority` specify the eviction policy for L1 and L2 cache respectively which may be applied during memory access.

Qualifier `.level2::eviction_priority` is supported if:

- `.vec` is `.v8` and `.type` is `.b32` or `.s32` or `.u32` or `.f32`
  - AND Operand d is vector of 8 registers with type specified with `.type`
- OR `.vec` is `.v4` and `.type` is `.b64` or `.s64` or `.u64` or `.f64`
  - AND Operand d is vector of 4 registers with type specified with `.type`

Optionally, sink symbol '_' can be used in vector expression d when:

- `.vec` is `.v8` and `.type` is `.b32` or `.s32` or `.u32` or `.f32` OR
- `.vec` is `.v4` and `.type` is `.b64` or `.s64` or `.u64` or `.f64`

which indicates that data from corresponding memory location is not read.

The `.level::prefetch_size` qualifier is a hint to fetch additional data of the specified size into the respective cache level.The sub-qualifier `prefetch_size` can be set to either of 64B, 128B, 256B thereby allowing the prefetch size to be 64 Bytes, 128 Bytes or 256 Bytes respectively.

The qualifier `.level::prefetch_size` may only be used with `.global` state space and with generic addressing where the address points to `.global` state space. If the generic address does not fall within the address window of the global memory, then the prefetching behavior is undefined.

The `.level::prefetch_size` qualifier is treated as a performance hint only.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

The qualifiers `.unified` and `.level::cache_hint` are only supported for `.global` state space and for generic addressing where the address points to the `.global` state space.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

[1] This synchronization is further extended to other threads through the transitive nature of *causality order*, as described in the memory consistency model.

Semantics

```
d = a;              // named variable a
d = *(&a+immOff)    // variable-plus-offset
d = *a;             // register
d = *(a+immOff);    // register-plus-offset
d = *(immAddr);     // immediate address
```

Notes

Destination d must be in the `.reg` state space.

A destination register wider than the specified type may be used. The value loaded is sign-extended to the destination register width for signed integers, and is zero-extended to the destination register width for unsigned and bit-size types. See Table 29 for a description of these relaxed type-checking rules.

`.f16` data may be loaded using `ld.b16`, and then converted to `.f32` or `.f64` using `cvt` or can be used in half precision floating point instructions.

`.f16x2` data may be loaded using `ld.b32` and then used in half precision floating point instructions.

PTX ISA Notes

ld introduced in PTX ISA version 1.0. `ld.volatile` introduced in PTX ISA version 1.1.

Generic addressing and cache operations introduced in PTX ISA version 2.0.

Support for scope qualifier, `.relaxed`, `.acquire`, `.weak` qualifiers introduced in PTX ISA version 6.0.

Support for generic addressing of .const space added in PTX ISA version 3.1.

Support for `.level1::eviction_priority`, `.level::prefetch_size` and `.level::cache_hint` qualifiers introduced in PTX ISA version 7.4.

Support for `.cluster` scope qualifier introduced in PTX ISA version 7.8.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for `.unified` qualifier introduced in PTX ISA version 8.0.

Support for `.mmio` qualifier introduced in PTX ISA version 8.2.

Support for `::entry` and `::func` sub-qualifiers on `.param` space introduced in PTX ISA version 8.3.

Support for `.b128` type introduced in PTX ISA version 8.3.

Support for `.sys` scope with `.b128` type introduced in PTX ISA version 8.4.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` introduced in PTX ISA version 8.8.

Target ISA Notes

`ld.f64` requires `sm_13` or higher.

Support for scope qualifier, `.relaxed`, `.acquire`, `.weak` qualifiers require `sm_70` or higher.

Generic addressing requires `sm_20` or higher.

Cache operations require `sm_20` or higher.

Support for `.level::eviction_priority` qualifier requires `sm_70` or higher.

Support for `.level::prefetch_size` qualifier requires `sm_75` or higher.

Support for `.L2::256B` and `.L2::cache_hint` qualifiers requires `sm_80` or higher.

Support for `.cluster` scope qualifier requires `sm_90` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for `.unified` qualifier requires `sm_90` or higher.

Support for `.mmio` qualifier requires `sm_70` or higher.

Support for `.b128` type requires `sm_70` or higher.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` require `sm_100` or higher.

Examples

```
ld.global.f32    d,[a];
ld.shared.v4.b32 Q,[p];
ld.const.s32     d,[p+4];
ld.local.b32     x,[p+-8]; // negative offset
ld.local.b64     x,[240];  // immediate address

ld.global.b16    %r,[fs];  // load .f16 data into 32-bit reg
cvt.f32.f16      %r,%r;    // up-convert f16 data to f32

ld.global.b32    %r0, [fs];     // load .f16x2 data in 32-bit reg
ld.global.b32    %r1, [fs + 4]; // load .f16x2 data in 32-bit reg
add.rn.f16x2     %d0, %r0, %r1; // addition of f16x2 data
ld.global.relaxed.gpu.u32 %r0, [gbl];
ld.shared.acquire.gpu.u32 %r1, [sh];
ld.global.relaxed.cluster.u32 %r2, [gbl];
ld.shared::cta.acquire.gpu.u32 %r2, [sh + 4];
ld.shared::cluster.u32 %r3, [sh + 8];
ld.global.mmio.relaxed.sys.u32 %r3, [gbl];

ld.global.f32    d,[ugbl].unified;
ld.b32           %r0, [%r1].unified;

ld.global.L1::evict_last.u32  d, [p];

ld.global.L2::64B.b32   %r0, [gbl]; // Prefetch 64B to L2
ld.L2::128B.f64         %r1, [gbl]; // Prefetch 128B to L2
ld.global.L2::256B.f64  %r2, [gbl]; // Prefetch 256B to L2
```

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```
createpolicy.fractional.L2::evict_last.L2::evict_unchanged.b64 cache-policy, 1;
ld.global.L2::cache_hint.b64  x, [p], cache-policy;
ld.param::entry.b32 %rp1, [kparam1];

ld.global.b128   %r0, [gbl];   // 128-bit load

// 256-bit load
ld.global.L2::evict_last.v8.f32 { %reg0, _, %reg2, %reg3, %reg4, %reg5, %reg6, %reg7},
↪ [addr];
ld.global.L2::evict_last.L1::evict_last.v4.u64 { %reg0, %reg1, %reg2, %reg3}, [addr];
```

9.7.9.9 Data Movement and Conversion Instructions: `ld.global.nc`

`ld.global.nc`

Load a register variable from global state space via non-coherent cache.

Syntax

```
ld.global{.cop}.nc{.level::cache_hint}{.level::prefetch_size}.type                d,
↪[a]{, cache-policy};
ld.global{.cop}.nc{.level::cache_hint}{.level::prefetch_size}.vec.type            d,
↪[a]{, cache-policy};

ld.global.nc{.level1::eviction_priority}{.level2::eviction_priority}{.level::cache_
↪hint}{.level::prefetch_size}.type      d, [a]{, cache-policy};
ld.global.nc{.level1::eviction_priority}{.level2::eviction_priority}{.level::cache_
↪hint}{.level::prefetch_size}.vec.type  d, [a]{, cache-policy};

.cop  =                     { .ca, .cg, .cs };     // cache operation
.level1::eviction_priority = { .L1::evict_normal, .L1::evict_unchanged,
                               .L1::evict_first, .L1::evict_last, .L1::no_allocate};
.level2::eviction_priority = {.L2::evict_normal, .L2::evict_first, .L2::evict_last};
.level::cache_hint =        { .L2::cache_hint };
.level::prefetch_size =     { .L2::64B, .L2::128B, .L2::256B }
.vec  =                     { .v2, .v4, .v8 };
.type =                     { .b8, .b16, .b32, .b64, .b128,
                              .u8, .u16, .u32, .u64,
                              .s8, .s16, .s32, .s64,
                              .f32, .f64 };
```

Description

Load register variable d from the location specified by the source address operand a in the global state space, and optionally cache in non-coherent read-only cache.

Note: On some architectures, the texture cache is larger, has higher bandwidth, and longer latency than the global memory cache. For applications with sufficient parallelism to cover the longer latency, `ld.global.nc` should offer better performance than `ld.global` on such architectures.

The address operand a shall contain a global address. Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*.

The `.v8` (`.vec`) qualifier is supported if:

- `.type` is `.b32`, `.s32`, `.u32`, or `.f32` AND
- State space is `.global` or with generic addressing where address points to `.global` state space

The `.v4` (`.vec`) qualifier with type `.b64` or `.s64` or `.u64` or `.f64` is supported if:

- State space is `.global` or with generic addressing where address points to `.global` state space

Qualifiers `.level1::eviction_priority` and `.level2::eviction_priority` specify the eviction policy for L1 and L2 cache respectively which may be applied during memory access.

Qualifier `.level2::eviction_priority` is supported if:

- `.vec` is `.v8` and `.type` is `.b32` or `.s32` or `.u32` or `.f32`
  - AND Operand d is vector of 8 registers with type specified with `.type`
- OR `.vec` is `.v4` and `.type` is `.b64` or `.s64` or `.u64` or `.f64`
  - AND Operand d is vector of 4 registers with type specified with `.type`

Optionally, sink symbol '_' can be used in vector expression d when:

- `.vec` is `.v8` and `.type` is `.b32` or `.s32` or `.u32` or `.f32` OR
- `.vec` is `.v4` and `.type` is `.b64` or `.s64` or `.u64` or `.f64`

which indicates that data from corresponding memory location is not read.

The `.level::prefetch_size` qualifier is a hint to fetch additional data of the specified size into the respective cache level.The sub-qualifier `prefetch_size` can be set to either of 64B, 128B, 256B thereby allowing the prefetch size to be 64 Bytes, 128 Bytes or 256 Bytes respectively.

The `.level::prefetch_size` qualifier is treated as a performance hint only.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

Semantics

```
d = a;              // named variable a
d = *(&a+immOff)    // variable-plus-offset
d = *a;             // register
d = *(a+immOff);    // register-plus-offset
d = *(immAddr);     // immediate address
```

Notes

Destination `d` must be in the `.reg` state space.

A destination register wider than the specified type may be used. The value loaded is sign-extended to the destination register width for signed integers, and is zero-extended to the destination register width for unsigned and bit-size types.

`.f16` data may be loaded using `ld.b16`, and then converted to `.f32` or `.f64` using `cvt`.

PTX ISA Notes

Introduced in PTX ISA version 3.1.

Support for `.level::eviction_priority`, `.level::prefetch_size` and `.level::cache_hint` qualifiers introduced in PTX ISA version 7.4.

Support for `.b128` type introduced in PTX ISA version 8.3.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` introduced in PTX ISA version 8.8.

Target ISA Notes

Requires `sm_32` or higher.

Support for `.level1::eviction_priority` qualifier requires `sm_70` or higher.

Support for `.level::prefetch_size` qualifier requires `sm_75` or higher.

Support for `.level::cache_hint` qualifier requires `sm_80` or higher.

Support for `.b128` type requires `sm_70` or higher.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` require `sm_100` or higher.

Examples

```
ld.global.nc.f32           d, [a];
ld.gloal.nc.L1::evict_last.u32 d, [a];

createpolicy.fractional.L2::evict_last.b64 cache-policy, 0.5;
ld.global.nc.L2::cache_hint.f32  d, [a], cache-policy;

ld.global.nc.L2::64B.b32      d,  [a];     // Prefetch 64B to L2
ld.global.nc.L2::256B.f64     d,  [a];     // Prefetch 256B to L2

ld.global.nc.b128             d,  [a];

ld.global.nc.L2::evict_first.v4.f64 {%reg0, %reg1. %reg2, %reg3}. [a]; // 256-bit load
```

9.7.9.10 Data Movement and Conversion Instructions: ldu

ldu

Load read-only data from an address that is common across threads in the warp.

Syntax

```
ldu{.ss}.type      d, [a];       // load from address
ldu{.ss}.vec.type  d, [a];       // vec load from address

.ss   = { .global };             // state space
.vec  = { .v2, .v4 };
.type = { .b8, .b16, .b32, .b64, .b128,
          .u8, .u16, .u32, .u64,
          .s8, .s16, .s32, .s64,
                     .f32, .f64 };
```

Description

Load *read-only* data into register variable d from the location specified by the source address operand a in the global state space, where the address is guaranteed to be the same across all threads in the warp. If no state space is given, perform the load using *Generic Addressing*.

Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*.

Semantics

```
d = a;              // named variable a
d = *(&a+immOff)    // variable-plus-offset
d = *a;             // register
d = *(a+immOff);    // register-plus-offset
d = *(immAddr);     // immediate address
```

Notes

Destination `d` must be in the `.reg` state space.

A destination register wider than the specified type may be used. The value loaded is sign-extended to the destination register width for signed integers, and is zero-extended to the destination register width for unsigned and bit-size types. See Table 29 for a description of these relaxed type-checking rules.

`.f16` data may be loaded using `ldu.b16`, and then converted to `.f32` or `.f64` using `cvt` or can be used in half precision floating point instructions.

`.f16x2` data may be loaded using `ldu.b32` and then used in half precision floating point instructions.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Support for `.b128` type introduced in PTX ISA version 8.3.

Target ISA Notes

`ldu.f64` requires `sm_13` or higher.

Support for `.b128` type requires `sm_70` or higher.

Examples

```
ldu.global.f32    d,[a];
ldu.global.b32    d,[p+4];
ldu.global.v4.f32 Q,[p];
ldu.global.b128   d,[a];
```

9.7.9.11 Data Movement and Conversion Instructions: st

st

Store data to an addressable state space variable.

Syntax

```
st{.weak}{.ss}{.cop}{.level::cache_hint}{.vec}.type   [a], b{, cache-policy};
st{.weak}{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.level::cache_
↪hint}{.vec}.type
                                                      [a], b{, cache-policy};
st.volatile{.ss}{.vec}.type                           [a], b;
st.relaxed.scope{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.
↪level::cache_hint}{.vec}.type
                                                      [a], b{, cache-policy};
st.release.scope{.ss}{.level1::eviction_priority}{.level2::eviction_priority}{.
↪level::cache_hint}{.vec}.type
                                                      [a], b{, cache-policy};
st.mmio.relaxed.sys{.global}.type         [a], b;

.ss =                        { .global, .local, .param{::func}, .shared{::cta,
↪::cluster} };
.level1::eviction_priority = { .L1::evict_normal, .L1::evict_unchanged,
                               .L1::evict_first, .L1::evict_last, .L1::no_allocate };
.level2::eviction_priority = { .L2::evict_normal, .L2::evict_first, .L2::evict_last };
.level::cache_hint =         { .L2::cache_hint };
.cop =                       { .wb, .cg, .cs, .wt };
.sem =                       { .relaxed, .release };
.scope =                     { .cta, .cluster, .gpu, .sys };
.vec =                       { .v2, .v4, .v8 };
.type =                      { .b8, .b16, .b32, .b64, .b128,
                               .u8, .u16, .u32, .u64,
                               .s8, .s16, .s32, .s64,
                               .f32, .f64 };
```

Description

Store the value of operand `b` in the location specified by the destination address operand `a` in specified state space. If no state space is given, perform the store using *Generic Addressing*. Stores to const memory are illegal.

If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

Supported addressing modes for operand `a` and alignment requirements are described in *Addresses as Operands*.

If `.param` is specified without any sub-qualifiers then it defaults to `.param::func`.

Instruction `st.param{::func}` used for passing arguments to device function cannot be predicated. See *Parameter State Space* and *Function Declarations and Definitions* for descriptions of the proper use of `st.param`.

The qualifiers `.relaxed` and `.release` indicate memory synchronization as described in the *Memory Consistency Model*. The `.scope` qualifier indicates the set of threads with which an `st.relaxed` or `st.release` instruction can directly synchronize[1]. The `.weak` qualifier indicates a memory instruction with no synchronization. The effects of this instruction become visible to other threads only when synchronization is established by other means.

The semantic details of `.mmio` qualifier are described in the *Memory Consistency Model*. Only `.sys` thread scope is valid for `st.mmio` operation. The qualifiers `.mmio` and `.relaxed` must be specified together.

The semantic details of `.volatile` qualifier are described in the *Memory Consistency Model*.

The .weak, .volatile, .relaxed and .release qualifiers are mutually exclusive. When none of these is specified, the .weak qualifier is assumed by default.

The qualifiers .volatile, .relaxed and .release may be used only with .global and .shared spaces and with generic addressing, where the address points to .global or .shared space. Cache operations are not permitted with these qualifiers. The qualifier .mmio may be used only with .global space and with generic addressing, where the address points to .global space.

The .v8 (.vec) qualifier is supported if:

- .type is .b32, .s32, .u32, or .f32 AND
- State space is .global or with generic addressing where address points to .global state space

The .v4 (.vec) qualifier with type .b64 or .s64 or .u64 or .f64 is supported if:

- State space is .global or with generic addressing where address points to .global state space

Qualifiers .level1::eviction_priority and .level2::eviction_priority specify the eviction policy for L1 and L2 cache respectively which may be applied during memory access.

Qualifier .level2::eviction_priority is supported if:

- .vec is .v8 and .type is .b32 or .s32 or .u32 or .f32
  - AND Operand d is vector of 8 registers with type specified with .type
- OR .vec is .v4 and .type is .b64 or .s64 or .u64 or .f64
  - AND Operand d is vector of 4 registers with type specified with .type

Optionally, sink symbol '_' can be used in vector expression b when:

- .vec is .v8 and .type is .b32 or .s32 or .u32 or .f32 OR
- .vec is .v4 and .type is .b64 or .s64 or .u64 or .f64

which indicates that no data is being written at the corresponding destination address.

When the optional argument cache-policy is specified, the qualifier .level::cache_hint is required. The 64-bit operand cache-policy specifies the cache eviction policy that may be used during the memory access.

The qualifier .level::cache_hint is only supported for .global state space and for generic addressing where the address points to the .global state space.

cache-policy is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

[1] This synchronization is further extended to other threads through the transitive nature of *causality order*, as described in the memory consistency model.

Semantics

```
d = a;                 // named variable d
*(&a+immOffset) = b;            // variable-plus-offset
*a = b;                // register
*(a+immOffset) = b;    // register-plus-offset
*(immAddr) = b;        // immediate address
```

Notes

Operand b must be in the `.reg` state space.

A source register wider than the specified type may be used. The lower n bits corresponding to the instruction-type width are stored to memory. See Table 28 for a description of these relaxed type-checking rules.

`.f16` data resulting from a `cvt` instruction may be stored using `st.b16`.

`.f16x2` data may be stored using `st.b32`.

PTX ISA Notes

st introduced in PTX ISA version 1.0. `st.volatile` introduced in PTX ISA version 1.1.

Generic addressing and cache operations introduced in PTX ISA version 2.0.

Support for scope qualifier, `.relaxed`, `.release`, `.weak` qualifiers introduced in PTX ISA version 6.0.

Support for `.level1::eviction_priority` and `.level::cache_hint` qualifiers introduced in PTX ISA version 7.4.

Support for `.cluster` scope qualifier introduced in PTX ISA version 7.8.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for `.mmio` qualifier introduced in PTX ISA version 8.2.

Support for `::func` sub-qualifier on `.param` space introduced in PTX ISA version 8.3.

Support for `.b128` type introduced in PTX ISA version 8.3.

Support for `.sys` scope with `.b128` type introduced in PTX ISA version 8.4.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` introduced in PTX ISA version 8.8.

Target ISA Notes

`st.f64` requires `sm_13` or higher.

Support for scope qualifier, `.relaxed`, `.release`, `.weak` qualifiers require `sm_70` or higher.

Generic addressing requires `sm_20` or higher.

Cache operations require `sm_20` or higher.

Support for `.level1::eviction_priority` qualifier requires `sm_70` or higher.

Support for `.level::cache_hint` qualifier requires `sm_80` or higher.

Support for `.cluster` scope qualifier requires `sm_90` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for `.mmio` qualifier requires `sm_70` or higher.

Support for `.b128` type requires `sm_70` or higher.

Support for `.level2::eviction_priority` qualifier and `.v8.b32/.v4.b64` require `sm_100` or higher.

Examples

```
st.global.f32    [a],b;
st.local.b32     [q+4],a;
st.global.v4.s32 [p],Q;
st.local.b32     [q+-8],a; // negative offset
st.local.s32     [100],r7; // immediate address

cvt.f16.f32      %r,%r;    // %r is 32-bit register
st.b16           [fs],%r;  // store lower
st.global.relaxed.sys.u32 [gbl], %r0;
st.shared.release.cta.u32 [sh], %r1;
st.global.relaxed.cluster.u32 [gbl], %r2;
st.shared::cta.release.cta.u32 [sh + 4], %r1;
st.shared::cluster.u32 [sh + 8], %r1;
st.global.mmio.relaxed.sys.u32 [gbl], %r1;

st.global.L1::no_allocate.f32 [p], a;

createpolicy.fractional.L2::evict_last.b64 cache-policy, 0.25;
st.global.L2::cache_hint.b32  [a], b, cache-policy;

st.param::func.b64 [param1], %rp1;

st.global.b128  [a], b;  // 128-bit store

// 256-bit store
st.global.L2::evict_last.v8.f32 [addr], { %reg0, _, %reg2, %reg3, %reg4, %reg5, %reg6,
↪ %reg7};
```

9.7.9.12 Data Movement and Conversion Instructions: st.async

st.async

Asynchronous store operation.

Syntax

```
st.async{.sem}{.scope}{.ss}{.completion_mechanism}{.vec}.type [a], b, [mbar];

.sem  =                 { .weak };
.scope =                { .cluster };
.ss   =                 { .shared::cluster };
.type =                 { .b32, .b64,
                          .u32, .u64,
                          .s32, .s64,
                          .f32, .f64 };
.vec  =                 { .v2, .v4 };
.completion_mechanism = { .mbarrier::complete_tx::bytes };

st.async{.mmio}.sem{.scope}{.ss}{.completion_mechanism}.type [a], b;

.sem =                  { .release };
```

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```
.scope =                { .gpu, .sys };
.ss =                   { .global };
.completion_mechanism = { };
.type =                 { .b8, .b16, .b32, .b64,
                          .u8, .u16, .u32, .u64,
                          .s8, .s16, .s32, .s64,
                                     .f32, .f64 };
```

Description

`st.async` is a non-blocking instruction which initiates an asynchronous store operation that stores the value specified by source operand `b` to the destination memory location specified by operand `a`.

Operands

- `a` is a destination address, and must be either a register, or of the form `register + immOff`, as described in *Addresses as Operands*.
- `b` is a source value, of the type indicated by qualifier `.type`.
- `mbar` is an mbarrier object address.

Qualifiers

- `.mmio` indicates whether this is an *mmio Operation*.
- `.sem` specifies the memory ordering semantics as described in the *Memory Consistency Model*.
  - If `.sem` is not specified, it defaults to `.weak`.
- `.scope` specifies the set of threads with which this instruction can directly synchronize.
- `.ss` specifies the state space of the destination operand `a` and the mbarrier operand `mbar`.
  - If `.ss` is not specified, *Generic Addressing* is used.
- `.completion_mechanism` specifies the mechanism for observing the completion of the asynchronous operation.
  - When `.completion_mechanism` is `.mbarrier::complete_tx::bytes`: upon completion of the asynchronous operation, a *complete-tx* operation will be performed on the mbarrier object specified by the operand `mbar`, with `completeCount` argument equal to the amount of data stored in bytes.
  - When `.completion_mechanism` is not specified: the completion of the store synchronizes with the end of the CTA.
- `.type` specifies the type of the source operand `b`.

Conditions

When `.sem` is `.weak`:

- This is a weak store to shared memory, which signals its completion through an mbarrier object.
- The store operation is treated as a weak memory operation.
- The complete-tx operation on the mbarrier has `.release` semantics at `.cluster` scope.
- Requires:
  - The shared memory addresses of destination operand `a` and the *mbarrier object* `mbar` belong to the same CTA within the same cluster as the executing thread.
  - The number of CTAs within the cluster is strictly greater than one; `%cluster_nctarank > 1` is true.

  Otherwise, the behavior is undefined.
- `.mmio` must not be specified.
- If `.scope` is specified, it must be `.cluster`.
- If `.scope` is not specified, it defaults to `.cluster`.
- If `.ss` is specified, it must be `.shared::cluster`.
- If `.ss` is not specified, generic addressing is used for operands `a` and `mbar`. If the generic addresses specified do not fall within the address window of `.shared::cluster` state space, the behavior is undefined.
- If `.completion_mechanism` is specified, it must be `.mbarrier::complete_tx::bytes`.
- If `.completion_mechanism` is not specified, it defaults to `.mbarrier::complete_tx::bytes`.

When `.sem` is `.release`:

- This is a release store to global memory.
- The store operation is a strong memory operation with `.release` semantics at the scope specified by `.scope`.
- If `.mmio` is specified, `.scope` must be `.sys`.
- If `.scope` is specified, it may be `.gpu` or `.sys`.
- If `.scope` is not specified, it defaults to `.sys`.
- If `.ss` is specified, it must be `.global`.
- If `.ss` is not specified, generic addressing is used for operand `a`. If the generic address specified does not fall within the address window of `.global` state space, the behavior is undefined.
- `.completion_mechanism` must not be specified.

PTX ISA Notes

Introduced in PTX ISA version 8.1.

Support for `.mmio` qualifier, `.release` semantics, `.global` state space, and `.scope` qualifier introduced in PTX ISA version 8.7.

Target ISA Notes

Requires `sm_90` or higher.

`.mmio` qualifier, `.release` semantics, `.global` state space, and `.scope` qualifier require `sm_100` or higher.

Examples

```
st.async.shared::cluster.mbarrier::complete_tx::bytes.u32 [addr], b, [mbar_addr];

st.async.release.global.u32 [addr], b;
```

9.7.9.13 Data Movement and Conversion Instructions: `st.bulk`

`st.bulk`

Initializes a region of memory as specified by state space.

Syntax

```
st.bulk{.weak}{.shared::cta}  [a], size, initval; // initval must be zero
```

Description

`st.bulk` instruction initializes a region of shared memory starting from the location specified by destination address operand `a`.

The 64-bit integer operand `size` specifies the amount of memory to be initialized in terms of number of bytes. `size` must be a multiple of 8. If the value is not a multiple of 8, then the behavior is undefined. The maximum value of `size` operand can be 34359738360.

The integer immediate operand `initval` specifies the initialization value for the memory locations. The only numeric value allowed for operand `initval` is 0.

If no state space is specified then *Generic Addressing* is used. If the address specified by `a` does not fall within the address window of `.shared` state space then the behavior is undefined.

The optional qualifier `.weak` specify the memory synchronizing effect of the `st.bulk` instruction as described in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_100` or higher.

Examples

```
st.bulk.weak.shared::cta  [dst], n, 0;

st.bulk                   [gdst], 4096, 0;
```

9.7.9.14 Data Movement and Conversion Instructions: multimem.ld_reduce, multimem.st, multimem.red

The multimem.* operations operate on multimem addresses and accesses all of the multiple memory locations which the multimem address points to.

Multimem addresses can only be accessed only by multimem.* operations. Accessing a multimem address with `ld`, `st` or any other memory operations results in undefined behavior.

Refer to *CUDA programming guide* for creation and management of the multimem addresses.

multimem.ld_reduce, multimem.st, multimem.red

Perform memory operations on the multimem address.

Syntax

```
// Integer type:

multimem.ld_reduce{.ldsem}{.scope}{.ss}.op.type      d, [a];
multimem.st{.stsem}{.scope}{.ss}.type                [a], b;
multimem.red{.redsem}{.scope}{.ss}.op.type           [a], b;

.ss =       { .global }
.ldsem =    { .weak, .relaxed, .acquire }
.stsem =    { .weak, .relaxed, .release }
.redsem =   { .relaxed, .release }
.scope =    { .cta, .cluster, .gpu, .sys }
.op  =      { .min, .max, .add, .and, .or, .xor }
.type =     { .b32, .b64,  .u32, .u64, .s32, .s64 }

// Floating point type:

multimem.ld_reduce{.ldsem}{.scope}{.ss}.op{.acc_prec}{.vec}.type    d, [a];
multimem.st{.stsem}{.scope}{.ss}{.vec}.type                         [a], b;
multimem.red{.redsem}{.scope}{.ss}.redop{.vec}.redtype              [a], b;
```

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```
.ss =       { .global }
.ldsem =    { .weak, .relaxed, .acquire }
.stsem =    { .weak, .relaxed, .release }
.redsem =   { .relaxed, .release }
.scope =    { .cta, .cluster, .gpu, .sys }
.op  =      { .min, .max, .add }
.redop  =   { .add }
.acc_prec = { .acc::f32, .acc::f16 }
.vec =      { .v2, .v4, .v8 }
.type=      { .f16, .f16x2, .bf16, .bf16x2, .f32, .f64, .e5m2, .e5m2x2, .e5m2x4, .
↪e4m3, .e4m3x2, .e4m3x4 }
.redtype =  { .f16, .f16x2, .bf16, .bf16x2, .f32, .f64 }
```

Description

Instruction `multimem.ld_reduce` performs the following operations:

- load operation on the multimem address a, which involves loading of data from all of the multiple memory locations pointed to by the multimem address a,
- reduction operation specified by `.op` on the multiple data loaded from the multimem address a.

The result of the reduction operation in returned in register d.

Instruction `multimem.st` performs a store operation of the input operand b to all the memory locations pointed to by the multimem address a.

Instruction `multimem.red` performs a reduction operation on all the memory locations pointed to by the multimem address a, with operand b.

Instruction `multimem.ld_reduce` performs reduction on the values loaded from all the memory locations that the multimem address points to. In contrast, the `multimem.red` perform reduction on all the memory locations that the multimem address points to.

Address operand a must be a multimem address. Otherwise, the behavior is undefined. Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*.

If no state space is specified then *Generic Addressing* is used. If the address specified by a does not fall within the address window of `.global` state space then the behavior is undefined.

For floating-point type multi- operations, the size of the specified type along with `.vec` must equal either 32-bits or 64-bits or 128-bits. No other combinations of `.vec` and type are allowed. Type `.f64` cannot be used with `.vec` qualifier. The following table describes the valid usage of `.vec` and base floating-point type:

.vec	Base float-type supported
No `.vec` specified	`.f16x2`, `.bf16x2`, `.f32`, `.f64`, `.e5m2x4`, `.e4m3x4`
`.v2`	`.f16`, `.f16x2`, `.bf16`, `.bf16x2` `.f32`, `.e5m2`, `.e5m2x2`, `.e5m2x4`, `.e4m3`, `.e4m3x2`, `.e4m3x4`
`.v4`	`.f16`, `.f16x2`, `.bf16`, `.bf16x2` `.f32`, `.e5m2`, `.e5m2x2`, `.e5m2x4`, `.e4m3`, `.e4m3x2`, `.e4m3x4`
`.v8`	`.f16`, `.bf16`, `.e5m2`, `.e4m3`, `.e5m2x2`, `.e4m3x2`

The following table describes the valid combinations of .op and base type:

op	Base type
.add	.u32, .u64, .s32 .f16, .f16x2, .bf16, .bf16x2 .f32, .f64, .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4
.and, .or, .xor	.b32, .b64
.min, .max	.u32, .s32, .u64, .s64 .f16, .f16x2, .bf16, .bf16x2 .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4

For multimem.ld_reduce, the default precision of the intermediate accumulation is same as the specified type.

Optionally, .acc_prec qualifier can be specified to change the precision of intermediate accumulation as follows:

.type	.acc::prec	Changes precision to
.f16, .f16x2, .bf16, .bf16x2	.acc::f32	.f32
.e5m2, .e4m3, .e5m2x2, .e4m3x2, .e4m3x4, .e5m2x4	.acc::f16	.f16

Optional qualifiers .ldsem, .stsem and .redsem specify the memory synchronizing effect of the multimem.ld_reduce, multimem.st and multimem.red respectively, as described in *Memory Consistency Model*. If explicit semantics qualifiers are not specified, then multimem.ld_reduce and multimem.st default to .weak and multimem.red defaults to .relaxed.

The optional .scope qualifier specifies the set of threads that can directly observe the memory synchronizing effect of this operation, as described in *Memory Consistency Model*. If the .scope qualifier is not specified for multimem.red then .sys scope is assumed by default.

PTX ISA Notes

Introduced in PTX ISA version 8.1.

Support for .acc::f32 qualifier introduced in PTX ISA version 8.2.

Support for types .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4 introduced in PTX ISA version 8.6.

Support for .acc::f16 qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

Requires sm_90 or higher.

Types .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4 are supported on following architectures:

- sm_100a
- sm_101a
- sm_120a

- sm_121a
- And are supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family

Qualifier .acc::f16 is supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- sm_121a
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family

Examples

```
multimem.ld_reduce.and.b32                     val1_b32, [addr1];
multimem.ld_reduce.acquire.gpu.global.add.u32 val2_u32, [addr2];

multimem.st.relaxed.gpu.b32                [addr3], val3_b32;
multimem.st.release.cta.global.u32         [addr4], val4_u32;

multimem.red.relaxed.gpu.max.f64           [addr5], val5_f64;
multimem.red.release.cta.global.add.v4.f32 [addr6], {val6, val7, val8, val9};
multimem.ld_reduce.add.acc::f32.v2.f16x2   {val_10, val_11}, [addr7];

multimem.ld_reduce.relaxed.cta.min.v2.e4m3x2 {val_12, val_13}, [addr8];
multimem.ld_reduce.relaxed.cta.add.v4.e4m3   {val_14, val_15, val_16, val_17},
↪[addr9];
multimem.ld_reduce.add.acc::f16.v4.e5m2      {val_18, val_19, val_20, val_21},
↪[addr10];
```

9.7.9.15 Data Movement and Conversion Instructions: prefetch, prefetchu

prefetch, prefetchu

Prefetch line containing a generic address at a specified level of memory hierarchy, in specified state space.

Syntax

```
prefetch{.space}.level                    [a];   // prefetch to data cache
prefetch.global.level::eviction_priority  [a];   // prefetch to data cache

prefetchu.L1  [a];             // prefetch to uniform cache

prefetch{.tensormap_space}.tensormap [a];  // prefetch the tensormap

.space =                    { .global, .local };
.level =                    { .L1, .L2 };
.level::eviction_priority = { .L2::evict_last, .L2::evict_normal };
.tensormap_space =          { .const, .param };
```

Description

The `prefetch` instruction brings the cache line containing the specified address in global or local memory state space into the specified cache level.

If the `.tensormap` qualifier is specified then the `prefetch` instruction brings the cache line containing the specified address in the `.const` or `.param` memory state space for subsequent use by the `cp.async.bulk.tensor` instruction.

If no state space is given, the `prefetch` uses *Generic Addressing*.

Optionally, the eviction priority to be applied on the prefetched cache line can be specified by the modifier `.level::eviction_priority`.

Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*

The `prefetchu` instruction brings the cache line containing the specified generic address into the specified uniform cache level.

A `prefetch` to a shared memory location performs no operation.

A `prefetch` into the uniform cache requires a generic address, and no operation occurs if the address maps to a `const`, `local`, or `shared` memory location.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Support for `.level::eviction_priority` qualifier introduced in PTX ISA version 7.4.

Support for the `.tensormap` qualifier is introduced in PTX ISA version 8.0.

Target ISA Notes

`prefetch` and `prefetchu` require `sm_20` or higher.

Support for `.level::eviction_priority` qualifier requires `sm_80` or higher.

Support for the `.tensormap` qualifier requires `sm_90` or higher.

Examples

```
prefetch.global.L1             [ptr];
prefetch.global.L2::evict_last [ptr];
prefetchu.L1  [addr];
prefetch.const.tensormap       [ptr];
```

9.7.9.16 Data Movement and Conversion Instructions: `applypriority`

`applypriority`

Apply the cache eviction priority to the specified address in the specified cache level.

Syntax

```
applypriority{.global}.level::eviction_priority  [a], size;

.level::eviction_priority = { .L2::evict_normal };
```

Description

The `applypriority` instruction applies the cache eviction priority specified by the `.level::eviction_priority` qualifier to the address range `[a..a+size)` in the specified cache level.

If no state space is specified then *Generic Addressing* is used. If the specified address does not fall within the address window of `.global` state space then the behavior is undefined.

The operand `size` is an integer constant that specifies the amount of data, in bytes, in the specified cache level on which the priority is to be applied. The only supported value for the `size` operand is 128.

Supported addressing modes for operand a are described in *Addresses as Operands*. a must be aligned to 128 bytes.

PTX ISA Notes

Introduced in PTX ISA version 7.4.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
applypriority.global.L2::evict_normal [ptr], 128;
```

9.7.9.17 Data Movement and Conversion Instructions: `discard`

`discard`

Discard the data at the specified address range and cache level.

Syntax

```
discard{.global}.level  [a], size;

.level = { .L2 };
```

Description

Semantically, this behaves like a weak write of an *unstable indeterminate value*: reads of memory locations with *unstable indeterminate values* may return different bit patterns each time until the memory is overwritten. This operation *hints* to the implementation that data in the specified cache `.level` can be destructively discarded without writing it back to memory.

The operand `size` is an integer constant that specifies the length in bytes of the address range `[a, a + size)` to write *unstable indeterminate values* into. The only supported value for the `size` operand is 128.

If no state space is specified then *Generic Addressing* is used. If the specified address does not fall within the address window of `.global` state space then the behavior is undefined.

Supported addressing modes for address operand a are described in *Addresses as Operands*. a must be aligned to 128 bytes.

PTX ISA Notes

Introduced in PTX ISA version 7.4.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
discard.global.L2 [ptr], 128;
ld.weak.u32 r0, [ptr];
ld.weak.u32 r1, [ptr];
// The values in r0 and r1 may differ!
```

9.7.9.18 Data Movement and Conversion Instructions: `createpolicy`

`createpolicy`

Create a cache eviction policy for the specified cache level.

Syntax

```
// Range-based policy
createpolicy.range{.global}.level::primary_priority{.level::secondary_priority}.b64
                                    cache-policy, [a], primary-size, total-size;

// Fraction-based policy
createpolicy.fractional.level::primary_priority{.level::secondary_priority}.b64
                                    cache-policy{, fraction};

// Converting the access property from CUDA APIs
createpolicy.cvt.L2.b64             cache-policy, access-property;

.level::primary_priority =   { .L2::evict_last, .L2::evict_normal,
                               .L2::evict_first, .L2::evict_unchanged };
.level::secondary_priority = { .L2::evict_first, .L2::evict_unchanged };
```

Description

The `createpolicy` instruction creates a cache eviction policy for the specified cache level in an opaque 64-bit register specified by the destination operand `cache-policy`. The cache eviction policy specifies how cache eviction priorities are applied to global memory addresses used in memory operations with `.level::cache_hint` qualifier.

There are two types of cache eviction policies:

- Range-based policy

  The cache eviction policy created using `createpolicy.range` specifies the cache eviction behaviors for the following three address ranges:

  - `[a .. a + (primary-size - 1)]` referred to as primary range.
  - `[a + primary-size .. a + (total-size - 1)]` referred to as trailing secondary range.
  - `[a - (total-size - primary-size) .. (a - 1)]` referred to as preceding secondary range.

  When a range-based cache eviction policy is used in a memory operation with `.level::cache_hint` qualifier, the eviction priorities are applied as follows:

  - If the memory address falls in the primary range, the eviction priority specified by `.L2::primary_priority` is applied.
  - If the memory address falls in any of the secondary ranges, the eviction priority specified by `.L2::secondary_priority` is applied.
  - If the memory address does not fall in either of the above ranges, then the applied eviction priority is unspecified.

  The 32-bit operand `primary-size` specifies the size, in bytes, of the primary range. The 32-bit operand `total-size` specifies the combined size, in bytes, of the address range including primary and secondary ranges. The value of `primary-size` must be less than or equal to the value of `total-size`. Maximum allowed value of `total-size` is 4GB.

  If `.L2::secondary_priority` is not specified, then it defaults to `.L2::evict_unchanged`.

  If no state space is specified then *Generic Addressing* is used. If the specified address does not fall within the address window of `.global` state space then the behavior is undefined.

- Fraction-based policy

  A memory operation with `.level::cache_hint` qualifier can use the fraction-based cache eviction policy to request the cache eviction priority specified by `.L2:primary_priority` to be applied to a fraction of cache accesses specified by the 32-bit floating point operand `fraction`. The remainder of the cache accesses get the eviction priority specified by `.L2::secondary_priority`. This implies that in a memory operation that uses a fraction-based cache policy, the memory access has a probability specified by the operand `fraction` of getting the cache eviction priority specified by `.L2::primary_priority`.

  The valid range of values for the operand `fraction` is `(0.0, .., 1.0]`. If the operand `fraction` is not specified, it defaults to 1.0.

  If `.L2::secondary_priority` is not specified, then it defaults to `.L2::evict_unchanged`.

The access property created using the CUDA APIs can be converted into cache eviction policy by the instruction `createpolicy.cvt`. The source operand `access-property` is a 64-bit opaque register. Refer to *CUDA programming guide* for more details.

PTX ISA Notes

Introduced in PTX ISA version 7.4.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
createpolicy.fractional.L2::evict_last.b64                      policy, 1.0;
createpolicy.fractional.L2::evict_last.L2::evict_unchanged.b64  policy, 0.5;

createpolicy.range.L2::evict_last.L2::evict_first.b64
                                            policy, [ptr], 0x100000, 0x200000;

// access-prop is created by CUDA APIs.
createpolicy.cvt.L2.b64 policy, access-prop;
```

9.7.9.19 Data Movement and Conversion Instructions: `isspacep`

`isspacep`

Query whether a generic address falls within a specified state space window.

Syntax

```
isspacep.space  p, a;    // result is .pred

.space = { const, .global, .local, .shared{::cta, ::cluster}, .param{::entry} };
```

Description

Write predicate register `p` with 1 if generic address `a` falls within the specified state space window and with `0` otherwise. Destination `p` has type `.pred`; the source address operand must be of type `.u32` or `.u64`.

`isspacep.param{::entry}` returns 1 if the generic address falls within the window of *Kernel Function Parameters*, otherwise returns `0`. If `.param` is specified without any sub-qualifiers then it defaults to `.param::entry`.

`isspacep.global` returns 1 for *Kernel Function Parameters* as `.param` window is contained within the `.global` window.

If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

Note: `ispacep.shared::cluster` will return 1 for every shared memory address that is accessible to the threads in the cluster, whereas `ispacep.shared::cta` will return 1 only if the address is of a variable declared in the executing CTA.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

`isspacep.const` introduced in PTX ISA version 3.1.

`isspacep.param` introduced in PTX ISA version 7.7.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for sub-qualifier `::entry` on `.param` space introduced in PTX ISA version 8.3.

Target ISA Notes

`isspacep` requires `sm_20` or higher.

`isspacep.param{::entry}` requires `sm_70` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Examples

```
isspacep.const           iscnst, cptr;
isspacep.global          isglbl, gptr;
isspacep.local           islcl,  lptr;
isspacep.shared          isshrd, sptr;
isspacep.param::entry    isparam, pptr;
isspacep.shared::cta     isshrdcta, sptr;
isspacep.shared::cluster ishrdany sptr;
```

9.7.9.20 Data Movement and Conversion Instructions: `cvta`

`cvta`

Convert address from `.const`, *Kernel Function Parameters* (`.param`), `.global`, `.local`, or `.shared` state space to generic, or vice-versa. Take the generic address of a variable declared in `.const`, *Kernel Function Parameters* (`.param`), `.global`, `.local`, or `.shared` state space.

Syntax

```
// convert const, global, local, or shared address to generic address
cvta.space.size  p, a;        // source address in register a
cvta.space.size  p, var;      // get generic address of var
cvta.space.size  p, var+imm;  // generic address of var+offset

// convert generic address to const, global, local, or shared address
cvta.to.space.size  p, a;

.space = { .const, .global, .local, .shared{::cta, ::cluster}, .param{::entry} };
.size  = { .u32, .u64 };
```

Description

Convert a `const`, *Kernel Function Parameters* (`.param`), `global`, `local`, or `shared` address to a generic address, or vice-versa. The source and destination addresses must be the same size. Use `cvt.u32.u64` or `cvt.u64.u32` to truncate or zero-extend addresses.

For variables declared in `.const`, *Kernel Function Parameters* (`.param`), `.global`, `.local`, or `.shared` state space, the generic address of the variable may be taken using `cvta`. The source is either a register or a variable defined in `const`, *Kernel Function Parameters* (`.param`), `global`, `local`, or `shared` memory with an optional offset.

When converting a generic address into a `const`, *Kernel Function Parameters* (`.param`), `global`, `local`, or `shared` address, the resulting address is undefined in cases where the generic address does not fall within the address window of the specified state space. A program may use `isspacep` to guard against such incorrect behavior.

For `cvta` with `.shared` state space, the address must belong to the space specified by `::cta` or `::cluster` sub-qualifier, otherwise the behavior is undefined. If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

If `.param` is specified without any sub-qualifiers then it defaults to `.param::entry`. For `.param{::entry}` state space, operand `a` must be a kernel parameter address, otherwise behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

`cvta.const` and `cvta.to.const` introduced in PTX ISA version 3.1.

`cvta.param` and `cvta.to.param` introduced in PTX ISA version 7.7.

Note: The current implementation does not allow generic pointers to `const` space variables in programs that contain pointers to constant buffers passed as kernel parameters.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for sub-qualifier `::entry` on `.param` space introduced in PTX ISA version 8.3.

Target ISA Notes

`cvta` requires `sm_20` or higher.

`cvta.param{::entry}` and `cvta.to.param{::entry}` requires `sm_70` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Examples

```
cvta.const.u32   ptr,cvar;
cvta.local.u32   ptr,lptr;
cvta.shared::cta.u32  p,As+4;
cvta.shared::cluster.u32 ptr, As;
cvta.to.global.u32  p,gptr;
cvta.param.u64   ptr,pvar;
cvta.to.param::entry.u64  epptr, ptr;
```

9.7.9.21 Data Movement and Conversion Instructions: cvt

cvt

Convert a value from one type to another.

Syntax

```
cvt{.irnd}{.ftz}{.sat}.dtype.atype          d, a;  // integer rounding
cvt{.frnd}{.ftz}{.sat}.dtype.atype          d, a;  // fp rounding

cvt.frnd2{.relu}{.satfinite}.f16.f32        d, a;
cvt.frnd2{.relu}{.satfinite}.f16x2.f32      d, a, b;
cvt.rs{.relu}{.satfinite}.f16x2.f32         d, a, b, rbits;

cvt.frnd2{.relu}{.satfinite}.bf16.f32       d, a;
cvt.frnd2{.relu}{.satfinite}.bf16x2.f32     d, a, b;
cvt.rs{.relu}{.satfinite}.bf16x2.f32        d, a, b, rbits;

cvt.rna{.satfinite}.tf32.f32                d, a;
cvt.frnd2{.satfinite}{.relu}.tf32.f32       d, a;

cvt.rn.satfinite{.relu}.f8x2type.f32        d, a, b;
cvt.rn.satfinite{.relu}.f8x2type.f16x2      d, a;
cvt.rn.{.relu}.f16x2.f8x2type               d, a;
cvt.rs{.relu}.satfinite.f8x4type.f32        d, {a, b, e, f}, rbits;

cvt.rn.satfinite{.relu}.f4x2type.f32        d, a, b;
cvt.rn{.relu}.f16x2.f4x2type                d, a;
cvt.rs{.relu}.satfinite.f4x4type.f32        d, {a, b, e, f}, rbits;

cvt.rn.satfinite{.relu}.f6x2type.f32        d, a, b;
cvt.rn{.relu}.f16x2.f6x2type                d, a;
cvt.rs{.relu}.satfinite.f6x4type.f32        d, {a, b, e, f}, rbits;

cvt.frnd3{.satfinite}.ue8m0x2.f32           d, a, b;
cvt.frnd3{.satfinite}.ue8m0x2.bf16x2        d, a;
cvt.rn.bf16x2.ue8m0x2                       d, a;

.irnd   = { .rni, .rzi, .rmi, .rpi };
.frnd   = { .rn,  .rz,  .rm,  .rp  };
.frnd2  = { .rn,  .rz };
.frnd2  = { .rn,  .rz };
```

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```
.frnd3  = { .rz,  .rp };
.dtype = .atype = { .u8,   .u16, .u32, .u64,
                    .s8,   .s16, .s32, .s64,
                    .bf16, .f16, .f32, .f64 };
.f8x2type = { .e4m3x2, .e5m2x2 };
.f4x2type = { .e2m1x2 };
.f6x2type = { .e2m3x2, .e3m2x2 };
.f4x4type = { .e2m1x4 };
.f8x4type = { .e4m3x4, .e5m2x4 };
.f6x4type = { .e2m3x4, .e3m2x4 };
```

Description

Convert between different types and sizes.

For `.f16x2` and `.bf16x2` instruction type, two inputs a and b of `.f32` type are converted into `.f16` or `.bf16` type and the converted values are packed in the destination register d, such that the value converted from input a is stored in the upper half of d and the value converted from input b is stored in the lower half of d

For `.f16x2` instruction type, destination operand d has `.f16x2` or `.b32` type. For `.bf16` instruction type, operand d has `.b16` type. For `.bf16x2` instruction type, operand d has `.b32` type. For `.tf32` instruction type, operand d has `.b32` type.

When converting to `.e4m3x2/.e5m2x2` data formats, the destination operand d has `.b16` type. When converting two `.f32` inputs to `.e4m3x2/.e5m2x2`, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from input a is stored in the upper 8 bits of d and the value converted from input b is stored in the lower 8 bits of d. When converting an `.f16x2` input to `.e4m3x2/ .e5m2x2`, each `.f16` input from operand a is converted to the specified format. The converted values are packed in the destination operand d such that the value converted from the upper 16 bits of input a is stored in the upper 8 bits of d and the value converted from the lower 16 bits of input a is stored in the lower 8 bits of d.

When converting from `.e4m3x2/.e5m2x2` to `.f16x2`, source operand a has `.b16` type. Each 8-bit input value in operand a is converted to `.f16` type. The converted values are packed in the destination operand d such that the value converted from the upper 8 bits of a is stored in the upper 16 bits of d and the value converted from the lower 8 bits of a is stored in the lower 16 bits of d.

When converting to `.e2m1x2` data formats, the destination operand d has `.b8` type. When converting two `.f32` inputs to `.e2m1x2`, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from input a is stored in the upper 4 bits of d and the value converted from input b is stored in the lower 4 bits of d.

When converting from `.e2m1x2` to `.f16x2`, source operand a has `.b8` type. Each 4-bit input value in operand a is converted to `.f16` type. The converted values are packed in the destination operand d such that the value converted from the upper 4 bits of a is stored in the upper 16 bits of d and the value converted from the lower 4 bits of a is stored in the lower 16 bits of d.

When converting to `.e2m1x4` data format, the destination operand d has `.b16` type. When converting four `.f32` inputs to `.e2m1x4`, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from inputs a, b, e, f are stored in each 4 bits starting from upper bits of d.

When converting to `.e2m3x2/.e3m2x2` data formats, the destination operand d has `.b16` type. When converting two `.f32` inputs to `.e2m3x2/.e3m2x2`, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from

input a is stored in the upper 8 bits of d with 2 MSB bits padded with zeros and the value converted from input b is stored in the lower 8 bits of d with 2 MSB bits padded with zeros.

When converting from .e2m3x2/.e3m2x2 to .f16x2, source operand a has .b16 type. Each 8-bit input value with 2 MSB bits 0 in operand a is converted to .f16 type. The converted values are packed in the destination operand d such that the value converted from the upper 8 bits of a is stored in the upper 16 bits of d and the value converted from the lower 8 bits of a is stored in the lower 16 bits of d.

When converting to .e5m2x4/.e4m3x4/.e3m2x4/.e2m3x4 data format, the destination operand d has .b32 type. When converting four .f32 inputs to .e5m2x4/.e4m3x4/.e3m2x4/.e2m3x4, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from inputs a, b, e, f are stored in each 8 bits starting from upper bits of d. For .e3m2x4/.e2m3x4, each 8-bit output will have 2 MSB bits padded with zeros.

When converting to .ue8m0x2 data formats, the destination operand d has .b16 type. When converting two .f32 or two packed .bf16 inputs to .ue8m0x2, each input is converted to the specified format, and the converted values are packed in the destination operand d such that the value converted from input a is stored in the upper 8 bits of d and the value converted from input b is stored in the lower 8 bits of d.

When converting from .ue8m0x2 to .bf16x2, source operand a has .b16 type. Each 8-bit input value in operand a is converted to .bf16 type. The converted values are packed in the destination operand d such that the value converted from the upper 8 bits of a is stored in the upper 16 bits of d and the value converted from the lower 8 bits of a is stored in the lower 16 bits of d.

rbits is a .b32 type register operand used for providing random bits for .rs rounding mode.

When converting to .f16x2, two 16-bit values are provided from rbits where 13 LSBs from upper 16-bits are used as random bits for operand a with 3 MSBs are 0 and 13 LSBs from lower 16-bits are used as random bits for operand b with 3 MSBs are 0.

When converting to .bf16x2, two 16-bit values are provided from rbits where upper 16-bits are used as random bits for operand a and lower 16-bits are used as random bits for operand b.

When converting to .e4m3x4/.e5m2x4/.e2m3x4/.e3m2x4, two 16-bit values are provided from rbits where lower 16-bits are used for operands e, f and upper 16 bits are used for operands a, b.

When converting to .e2m1x4, two 16-bit values are provided from rbits where lower 8-bits from both 16-bits half of rbits are used for operands e, f and upper 8-bits from both 16-bits half of rbits are used for operands a, b.

Rounding modifier is mandatory in all of the following cases:

- float-to-float conversions, when destination type is smaller than source type
- All float-to-int conversions
- All int-to-float conversions
- All conversions involving .f16x2, .e4m3x2, .e5m2x2,, .bf16x2, .tf32, .e2m1x2, .e2m3x2, .e3m2x2, .e4m3x4, .e5m2x4, .e2m1x4, .e2m3x4, .e3m2x4 and .ue8m0x2 instruction types.

.satfinite modifier is only supported for conversions involving the following types:

- .e4m3x2, .e5m2x2, .e2m1x2, .e2m3x2, .e3m2x2, .e4m3x4, .e5m2x4, .e2m1x4, .e2m3x4, .e3m2x4 destination types. .satfinite modifier is mandatory for such conversions.
- .f16, .bf16, .f16x2, .bf16x2, .tf32, .ue8m0x2 as destination types.

Semantics

```
if (/* inst type is .f16x2 or .bf16x2 */) {
    d[31:16] = convert(a);
    d[15:0]  = convert(b);
} else if (/* inst destination type is .e5m2x2 or .e4m3x2 or .ue8m0x2 */) {
    d[15:8] = convert(a);
    d[7:0]  = convert(b);
} else if (/* inst destination type is .e2m1x2 */) {
    d[7:4] = convert(a);
    d[3:0] = convert(b);
} else if (/* inst destination type is .e2m3x2 or .e3m2x2 */) {
    d[15:14] = 0;
    d[13:8] = convert(a);
    d[7:6] = 0;
    d[5:0] = convert(b);
} else if (/* inst destination type is .e2m1x4 */) {
    d[15:12] = convert(a);
    d[11:8] = convert(b);
    d[7:4] = convert(e);
    d[3:0] = convert(f);
} else if (/* inst destination type is .e4m3x4 or .e5m2x4 */) {
    d[31:24] = convert(a);
    d[23:16] = convert(b);
    d[15:8] = convert(e);
    d[7:0] = convert(f);
} else if (/* inst destination type is .e2m3x4 or .e3m2x4 */) {
    d[31:30] = 0;
    d[29:24] = convert(a);
    d[23:22] = 0;
    d[21:16] = convert(b);
    d[15:14] = 0;
    d[13:8] = convert(e);
    d[7:6] = 0;
    d[5:0] = convert(f);
} else {
    d = convert(a);
}
```

// Random bits `rbits` semantics for `.rs` rounding:

1. Destination type `.f16`: Refer Figure 38 for random bits layout details.

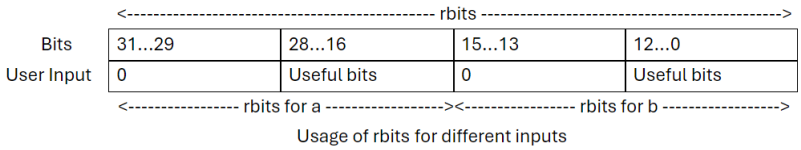

Figure 38: Random bits layout for `.rs` rounding with `.f16` destination type

2. Destination type `.bf16`: Refer Figure 39 for random bits layout details.
3. Destination type `.e2m1x4`: Refer Figure 40 for random bits layout details.
4. Destination type `.e5m2x4`, `.e4m3x4`, `.e3m2x4`, `.e2m3x4`: Refer Figure 41 for random bits layout details.

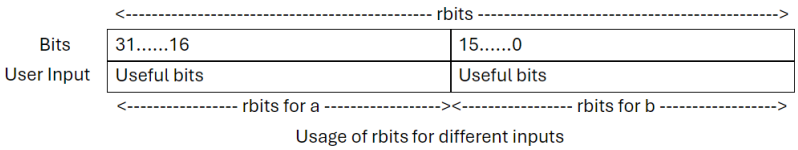

Figure 39: Random bits layout for `.rs` rounding with `.bf16` destination type

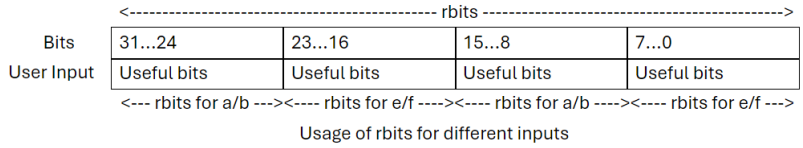

Figure 40: Random bits layout for `.rs` rounding with `.e2m1x4` destination type

Integer Notes

Integer rounding is required for float-to-integer conversions, and for same-size float-to-float conversions where the value is rounded to an integer. Integer rounding is illegal in all other instances.

Integer rounding modifiers:

`.rni`
round to nearest integer, choosing even integer if source is equidistant between two integers

`.rzi`
round to nearest integer in the direction of zero

`.rmi`
round to nearest integer in direction of negative infinity

`.rpi`
round to nearest integer in direction of positive infinity

In float-to-integer conversions, depending upon conversion types, `NaN` input results in following value:

1. Zero if source is not `.f64` and destination is not `.s64`, `.u64`.
2. Otherwise `1 << (BitWidth(dst) - 1)` corresponding to the value of `(MAXINT >> 1) + 1` for unsigned type or `MININT` for signed type.

Subnormal numbers:

`sm_20+`
By default, subnormal numbers are supported.

For `cvt.ftz.dtype.f32` float-to-integer conversions and `cvt.ftz.f32.f32` float-to-float

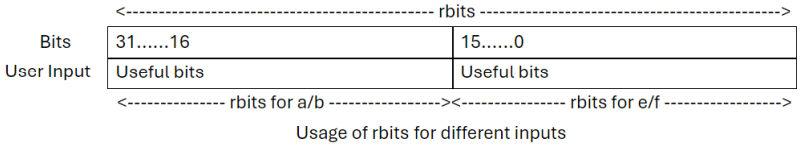

Figure 41: Random bits layout for `.rs` rounding with `.e5m2x4/.e4m3x4/.e3m2x4/.e2m3x4` destination type

conversions with integer rounding, subnormal inputs are flushed to sign-preserving zero. Modifier `.ftz` can only be specified when either `.dtype` or `.atype` is `.f32` and applies only to single precision (`.f32`) inputs and results.

sm_1x
For `cvt.ftz.dtype.f32` float-to-integer conversions and `cvt.ftz.f32.f32` float-to-float conversions with integer rounding, subnormal inputs are flushed to sign-preserving zero. The optional `.ftz` modifier may be specified in these cases for clarity.

Note: In PTX ISA versions 1.4 and earlier, the `cvt` instruction did not flush single-precision subnormal inputs or results to zero if the destination type size was 64-bits. The compiler will preserve this behavior for legacy PTX code.

Saturation modifier:

.sat
For integer destination types, `.sat` limits the result to `MININT..MAXINT` for the size of the operation. Note that saturation applies to both signed and unsigned integer types.

The saturation modifier is allowed only in cases where the destination type's value range is not a superset of the source type's value range; i.e., the `.sat` modifier is illegal in cases where saturation is not possible based on the source and destination types.

For float-to-integer conversions, the result is clamped to the destination range by default; i.e, `.sat` is redundant.

Floating Point Notes

Floating-point rounding is required for float-to-float conversions that result in loss of precision, and for integer-to-float conversions. Floating-point rounding is illegal in all other instances.

Floating-point rounding modifiers:

.rn rounding to nearest, with ties to even

.rna
rounding to nearest, with ties away from zero

.rz rounding toward zero

.rm rounding toward negative infinity

.rp rounding toward positive infinity

.rs Stochastic rounding is achieved through the use of the supplied random bits. Operation's result is rounded in the direction toward zero or away from zero based on the carry out of the integer addition of the supplied random bits (`rbits`) to the truncated off (discarded) bits of mantissa from the input.

A floating-point value may be rounded to an integral value using the integer rounding modifiers (see Integer Notes). The operands must be of the same size. The result is an integral value, stored in floating-point format.

Subnormal numbers:

sm_20+
By default, subnormal numbers are supported. Modifier `.ftz` may be specified to flush single-precision subnormal inputs and results to sign-preserving zero. Modifier `.ftz` can only be specified when either `.dtype` or `.atype` is `.f32` and applies only to single precision (`.f32`) inputs and results.

sm_1x
Single-precision subnormal inputs and results are flushed to sign-preserving zero. The optional `.ftz` modifier may be specified in these cases for clarity.

Note: In PTX ISA versions 1.4 and earlier, the `cvt` instruction did not flush single-precision subnormal inputs or results to zero if either source or destination type was `.f64`. The compiler will preserve this behavior for legacy PTX code. Specifically, if the PTX ISA version is 1.4 or earlier, single-precision subnormal inputs and results are flushed to sign-preserving zero only for `cvt.f32.f16`, `cvt.f16.f32`, and `cvt.f32.f32` instructions.

Saturation modifier:

.sat:
For floating-point destination types, `.sat` limits the result to the range [0.0, 1.0]. NaN results are flushed to positive zero. Applies to `.f16`, `.f32`, and `.f64` types.

.relu:
For `.f16`, `.f16x2`, `.bf16`, `.bf16x2`, `.e4m3x2`, `.e5m2x2`, `.e2m1x2`, `.e2m3x2`, `.e3m2x2`, `.e4m3x4`, `.e5m2x4`, `.e2m1x4`, `.e2m3x4`, `.e3m2x4` and `.tf32` destination types, `.relu` clamps the result to 0 if negative. NaN results are converted to canonical NaN.

.satfinite:
For `.f16`, `.f16x2`, `.bf16`, `.bf16x2`, `.e4m3x2`, `.e5m2x2`, `.ue8m0x2`, `.e4m3x4`, `.e5m2x4` and `.tf32` destination formats, if the input value is NaN, then the result is NaN in the specified destination format. For `.e2m1x2`, `.e2m3x2`, `.e3m2x2`, `.e2m1x4`, `.e2m3x4`, `.e3m2x4` destination formats NaN results are converted to positive *MAX_NORM*. If the absolute value of input (ignoring sign) is greater than *MAX_NORM* of the specified destination format, then the result is sign-preserved *MAX_NORM* of the destination format and a positive *MAX_NORM* in `.ue8m0x2` for which the destination sign is not supported.

Notes

A source register wider than the specified type may be used, except when the source operand has `.bf16` or `.bf16x2` format. The lower n bits corresponding to the instruction-type width are used in the conversion. See *Operand Size Exceeding Instruction-Type Size* for a description of these relaxed type-checking rules.

A destination register wider than the specified type may be used, except when the destination operand has `.bf16`, `.bf16x2` or `.tf32` format. The result of conversion is sign-extended to the destination register width for signed integers, and is zero-extended to the destination register width for unsigned, bit-size, and floating-point types. See *Operand Size Exceeding Instruction-Type Size* for a description of these relaxed type-checking rules.

For `cvt.f32.bf16`, NaN input yields unspecified NaN.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`.relu` modifier and {`.f16x2`, `.bf16`, `.bf16x2`, `.tf32`} destination formats introduced in PTX ISA version 7.0.

`cvt.bf16.{u8/s8/u16/s16/u32/s32/u64/s64/f16/f64/bf16}`, `cvt.{u8/s8/u16/s16/u32/s32/u64/s64/f16/f64}.bf16`, and `cvt.tf32.f32.{relu}.{rn/rz}` introduced in PTX ISA 7.8.

`cvt` with `.e4m3x2`/`.e5m2x2` for `sm_90` or higher introduced in PTX ISA version 7.8.

`cvt.satfinite.{e4m3x2, e5m2x2}.{f32, f16x2}` for `sm_90` or higher introduced in PTX ISA version 7.8.

`cvt` with `.e4m3x2/.e5m2x2` for `sm_89` introduced in PTX ISA version 8.1.

`cvt.satfinite.{e4m3x2, e5m2x2}.{f32, f16x2}` for `sm_89` introduced in PTX ISA version 8.1.

`cvt.satfinite.{f16, bf16, f16x2, bf16x2, tf32}.f32` introduced in PTX ISA version 8.1.

`cvt.{rn/rz}.satfinite.tf32.f32` introduced in PTX ISA version 8.6.

`cvt.rn.satfinite{.relu}.{e2m1x2/e2m3x2/e3m2x2/ue8m0x2}.f32` introduced in PTX ISA version 8.6.

`cvt.rn{.relu}.f16x2.{e2m1x2/e2m3x2/e3m2x2}` introduced in PTX ISA version 8.6.

`cvt.{rp/rz}{.satfinite}{.relu}.ue8m0x2.bf16x2` introduced in PTX ISA version 8.6.

`cvt.{rz/rp}.satfinite.ue8m0x2.f32` introduced in PTX ISA version 8.6.

`cvt.rn.bf16x2.ue8m0x2` introduced in PTX ISA version 8.6.

`.rs` rounding mode introduced in PTX ISA version 8.7.

`cvt.rs{.e2m1x4/.e4m3x4/.e5m2x4/.e3m2x4/.e2m3x4}.f32` introduced in PTX ISA version 8.7.

Target ISA Notes

`cvt` to or from `.f64` requires `sm_13` or higher.

`.relu` modifier and {`.f16x2`, `.bf16`, `.bf16x2`, `.tf32`} destination formats require `sm_80` or higher.

`cvt.bf16.{u8/s8/u16/s16/u32/s32/u64/s64/f16/f64/bf16}`, `cvt.{u8/s8/u16/s16/u32/s32/u64/s64/f16/f64}.bf16`, and `cvt.tf32.f32.{relu}.{rn/rz}` require `sm_90` or higher.

`cvt` with `.e4m3x2/.e5m2x2` requires `sm89` or higher.

`cvt.satfinite.{e4m3x2, e5m2x2}.{f32, f16x2}` requires `sm_89` or higher.

`cvt.{rn/rz}.satfinite.tf32.f32` requires `sm_100` or higher.

`cvt.rn.satfinite{.relu}.{e2m1x2/e2m3x2/e3m2x2/ue8m0x2}.f32` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

`cvt.rn{.relu}.f16x2.{e2m1x2/e2m3x2/e3m2x2}` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:

- sm_100f or higher in the same family
- sm_101f or higher in the same family
- sm_120f or higher in the same family

cvt.{rz/rp}{.satfinite}{.relu}.ue8m0x2.bf16x2 is supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

cvt.{rz/rp}.satfinite.ue8m0x2.f32 is supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

cvt.rn.bf16x2.ue8m0x2 is supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

.rs rounding mode requires sm_100a.

cvt.rs{.e2m1x4/.e4m3x4/.e5m2x4/.e3m2x4/.e2m3x4}.f32 requires sm_100a.

Examples

```
cvt.f32.s32 f,i;
cvt.s32.f64 j,r;     // float-to-int saturates by default
cvt.rni.f32.f32 x,y; // round to nearest int, result is fp
cvt.f32.f32 x,y;     // note .ftz behavior for sm_1x targets
cvt.rn.relu.f16.f32      b, f;        // result is saturated with .relu saturation
↪mode
cvt.rz.f16x2.f32         b1, f, f1;   // convert two fp32 values to packed fp16
↪outputs
cvt.rn.relu.satfinite.f16x2.f32    b1, f, f1;   // convert two fp32 values to packed
↪fp16 outputs with .relu saturation on each output
cvt.rn.bf16.f32          b, f;        // convert fp32 to bf16
cvt.rz.relu.satfinite.bf16.f3 2    b, f;        // convert fp32 to bf16 with .relu
↪and .satfinite saturation
cvt.rz.satfinite.bf16x2.f32        b1, f, f1;   // convert two fp32 values to packed
↪bf16 outputs
cvt.rn.relu.bf16x2.f32   b1, f, f1;   // convert two fp32 values to packed bf16
↪outputs with .relu saturation on each output
cvt.rna.satfinite.tf32.f32         b1, f;       // convert fp32 to tf32 format
cvt.rn.relu.tf32.f32     d, a;        // convert fp32 to tf32 format
cvt.f64.bf16.rp          f, b;        // convert bf16 to f64 format
cvt.bf16.f16.rz          b, f         // convert f16 to bf16 format
cvt.bf16.u64.rz          b, u         // convert u64 to bf16 format
cvt.s8.bf16.rpi          s, b         // convert bf16 to s8 format
cvt.bf16.bf16.rpi        b1, b2       // convert bf16 to corresponding int
↪represented in bf16 format
cvt.rn.satfinite.e4m3x2.f32 d, a, b;  // convert a, b to .e4m3 and pack as .e4m3x2
↪output
cvt.rn.relu.satfinite.e5m2x2.f16x2 d, a; // unpack a and convert the values to .e5m2
↪outputs with .relu
                                         // saturation on each output and pack as .
↪e5m2x2
cvt.rn.f16x2.e4m3x2 d, a;             // unpack a, convert two .e4m3 values to packed
↪f16x2 output
cvt.rn.satfinite.tf32.f32 d, a;       // convert fp32 to tf32 format
cvt.rn.relu.f16x2.e2m1x2 d, a;        // unpack a, convert two .e2m1 values to packed
↪f16x2 output
cvt.rn.satfinite.e2m3x2.f32 d, a, b;  // convert a, b to .e2m3 and pack as .e2m3x2
↪output
cvt.rn.relu.f16x2.e3m2x2 d, a;        // unpack a, convert two .e3m2 values to packed
↪f16x2 output

cvt.rs.f16x2.f32    d, a, b, rbits;  // convert 2 fp32 values to packed fp16 with
↪applying .rs rounding
cvt.rs.satfinite.e2m1x4.f32  d, {a, b, e, f}, rbits; // convert 4 fp32 values to
↪packed 4 e2m1 values with applying .rs rounding
```

9.7.9.22 Data Movement and Conversion Instructions: cvt.pack

cvt.pack

Convert two integer values from one integer type to another and pack the results.

Syntax

```
cvt.pack.sat.convertType.abType  d, a, b;
    .convertType  = { .u16, .s16 }
    .abType       = { .s32 }

cvt.pack.sat.convertType.abType.cType  d, a, b, c;
    .convertType  = { .u2, .s2, .u4, .s4, .u8, .s8 }
    .abType       = { .s32 }
    .cType        = { .b32 }
```

Description

Convert two 32-bit integers a and b into specified type and pack the results into d.

Destination d is an unsigned 32-bit integer. Source operands a and b are integers of type .abType and the source operand c is an integer of type .cType.

The inputs a and b are converted to values of type specified by .convertType with saturation and the results after conversion are packed into lower bits of d.

If operand c is specified then remaining bits of d are copied from lower bits of c.

Semantics

```
ta = a < MIN(convertType) ? MIN(convertType) : a;
ta = a > MAX(convertType) ? MAX(convertType) : a;
tb = b < MIN(convertType) ? MIN(convertType) : b;
tb = b > MAX(convertType) ? MAX(convertType) : b;

size = sizeInBits(convertType);
td = tb ;
for (i = size; i <= 2 * size - 1; i++) {
    td[i] = ta[i - size];
}

if (isU16(convertType) || isS16(convertType)) {
    d = td;
} else {
    for (i = 0; i < 2 * size; i++) {
        d[i] = td[i];
    }
    for (i = 2 * size; i <= 31; i++) {
        d[i] = c[i - 2 * size];
    }
}
```

`.sat` modifier limits the converted values to `MIN(convertType)`.. `MAX(convertedType)` (no overflow) if the corresponding inputs are not in the range of datatype specified as `.convertType`.

PTX ISA Notes

Introduced in PTX ISA version 6.5.

Target ISA Notes

Requires `sm_72` or higher.

Sub byte types (`.u4/.s4` and `.u2/.s2`) requires `sm_75` or higher.

Examples

```
cvt.pack.sat.s16.s32      %r1, %r2, %r3;           // 32-bit to 16-bit conversion
cvt.pack.sat.u8.s32.b32   %r4, %r5, %r6, 0;        // 32-bit to 8-bit conversion
cvt.pack.sat.u8.s32.b32   %r7, %r8, %r9, %r4;      // %r7 = { %r5, %r6, %r8, %r9 }
cvt.pack.sat.u4.s32.b32   %r10, %r12, %r13, %r14;  // 32-bit to 4-bit conversion
cvt.pack.sat.s2.s32.b32   %r15, %r16, %r17, %r18;  // 32-bits to 2-bit conversion
```

9.7.9.23 Data Movement and Conversion Instructions: `mapa`

`mapa`

Map the address of the shared variable in the target CTA.

Syntax

```
mapa{.space}.type          d, a, b;

// Maps shared memory address in register a into CTA b.
mapa.shared::cluster.type  d, a, b;

// Maps shared memory variable into CTA b.
mapa.shared::cluster.type  d, sh, b;

// Maps shared memory variable into CTA b.
mapa.shared::cluster.type  d, sh + imm, b;

// Maps generic address in register a into CTA b.
mapa.type                  d, a, b;

.space = { .shared::cluster }
.type  = { .u32, .u64 }
```

Description

Get address in the CTA specified by operand b which corresponds to the address specified by operand a.

Instruction type .type indicates the type of the destination operand d and the source operand a.

When space is .shared::cluster, source a is either a shared memory variable or a register containing a valid shared memory address and register d contains a shared memory address. When the optional qualifier .space is not specified, both a and d are registers containing generic addresses pointing to shared memory.

b is a 32-bit integer operand representing the rank of the target CTA.

Destination register d will hold an address in CTA b corresponding to operand a.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires sm_90 or higher.

Examples

```
mapa.shared::cluster.u64 d1, %reg1, cta;
mapa.shared::cluster.u32 d2, sh, 3;
mapa.u64                 d3, %reg2, cta;
```

9.7.9.24 Data Movement and Conversion Instructions: getctarank

getctarank

Generate the CTA rank of the address.

Syntax

```
getctarank{.space}.type d, a;

// Get cta rank from source shared memory address in register a.
getctarank.shared::cluster.type d, a;

// Get cta rank from shared memory variable.
getctarank.shared::cluster.type d, var;

// Get cta rank from shared memory variable+offset.
getctarank.shared::cluster.type d, var + imm;

// Get cta rank from generic address of shared memory variable in register a.
```

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```
getctarank.type d, a;

.space = { .shared::cluster }
.type  = { .u32, .u64 }
```

Description

Write the destination register `d` with the rank of the CTA which contains the address specified in operand `a`.

Instruction type `.type` indicates the type of source operand `a`.

When space is `.shared::cluster`, source `a` is either a shared memory variable or a register containing a valid shared memory address. When the optional qualifier `.space` is not specified, `a` is a register containing a generic addresses pointing to shared memory. Destination `d` is always a 32-bit register which holds the rank of the CTA.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
getctarank.shared::cluster.u32 d1, addr;
getctarank.shared::cluster.u64 d2, sh + 4;
getctarank.u64                 d3, src;
```

9.7.9.25 Data Movement and Conversion Instructions: Asynchronous copy

An asynchronous copy operation performs the underlying operation asynchronously in the background, thus allowing the issuing threads to perform subsequent tasks.

An asynchronous copy operation can be a *bulk* operation that operates on a large amount of data, or a *non-bulk* operation that operates on smaller sized data. The amount of data handled by a bulk asynchronous operation must be a multiple of 16 bytes.

An asynchronous copy operation typically includes the following sequence:

- Optionally, reading from the tensormap.
- Reading data from the source location(s).
- Writing data to the destination location(s).
- Writes being made visible to the executing thread or other threads.

9.7.9.25.1 Completion Mechanisms for Asynchronous Copy Operations

A thread must explicitly wait for the completion of an asynchronous copy operation in order to access the result of the operation. Once an asynchronous copy operation is initiated, modifying the source memory location or tensor descriptor or reading from the destination memory location before the asynchronous operation completes, exhibits undefined behavior.

This section describes two asynchronous copy operation completion mechanisms supported in PTX: Async-group mechanism and mbarrier-based mechanism.

Asynchronous operations may be tracked by either of the completion mechanisms or both mechanisms. The tracking mechanism is instruction/instruction-variant specific.

9.7.9.25.1.1 Async-group mechanism

When using the async-group completion mechanism, the issuing thread specifies a group of asynchronous operations, called *async-group*, using a *commit* operation and tracks the completion of this group using a *wait* operation. The thread issuing the asynchronous operation must create separate *async-groups* for bulk and non-bulk asynchronous operations.

A *commit* operation creates a per-thread *async-group* containing all prior asynchronous operations tracked by *async-group* completion and initiated by the executing thread but none of the asynchronous operations following the commit operation. A committed asynchronous operation belongs to a single *async-group*.

When an *async-group* completes, all the asynchronous operations belonging to that group are complete and the executing thread that initiated the asynchronous operations can read the result of the asynchronous operations. All *async-groups* committed by an executing thread always complete in the order in which they were committed. There is no ordering between asynchronous operations within an *async-group*.

A typical pattern of using *async-group* as the completion mechanism is as follows:

- Initiate the asynchronous operations.
- Group the asynchronous operations into an *async-group* using a *commit* operation.
- Wait for the completion of the async-group using the wait operation.
- Once the *async-group* completes, access the results of all asynchronous operations in that *async-group*.

9.7.9.25.1.2 Mbarrier-based mechanism

A thread can track the completion of one or more asynchronous operations using the current phase of an *mbarrier object*. When the current phase of the *mbarrier object* is complete, it implies that all asynchronous operations tracked by this phase are complete, and all threads participating in that *mbarrier object* can access the result of the asynchronous operations.

The *mbarrier object* to be used for tracking the completion of an asynchronous operation can be either specified along with the asynchronous operation as part of its syntax, or as a separate operation. For a bulk asynchronous operation, the *mbarrier object* must be specified in the asynchronous operation, whereas for non-bulk operations, it can be specified after the asynchronous operation.

A typical pattern of using mbarrier-based completion mechanism is as follows:

- Initiate the asynchronous operations.

- Set up an *mbarrier object* to track the asynchronous operations in its current phase, either as part of the asynchronous operation or as a separate operation.
- Wait for the *mbarrier object* to complete its current phase using `mbarrier.test_wait` or `mbarrier.try_wait`.
- Once the `mbarrier.test_wait` or `mbarrier.try_wait` operation returns `True`, access the results of the asynchronous operations tracked by the *mbarrier object*.

9.7.9.25.2 Async Proxy

The `cp{.reduce}.async.bulk` operations are performed in the *asynchronous proxy* (or *async proxy*).

Accessing the same memory location across multiple proxies needs a cross-proxy fence. For the *async proxy*, `fence.proxy.async` should be used to synchronize memory between *generic proxy* and the *async proxy*.

The completion of a `cp{.reduce}.async.bulk` operation is followed by an implicit *generic-async* proxy fence. So the result of the asynchronous operation is made visible to the generic proxy as soon as its completion is observed. *Async-group* OR *mbarrier-based* completion mechanism must be used to wait for the completion of the `cp{.reduce}.async.bulk` instructions.

9.7.9.25.3 Data Movement and Conversion Instructions: Non-bulk copy

9.7.9.25.3.1 Data Movement and Conversion Instructions: cp.async

cp.async

Initiates an asynchronous copy operation from one state space to another.

Syntax

```
cp.async.ca.shared{::cta}.global{.level::cache_hint}{.level::prefetch_size}
                         [dst], [src], cp-size{, src-size}{, cache-policy} ;
cp.async.cg.shared{::cta}.global{.level::cache_hint}{.level::prefetch_size}
                         [dst], [src], 16{, src-size}{, cache-policy} ;
cp.async.ca.shared{::cta}.global{.level::cache_hint}{.level::prefetch_size}
                         [dst], [src], cp-size{, ignore-src}{, cache-policy} ;
cp.async.cg.shared{::cta}.global{.level::cache_hint}{.level::prefetch_size}
                         [dst], [src], 16{, ignore-src}{, cache-policy} ;

.level::cache_hint =     { .L2::cache_hint }
.level::prefetch_size =  { .L2::64B, .L2::128B, .L2::256B }
cp-size =                { 4, 8, 16 }
```

Description

`cp.async` is a non-blocking instruction which initiates an asynchronous copy operation of data from the location specified by source address operand `src` to the location specified by destination address operand `dst`. Operand `src` specifies a location in the global state space and `dst` specifies a location in the shared state space.

Operand `cp-size` is an integer constant which specifies the size of data in bytes to be copied to the destination `dst`. `cp-size` can only be 4, 8 and 16.

Instruction `cp.async` allows optionally specifying a 32-bit integer operand `src-size`. Operand `src-size` represents the size of the data in bytes to be copied from `src` to `dst` and must be less than `cp-size`. In such case, remaining bytes in destination `dst` are filled with zeros. Specifying `src-size` larger than `cp-size` results in undefined behavior.

The optional and non-immediate predicate argument `ignore-src` specifies whether the data from the source location `src` should be ignored completely. If the source data is ignored then zeros will be copied to destination `dst`. If the argument `ignore-src` is not specified then it defaults to `False`.

Supported alignment requirements and addressing modes for operand `src` and `dst` are described in *Addresses as Operands*.

The mandatory `.async` qualifier indicates that the `cp` instruction will initiate the memory copy operation asynchronously and control will return to the executing thread before the copy operation is complete. The executing thread can then use *async-group based completion mechanism* or the *mbarrier based completion mechanism* to wait for completion of the asynchronous copy operation. No other synchronization mechanism guarantees the completion of the asynchronous copy operations.

There is no ordering guarantee between two `cp.async` operations if they are not explicitly synchronized using `cp.async.wait_all` or `cp.async.wait_group` or *mbarrier instructions*.

As described in *Cache Operators*, the `.cg` qualifier indicates caching of data only at global level cache L2 and not at L1 whereas `.ca` qualifier indicates caching of data at all levels including L1 cache. Cache operator are treated as performance hints only.

`cp.async` is treated as a weak memory operation in the *Memory Consistency Model*.

The `.level::prefetch_size` qualifier is a hint to fetch additional data of the specified size into the respective cache level.The sub-qualifier `prefetch_size` can be set to either of 64B, 128B, 256B thereby allowing the prefetch size to be 64 Bytes, 128 Bytes or 256 Bytes respectively.

The qualifier `.level::prefetch_size` may only be used with `.global` state space and with generic addressing where the address points to `.global` state space. If the generic address does not fall within the address window of the global memory, then the prefetching behavior is undefined.

The `.level::prefetch_size` qualifier is treated as a performance hint only.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

The qualifier `.level::cache_hint` is only supported for `.global` state space and for generic addressing where the address points to the `.global` state space.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for `.level::cache_hint` and `.level::prefetch_size` qualifiers introduced in PTX ISA version 7.4.

Support for `ignore-src` operand introduced in PTX ISA version 7.5.

Support for sub-qualifier `::cta` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_80` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Examples

```
cp.async.ca.shared.global  [shrd],    [gbl + 4], 4;
cp.async.ca.shared::cta.global  [%r0 + 8], [%r1],     8;
cp.async.cg.shared.global  [%r2],     [%r3],     16;

cp.async.cg.shared.global.L2::64B   [%r2],      [%r3],     16;
cp.async.cg.shared.global.L2::128B  [%r0 + 16], [%r1],     16;
cp.async.cg.shared.global.L2::256B  [%r2 + 32], [%r3],     16;

createpolicy.fractional.L2::evict_last.L2::evict_unchanged.b64 cache-policy, 0.25;
cp.async.ca.shared.global.L2::cache_hint [%r2], [%r1], 4, cache-policy;

cp.async.ca.shared.global                  [shrd], [gbl], 4, p;
cp.async.cg.shared.global.L2::cache_hint   [%r0], [%r2], 16, q, cache-policy;
```

9.7.9.25.3.2 Data Movement and Conversion Instructions: `cp.async.commit_group`

`cp.async.commit_group`

Commits all prior initiated but uncommitted `cp.async` instructions into a *cp.async-group*.

Syntax

```
cp.async.commit_group ;
```

Description

`cp.async.commit_group` instruction creates a new *cp.async-group* per thread and batches all prior `cp.async` instructions initiated by the executing thread but not committed to any *cp.async-group* into the new *cp.async-group*. If there are no uncommitted `cp.async` instructions then `cp.async.commit_group` results in an empty *cp.async-group*.

An executing thread can wait for the completion of all `cp.async` operations in a *cp.async-group* using `cp.async.wait_group`.

There is no memory ordering guarantee provided between any two `cp.async` operations within the same *cp.async-group*. So two or more `cp.async` operations within a *cp.async-group* copying data to the same location results in undefined behavior.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
// Example 1:
cp.async.ca.shared.global [shrd], [gbl], 4;
cp.async.commit_group ; // Marks the end of a cp.async group

// Example 2:
cp.async.ca.shared.global [shrd1],   [gbl1],   8;
cp.async.ca.shared.global [shrd1+8], [gbl1+8], 8;
cp.async.commit_group ; // Marks the end of cp.async group 1

cp.async.ca.shared.global [shrd2],    [gbl2],    16;
cp.async.cg.shared.global [shrd2+16], [gbl2+16], 16;
cp.async.commit_group ; // Marks the end of cp.async group 2
```

9.7.9.25.3.3 Data Movement and Conversion Instructions: `cp.async.wait_group` / `cp.async.wait_all`

`cp.async.wait_group`, `cp.async.wait_all`

Wait for completion of prior asynchronous copy operations.

Syntax

```
cp.async.wait_group N;
cp.async.wait_all ;
```

Description

`cp.async.wait_group` instruction will cause executing thread to wait till only `N` or fewer of the most recent *cp.async-group*s are pending and all the prior *cp.async-group*s committed by the executing threads are complete. For example, when `N` is 0, the executing thread waits on all the prior *cp.async-group*s to complete. Operand `N` is an integer constant.

`cp.async.wait_all` is equivalent to :

```
cp.async.commit_group;
cp.async.wait_group 0;
```

An empty *cp.async-group* is considered to be trivially complete.

Writes performed by `cp.async` operations are made visible to the executing thread only after:

1. The completion of `cp.async.wait_all` or
2. The completion of `cp.async.wait_group` on the *cp.async-group* in which the `cp.async` belongs to or
3. *mbarrier.test_wait* returns `True` on an *mbarrier object* which is tracking the completion of the `cp.async` operation.

There is no ordering between two `cp.async` operations that are not synchronized with `cp.async.wait_all` or `cp.async.wait_group` or *mbarrier objects*.

`cp.async.wait_group` and `cp.async.wait_all` does not provide any ordering and visibility guarantees for any other memory operation apart from `cp.async`.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
// Example of .wait_all:
cp.async.ca.shared.global [shrd1], [gbl1], 4;
cp.async.cg.shared.global [shrd2], [gbl2], 16;
cp.async.wait_all;  // waits for all prior cp.async to complete

// Example of .wait_group :
cp.async.ca.shared.global [shrd3], [gbl3], 8;
cp.async.commit_group;  // End of group 1
```

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```
cp.async.cg.shared.global [shrd4], [gbl4], 16;
cp.async.commit_group;  // End of group 2

cp.async.cg.shared.global [shrd5], [gbl5], 16;
cp.async.commit_group;  // End of group 3

cp.async.wait_group 1;  // waits for group 1 and group 2 to complete
```

9.7.9.25.4 Data Movement and Conversion Instructions: Bulk copy

9.7.9.25.4.1 Data Movement and Conversion Instructions: cp.async.bulk

cp.async.bulk

Initiates an asynchronous copy operation from one state space to another.

Syntax

```
// global -> shared::cta
cp.async.bulk.dst.src.completion_mechanism{.level::cache_hint}
                      [dstMem], [srcMem], size, [mbar] {, cache-policy}

.dst =                  { .shared::cta }
.src =                  { .global }
.completion_mechanism = { .mbarrier::complete_tx::bytes }
.level::cache_hint =    { .L2::cache_hint }


// global -> shared::cluster
cp.async.bulk.dst.src.completion_mechanism{.multicast}{.level::cache_hint}
                      [dstMem], [srcMem], size, [mbar] {, ctaMask} {, cache-policy}

.dst =                  { .shared::cluster }
.src =                  { .global }
.completion_mechanism = { .mbarrier::complete_tx::bytes }
.level::cache_hint =    { .L2::cache_hint }
.multicast =            { .multicast::cluster  }


// shared::cta -> shared::cluster
cp.async.bulk.dst.src.completion_mechanism [dstMem], [srcMem], size, [mbar]

.dst =                  { .shared::cluster }
.src =                  { .shared::cta }
.completion_mechanism = { .mbarrier::complete_tx::bytes }


// shared::cta -> global
cp.async.bulk.dst.src.completion_mechanism{.level::cache_hint}{.cp_mask}
                      [dstMem], [srcMem], size {, cache-policy} {, byteMask}
```

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```
.dst =                  { .global }
.src =                  { .shared::cta }
.completion_mechanism = { .bulk_group }
.level::cache_hint =    { .L2::cache_hint }
```

Description

`cp.async.bulk` is a non-blocking instruction which initiates an asynchronous bulk-copy operation from the location specified by source address operand `srcMem` to the location specified by destination address operand `dstMem`.

The direction of bulk-copy is from the state space specified by the `.src` modifier to the state space specified by the `.dst` modifiers.

The 32-bit operand `size` specifies the amount of memory to be copied, in terms of number of bytes. `size` must be a multiple of 16. If the value is not a multiple of 16, then the behavior is undefined. The memory range `[dstMem, dstMem + size - 1]` must not overflow the destination memory space and the memory range `[srcMem, srcMem + size - 1]` must not overflow the source memory space. Otherwise, the behavior is undefined. The addresses `dstMem` and `srcMem` must be aligned to 16 bytes.

When the destination of the copy is `.shared::cta` the destination address has to be in the shared memory of the executing CTA within the cluster, otherwise the behavior is undefined.

When the source of the copy is `.shared::cta` and the destination is `.shared::cluster`, the destination has to be in the shared memory of a different CTA within the cluster.

The modifier `.completion_mechanism` specifies the completion mechanism that is supported on the instruction variant. The completion mechanisms that are supported for different variants are summarized in the following table:

.completion-mechanism	**.dst**	**.src**	**Completion mechanism**	
			Needed for completion of entire Async operation	**optionally can be used for the completion of - Reading data from the source - Reading from the tensormap, if applicable**
`.mbarrier::...`	`.shared::cta`	`.global`	mbarrier based	*Bulk async-group* based
	`.shared::cluster`	`.global`		
	`.shared::cluster`	`.shared::cta`		
`.bulk_group`	`.global`	`.shared::cta`	*Bulk async-group* based	

The modifier `.mbarrier::complete_tx::bytes` specifies that the `cp.async.bulk` variant uses mbarrier based completion mechanism. The *complete-tx* operation, with `completeCount` argument equal to amount of data copied in bytes, will be performed on the mbarrier object specified by the operand `mbar`.

The modifier `.bulk_group` specifies that the `cp.async.bulk` variant uses *bulk async-group* based completion mechanism.

The optional modifier `.multicast::cluster` allows copying of data from global memory to shared memory of multiple CTAs in the cluster. Operand `ctaMask` specifies the destination CTAs in the cluster such that each bit position in the 16-bit `ctaMask` operand corresponds to the `%ctaid` of the destination CTA. The source data is multicast to the same CTA-relative offset as `dstMem` in the shared memory of each destination CTA. The mbarrier signal is also multicast to the same CTA-relative offset as `mbar` in the shared memory of the destination CTA.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program. The qualifier `.level::cache_hint` is only supported when at least one of the `.src` or `.dst` statespaces is `.global` state space.

When the optional qualifier `.cp_mask` is specified, the argument `byteMask` is required. The i-th bit in the 16-bit wide `byteMask` operand specifies whether the i-th byte of each 16-byte wide chunk of source data is copied to the destination. If the bit is set, the byte is copied.

The copy operation in `cp.async.bulk` is treated as a weak memory operation and the *complete-tx* operation on the mbarrier has `.release` semantics at the `.cluster` scope as described in the *Memory Consistency Model*.

Notes

`.multicast::cluster` qualifier is optimized for target architecture `sm_90a/sm_100f/sm_100a/sm_101f/sm_101a/sm_103f/sm_103a` and may have substantially reduced performance on other targets and hence `.multicast::cluster` is advised to be used with `.target sm_90a/sm_100f/sm_100a/sm_101f/sm_101a/sm_103f/sm_103a`.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Support for `.shared::cta` as destination state space is introduced in PTX ISA version 8.6.

Support for `.cp_mask` qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_90` or higher.

`.multicast::cluster` qualifier advised to be used with `.target sm_90a` or `sm_100f` or `sm_100a` or `sm_101f` or `sm_101a` or `sm_103f` or `sm_103a`.

Support for `.cp_mask` qualifier requires `sm_100` or higher.

Examples

```
// .global -> .shared::cta (strictly non-remote):
cp.async.bulk.shared::cta.global.mbarrier::complete_tx::bytes [dstMem], [srcMem],
↪size, [mbar];

cp.async.bulk.shared::cta.global.mbarrier::complete_tx::bytes.L2::cache_hint
                                                [dstMem], [srcMem], size, [mbar], cache-
↪policy;

// .global -> .shared::cluster:
cp.async.bulk.shared::cluster.global.mbarrier::complete_tx::bytes [dstMem], [srcMem],
↪size, [mbar];

cp.async.bulk.shared::cluster.global.mbarrier::complete_tx::bytes.multicast::cluster
                                                [dstMem], [srcMem], size, [mbar],
↪ctaMask;

cp.async.bulk.shared::cluster.global.mbarrier::complete_tx::bytes.L2::cache_hint
                                                [dstMem], [srcMem], size, [mbar], cache-
↪policy;


// .shared::cta -> .shared::cluster (strictly remote):
cp.async.bulk.shared::cluster.shared::cta.mbarrier::complete_tx::bytes [dstMem],
↪[srcMem], size, [mbar];

// .shared::cta -> .global:
cp.async.bulk.global.shared::cta.bulk_group [dstMem], [srcMem], size;

cp.async.bulk.global.shared::cta.bulk_group.L2::cache_hint} [dstMem], [srcMem], size,
↪cache-policy;

// .shared::cta -> .global with .cp_mask:
cp.async.bulk.global.shared::cta.bulk_group.L2::cache_hint.cp_mask [dstMem], [srcMem],
↪ size, cache-policy, byteMask;
```

9.7.9.25.4.2 Data Movement and Conversion Instructions: cp.reduce.async.bulk

cp.reduce.async.bulk

Initiates an asynchronous reduction operation.

Syntax

```
cp.reduce.async.bulk.dst.src.completion_mechanism.redOp.type
             [dstMem], [srcMem], size, [mbar]

.dst =                  { .shared::cluster }
.src =                  { .shared::cta }
.completion_mechanism = { .mbarrier::complete_tx::bytes }
.redOp=                 { .and, .or, .xor,
                          .add, .inc, .dec,
```

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```
                          .min, .max }
.type =                 { .b32, .u32, .s32, .b64, .u64 }


cp.reduce.async.bulk.dst.src.completion_mechanism{.level::cache_hint}.redOp.type
               [dstMem], [srcMem], size{, cache-policy}

.dst =                  { .global      }
.src =                  { .shared::cta }
.completion_mechanism = { .bulk_group }
.level::cache_hint    = { .L2::cache_hint }
.redOp=                 { .and, .or, .xor,
                          .add, .inc, .dec,
                          .min, .max }
.type =                 { .f16, .bf16, .b32, .u32, .s32, .b64, .u64, .s64, .f32, .f64
↪}


cp.reduce.async.bulk.dst.src.completion_mechanism{.level::cache_hint}.add.noftz.type
               [dstMem], [srcMem], size{, cache-policy}
.dst  =                 { .global }
.src  =                 { .shared::cta }
.completion_mechanism = { .bulk_group }
.type =                 { .f16, .bf16 }
```

Description

`cp.reduce.async.bulk` is a non-blocking instruction which initiates an asynchronous reduction operation on an array of memory locations specified by the destination address operand `dstMem` with the source array whose location is specified by the source address operand `srcMem`. The size of the source and the destination array must be the same and is specified by the operand `size`.

Each data element in the destination array is reduced inline with the corresponding data element in the source array with the reduction operation specified by the modifier `.redOp`. The type of each data element in the source and the destination array is specified by the modifier `.type`.

The source address operand `srcMem` is located in the state space specified by `.src` and the destination address operand `dstMem` is located in the state specified by the `.dst`.

The 32-bit operand `size` specifies the amount of memory to be copied from the source location and used in the reduction operation, in terms of number of bytes. `size` must be a multiple of 16. If the value is not a multiple of 16, then the behavior is undefined. The memory range `[dstMem, dstMem + size - 1]` must not overflow the destination memory space and the memory range `[srcMem, srcMem + size - 1]` must not overflow the source memory space. Otherwise, the behavior is undefined. The addresses `dstMem` and `srcMem` must be aligned to 16 bytes.

The operations supported by `.redOp` are classified as follows:

- The bit-size operations are `.and`, `.or`, and `.xor`.
- The integer operations are `.add`, `.inc`, `.dec`, `.min`, and `.max`. The `.inc` and `.dec` operations return a result in the range `[0..x]` where x is the value at the source state space.
- The floating point operation `.add` rounds to the nearest even. The current implementation of `cp.reduce.async.bulk.add.f32` flushes subnormal inputs and results to sign-preserving

zero. The `cp.reduce.async.bulk.add.f16` and `cp.reduce.async.bulk.add.bf16` operations require `.noftz` qualifier. It preserves input and result subnormals, and does not flush them to zero.

The following table describes the valid combinations of `.redOp` and element type:

.dst	.redOp	Element type
.shared::cluster	.add	.u32, .s32, .u64
	.min, .max	.u32, .s32
	.inc, .dec	.u32
	.and, .or, .xor	.b32
.global	.add	.u32, .s32, .u64, .f32, .f64, .f16, .bf16
	.min, .max	.u32, .s32, .u64, .s64, .f16, .bf16
	.inc, .dec	.u32
	.and, .or, .xor	.b32, .b64

The modifier `.completion_mechanism` specifies the completion mechanism that is supported on the instruction variant. The completion mechanisms that are supported for different variants are summarized in the following table:

.completion-mechanism	.dst	.src	Completion mechanism	
			Needed for completion of entire Async operation	**optionally can be used for the completion of - Reading data from the source - Reading from the tensormap, if applicable**
.mbarrier::...	.shared::cluster	.global	mbarrier based	*Bulk async-group* based
	.shared::cluster	.shared::cta		
.bulk_group	.global	.shared::cta	*Bulk async-group* based	

The modifier `.mbarrier::complete_tx::bytes` specifies that the `cp.reduce.async.bulk` variant uses mbarrier based completion mechanism. The *complete-tx* operation, with `completeCount` argument equal to amount of data copied in bytes, will be performed on the mbarrier object specified by the operand `mbar`.

The modifier `.bulk_group` specifies that the `cp.reduce.async.bulk` variant uses *bulk async-group* based completion mechanism.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program. The

qualifier `.level::cache_hint` is only supported when at least one of the `.src` or `.dst` statespaces is `.global` state space.

Each reduction operation performed by the `cp.reduce.async.bulk` has individually `.relaxed.gpu` memory ordering semantics. The load operations in `cp.reduce.async.bulk` are treated as weak memory operation and the *complete-tx* operation on the mbarrier has `.release` semantics at the `.cluster` scope as described in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
cp.reduce.async.bulk.shared::cluster.shared::cta.mbarrier::complete_tx::bytes.add.u64
                                                                    [dstMem], [srcMem],
↪size, [mbar];

cp.reduce.async.bulk.shared::cluster.shared::cta.mbarrier::complete_tx::bytes.min.s32
                                                                    [dstMem], [srcMem],
↪size, [mbar];

cp.reduce.async.bulk.global.shared::cta.bulk_group.min.f16 [dstMem], [srcMem], size;

cp.reduce.async.bulk.global.shared::cta.bulk_group.L2::cache_hint.xor.s32 [dstMem],
↪[srcMem], size, policy;

cp.reduce.async.bulk.global.shared::cta.bulk_group.add.noftz.f16 [dstMem], [srcMem],
↪size;
```

9.7.9.25.4.3 Data Movement and Conversion Instructions: `cp.async.bulk.prefetch`

`cp.async.bulk.prefetch`

Provides a hint to the system to initiate the asynchronous prefetch of data to the cache.

Syntax

```
cp.async.bulk.prefetch.L2.src{.level::cache_hint}   [srcMem], size {, cache-policy}

.src =                { .global }
.level::cache_hint =  { .L2::cache_hint }
```

Description

`cp.async.bulk.prefetch` is a non-blocking instruction which may initiate an asynchronous prefetch of data from the location specified by source address operand `srcMem`, in `.src` statespace, to the L2 cache.

The 32-bit operand `size` specifies the amount of memory to be prefetched in terms of number of bytes. `size` must be a multiple of 16. If the value is not a multiple of 16, then the behavior is undefined. The address `srcMem` must be aligned to 16 bytes.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

`cp.async.bulk.prefetch` is treated as a weak memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
cp.async.bulk.prefetch.L2.global                 [srcMem], size;

cp.async.bulk.prefetch.L2.global.L2::cache_hint  [srcMem], size, policy;
```

9.7.9.25.5 Data Movement and Conversion Instructions: Tensor copy

9.7.9.25.5.1 Restriction on Tensor Copy instructions

Following are the restrictions on the types `.b4x16`, `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`:

1. `cp.reduce.async.bulk` doesn't support the types `.b4x16`, `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`.
2. `cp.async.bulk.tensor` with the direction `.global.shared::cta` doesn't support the type `.b4x16_p64`.
3. `cp.async.bulk.tensor` with the direction `.shared::cluster.global` doesn't support the sub-byte types on `sm_120a`.
4. OOB-NaN fill mode doesn't support the types `.b4x16`, `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`.
5. Box-Size[0] must be exactly:
    1. 96B for `b6x16_p32` and `.b6p2x16`.

2. 64B for `b4x16_p64`.

6. Tensor-Size[0] must be a multiple of:
   1. 96B for `b6x16_p32` and `.b6p2x16`.
   2. 64B for `b4x16_p64`.
7. For `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`, the first coordinate in the tensorCoords argument vector must be a multiple of 128.
8. For `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`, the global memory address must be 32B aligned. Additionally, tensor stride in every dimension must be 32B aligned.
9. `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16` supports the following swizzling modes:
   1. None.
   2. 128B (With all potential swizzle atomicity values except: 32B with 8B flip)

Following are the restrictions on the 96B swizzle mode:

1. The `.swizzle_atomicity` must be 16B.
2. The `.interleave_layout` must not be set.
3. Box-Size[0] must be less than or equal to 96B.
4. The type must not be among following: `.b4x16_p64`, `.b6x16_p32` and `.b6p2x16`.
5. The `.load_mode` must not be set to `.im2col::w::128`.

Following are the restrictions on the `.global.shared::cta` direction:

1. Starting co-ordinates for Bounding Box (`tensorCoords`) must be non-negative.
2. The bounding box along the D, W and H dimensions must stay within the tensor boundaries. This implies:
   1. Bounding-Box Lower-Corner must be non-negative.
   2. Bounding-Box Upper-Corner must be non-positive.

Following are the restrictions for `sm_120a`:

1. `cp.async.bulk.tensor` with the direction `.shared::cluster.global` doesn't support:
   1. the sub-byte types
   2. the qualifier `.swizzle_atomicity`

Following are the restrictions for `sm_103a` while using type `.b6p2x16` on `cp.async.bulk.tensor` with the direction `.global.shared::cta`:

1. Box-Size[0] must be exactly either of 48B or 96B.
2. The global memory address must be 16B aligned.
3. Tensor Stride in every dimension must be 16B aligned.
4. The first coordinate in the tensorCoords argument vector must be a multiple of 64.
5. Tensor-Size[0] must be a multiple of 48B.
6. The following swizzle modes are supported:
   1. None.
   2. 128B (With all potential swizzle atomicity values except: 32B with 8B flip)

3. 64B swizzle with 16B swizzle atomicity

9.7.9.25.5.2 Data Movement and Conversion Instructions: cp.async.bulk.tensor

cp.async.bulk.tensor

Initiates an asynchronous copy operation on the tensor data from one state space to another.

Syntax

```
// global -> shared::cta
cp.async.bulk.tensor.dim.dst.src{.load_mode}.completion_mechanism{.cta_group}{.
↪level::cache_hint}
                                  [dstMem], [tensorMap, tensorCoords], [mbar]{,
↪im2colInfo} {, cache-policy}

.dst =                  { .shared::cta }
.src =                  { .global }
.dim =                  { .1d, .2d, .3d, .4d, .5d }
.completion_mechanism = { .mbarrier::complete_tx::bytes }
.cta_group =            { .cta_group::1, .cta_group::2 }
.load_mode =            { .tile, .tile::gather4, .im2col, .im2col::w, .im2col::w::128
↪}
.level::cache_hint =    { .L2::cache_hint }


// global -> shared::cluster
cp.async.bulk.tensor.dim.dst.src{.load_mode}.completion_mechanism{.multicast}{.cta_
↪group}{.level::cache_hint}
                                  [dstMem], [tensorMap, tensorCoords], [mbar]{,
↪im2colInfo}
                                  {, ctaMask} {, cache-policy}

.dst =                  { .shared::cluster }
.src =                  { .global }
.dim =                  { .1d, .2d, .3d, .4d, .5d }
.completion_mechanism = { .mbarrier::complete_tx::bytes }
.cta_group =            { .cta_group::1, .cta_group::2 }
.load_mode =            { .tile, .tile::gather4, .im2col, .im2col::w, .im2col::w::128
↪}
.level::cache_hint =    { .L2::cache_hint }
.multicast =            { .multicast::cluster  }


// shared::cta -> global
cp.async.bulk.tensor.dim.dst.src{.load_mode}.completion_mechanism{.level::cache_hint}
                                  [tensorMap, tensorCoords], [srcMem] {, cache-
↪policy}

.dst =                  { .global }
.src =                  { .shared::cta }
.dim =                  { .1d, .2d, .3d, .4d, .5d }
.completion_mechanism = { .bulk_group }
.load_mode =            { .tile, .tile::scatter4, .im2col_no_offs }
.level::cache_hint =    { .L2::cache_hint }
```

Description

`cp.async.bulk.tensor` is a non-blocking instruction which initiates an asynchronous copy operation of tensor data from the location in `.src` state space to the location in the `.dst` state space.

The operand `dstMem` specifies the location in the `.dst` state space into which the tensor data has to be copied and `srcMem` specifies the location in the `.src` state space from which the tensor data has to be copied.

When `.dst` is specified as `.shared::cta`, the address `dstMem` must be in the shared memory of the executing CTA within the cluster, otherwise the behavior is undefined.

When `.dst` is specified as `.shared::cluster`, the address `dstMem` can be in the shared memory of any of the CTAs within the current cluster.

The operand `tensorMap` is the generic address of the opaque tensor-map object which resides in `.param` space or `.const` space or `.global` space. The operand `tensorMap` specifies the properties of the tensor copy operation, as described in *Tensor-map*. The `tensorMap` is accessed in tensormap proxy. Refer to the *CUDA programming guide* for creating the tensor-map objects on the host side.

The dimension of the tensor data is specified by the `.dim` modifier.

The vector operand `tensorCoords` specifies the starting coordinates in the tensor data in the global memory from or to which the copy operation has to be performed. The individual tensor coordinates in `tensorCoords` are of type `.s32`. The format of vector argument `tensorCoords` is dependent on `.load_mode` specified and is as follows:

.load_mode	tensorCoords	Semantics
`.tile::scatter4`	{col_idx, row_idx0, row_idx1, row_idx2, row_idx3}	Fixed length vector of size 5. The five elements together specify the start coordinates of the four rows.
`.tile::gather4`		
Rest all	{d0, .., dn} for n = .dim	Vector of n elements where n = .dim. The elements indicate the offset in each of the dimension.

The modifier `.completion_mechanism` specifies the completion mechanism that is supported on the instruction variant. The completion mechanisms that are supported for different variants are summarized in the following table:

.completion-mechanism	.dst	.src	Completion mechanism	
			Needed for completion of entire Async operation	**optionally can be used for the completion of - Reading data from the source - Reading from the tensormap, if applicable**
.mbarrier::...	.shared::cta	.global	mbarrier based	*Bulk async-group* based
	.shared::cluster	.global		
.bulk_group	.global	.shared::cta	*Bulk async-group* based	

The modifier `.mbarrier::complete_tx::bytes` specifies that the `cp.async.bulk.tensor` variant uses mbarrier based completion mechanism. Upon the completion of the asynchronous copy operation, the *complete-tx* operation, with `completeCount` argument equal to amount of data copied in bytes, will be performed on the mbarrier object specified by the operand `mbar`.

The modifier `.cta_group` can only be specified with the mbarrier based completion mechanism. The modifier `.cta_group` is used to signal either the odd numbered CTA or the even numbered CTA among the *CTA-Pair*. When `.cta_group::1` is specified, the mbarrier object `mbar` that is specified must be in the shared memory of the same CTA as the shared memory destination `dstMem`. When `.cta_group::2` is specified, the mbarrier object `mbar` can be in shared memory of either the same CTA as the shared memory destination `dstMem` or in its *peer-CTA*. If `.cta_group` is not specified, then it defaults to `.cta_group::1`.

The modifier `.bulk_group` specifies that the `cp.async.bulk.tensor` variant uses *bulk async-group* based completion mechanism.

The qualifier `.load_mode` specifies how the data in the source location is copied into the destination location. If `.load_mode` is not specified, it defaults to `.tile`.

In `.tile` mode, the multi-dimensional layout of the source tensor is preserved at the destination. In `.tile::gather4` mode, four rows in 2-dimnesional source tensor are combined to form a single 2-dimensional destination tensor. In `.tile::scatter4` mode, single 2-dimensional source tensor is divided into four rows in 2-dimensional destination tensor. Details of `.tile::scatter4`/`.tile::gather4` modes are described in *.tile::scatter4 and .tile::gather4 modes*.

In `.im2col` and `.im2col::*` modes, some dimensions of the source tensors are unrolled in a single dimensional column at the destination. Details of the `im2col` and `.im2col::*` modes are described in *im2col mode* and *im2col::w and im2col::w::128 modes* respectively. In `.im2col` and `.im2col::*` modes, the tensor has to be at least 3-dimensional. The vector operand `im2colInfo` can be specified only when `.load_mode` is `.im2col` or `.im2col::w` or `.im2col::w::128`. The format of the vector argument `im2colInfo` is dependent on the exact im2col mode and is as follows:

Exact im2col mode	im2colInfo argument	Semantics
.im2col	{ i2cOffW , i2cOffH , i2cOffD } for .dim = .5d	A vector of im2col offsets whose vector size is two less than number of dimensions .dim.
.im2col::w	{ wHalo, wOffset }	A vector of 2 arguments containing *wHalo* and *wOffset* arguments.
.im2col::w::128		
.im2col_no_offs	im2colInfo is not applicable.	im2colInfo is not applicable.

Argument wHalo is a 16bit unsigned integer whose valid set of values differs on the load-mode and is as follows: - Im2col::w mode : valid range is [0, 512). - Im2col::w::128 mode : valid range is [0, 32).

Argument wOffset is a 16bit unsigned integer whose valid range of values is [0, 32).

The optional modifier .multicast::cluster allows copying of data from global memory to shared memory of multiple CTAs in the cluster. Operand ctaMask specifies the destination CTAs in the cluster such that each bit position in the 16-bit ctaMask operand corresponds to the %ctaid of the destination CTA. The source data is multicast to the same offset as dstMem in the shared memory of each destination CTA. When .cta_group is specified as:

- .cta_group::1 : The mbarrier signal is also multicasted to the same offset as mbar in the shared memory of the destination CTA.
- .cta_group::2 : The mbarrier signal is multicasted either to all the odd numbered CTAs or the even numbered CTAs within the corresponding *CTA-Pair*. For each destination CTA specified in the ctaMask, the mbarrier signal is sent either to the destination CTA or its *peer-CTA* based on CTAs %cluster_ctarank parity of shared memory where the mbarrier object mbar resides.

When the optional argument cache-policy is specified, the qualifier .level::cache_hint is required. The 64-bit operand cache-policy specifies the cache eviction policy that may be used during the memory access.

cache-policy is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

The copy operation in cp.async.bulk.tensor is treated as a weak memory operation and the *complete-tx* operation on the mbarrier has .release semantics at the .cluster scope as described in the *Memory Consistency Model*.

Notes

.multicast::cluster qualifier is optimized for target architecture sm_90a/sm_100f/sm_100a/sm_101f/sm_101a/sm_103f/sm_103a and may have substantially reduced performance on other targets and hence .multicast::cluster is advised to be used with .target sm_90a/sm_100f/sm_100a/sm_101f/sm_101a/sm_103f/sm_103a.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Support for `.shared::cta` as destination state space is introduced in PTX ISA version 8.6.

Support for qualifiers `.tile::gather4` and `.tile::scatter4` introduced in PTX ISA version 8.6.

Support for qualifiers `.im2col::w` and `.im2col::w::128` introduced in PTX ISA version 8.6.

Support for qualifier `.cta_group` introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_90` or higher.

`.multicast::cluster` qualifier advised to be used with `.target` `sm_90a` or `sm_100f` or `sm_100a` or `sm_101f` or `sm_101a` or `sm_103f` or `sm_103a`.

Qualifiers `.tile::gather4` and `.im2col::w` require:

- `sm_100a` when destination state space is `.shared::cluster` and is supported on `sm_100f` from PTX ISA version 8.8.
- `sm_100` or higher when destination state space is `.shared::cta`.

Qualifier `.tile::scatter4` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifier `.im2col::w::128` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifier `.cta_group` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
.reg .b16 ctaMask;
.reg .u16 i2cOffW, i2cOffH, i2cOffD;
.reg .b64 l2CachePolicy;

cp.async.bulk.tensor.1d.shared::cta.global.mbarrier::complete_tx::bytes.tile  [sMem0],
↪ [tensorMap0, {tc0}], [mbar0];

@p cp.async.bulk.tensor.5d.shared::cta.global.im2col.mbarrier::complete_tx::bytes
                     [sMem2], [tensorMap2, {tc0, tc1, tc2, tc3, tc4}], [mbar2],
↪{i2cOffW, i2cOffH, i2cOffD};

cp.async.bulk.tensor.1d.shared::cluster.global.mbarrier::complete_tx::bytes.tile
↪[sMem0], [tensorMap0, {tc0}], [mbar0];

@p cp.async.bulk.tensor.2d.shared::cluster.global.mbarrier::complete_tx::bytes.
↪multicast::cluster
                     [sMem1], [tensorMap1, {tc0, tc1}], [mbar2], ctaMask;

@p cp.async.bulk.tensor.5d.shared::cluster.global.im2col.mbarrier::complete_tx::bytes
                     [sMem2], [tensorMap2, {tc0, tc1, tc2, tc3, tc4}], [mbar2],
↪{i2cOffW, i2cOffH, i2cOffD};

@p cp.async.bulk.tensor.3d.im2col.shared::cluster.global.mbarrier::complete_tx::bytes.
↪L2::cache_hint
                     [sMem3], [tensorMap3, {tc0, tc1, tc2}], [mbar3], {i2cOffW},
↪policy;

@p cp.async.bulk.tensor.1d.global.shared::cta.bulk_group  [tensorMap3, {tc0}],
↪[sMem3];

cp.async.bulk.tensor.2d.tile::gather4.shared::cluster.global.mbarrier::complete_
↪tx::bytes
                     [sMem5], [tensorMap6, {x0, y0, y1, y2, y3}], [mbar5];

cp.async.bulk.tensor.3d.im2col::w.shared::cluster.global.mbarrier::complete_tx::bytes
                     [sMem4], [tensorMap5, {t0, t1, t2}], [mbar4], {im2colwHalo,
↪im2colOff};

cp.async.bulk.tensor.1d.shared::cluster.global.tile.cta_group::2
                     [sMem6], [tensorMap7, {tc0}], [peerMbar];
```

9.7.9.25.5.3 Data Movement and Conversion Instructions: `cp.reduce.async.bulk.tensor`

`cp.reduce.async.bulk.tensor`

Initiates an asynchronous reduction operation on the tensor data.

Syntax

```
// shared::cta -> global:
cp.reduce.async.bulk.tensor.dim.dst.src.redOp{.load_mode}.completion_mechanism{.
↪level::cache_hint}
                                        [tensorMap, tensorCoords], [srcMem] {,cache-
↪policy}

.dst =                  { .global }
.src =                  { .shared::cta }
.dim =                  { .1d, .2d, .3d, .4d, .5d }
.completion_mechanism = { .bulk_group }
.load_mode =            { .tile, .im2col_no_offs }
.redOp =                { .add, .min, .max, .inc, .dec, .and, .or, .xor}
```

Description

`cp.reduce.async.bulk.tensor` is a non-blocking instruction which initiates an asynchronous reduction operation of tensor data in the `.dst` state space with tensor data in the `.src` state space.

The operand `srcMem` specifies the location of the tensor data in the `.src` state space using which the reduction operation has to be performed.

The operand `tensorMap` is the generic address of the opaque tensor-map object which resides in `.param` space or `.const` space or `.global` space. The operand `tensorMap` specifies the properties of the tensor copy operation, as described in *Tensor-map*. The `tensorMap` is accessed in tensormap proxy. Refer to the *CUDA programming guide* for creating the tensor-map objects on the host side.

Each element of the tensor data in the `.dst` state space is reduced inline with the corresponding element from the tensor data in the `.src` state space. The modifier `.redOp` specifies the reduction operation used for the inline reduction. The type of each tensor data element in the source and the destination tensor is specified in *Tensor-map*.

The dimension of the tensor is specified by the `.dim` modifier.

The vector operand `tensorCoords` specifies the starting coordinates of the tensor data in the global memory on which the reduce operation is to be performed. The number of tensor coordinates in the vector argument `tensorCoords` should be equal to the dimension specified by the modifier `.dim`. The individual tensor coordinates are of the type `.s32`.

The following table describes the valid combinations of `.redOp` and element type:

.redOp	**Element type**
.add	.u32, .s32, .u64, .f32, .f16, .bf16
.min, .max	.u32, .s32, .u64, .s64, .f16, .bf16
.inc, .dec	.u32
.and, .or, .xor	.b32, .b64

The modifier `.completion_mechanism` specifies the completion mechanism that is supported on the instruction variant. Value `.bulk_group` of the modifier `.completion_mechanism` specifies that `cp.reduce.async.bulk.tensor` instruction uses *bulk async-group* based completion mechanism.

The qualifier `.load_mode` specifies how the data in the source location is copied into the destination location. If `.load_mode` is not specified, it defaults to `.tile`. In `.tile` mode, the multi-dimensional

layout of the source tensor is preserved at the destination. In `.im2col_no_offs` mode, some dimensions of the source tensors are unrolled in a single dimensional column at the destination. Details of the `im2col` mode are described in *im2col mode*. In `.im2col` mode, the tensor has to be at least 3-dimensional.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program. The qualifier `.level::cache_hint` is only supported when at least one of the `.src` or `.dst` statespaces is `.global` state space.

Each reduction operation performed by `cp.reduce.async.bulk.tensor` has individually `.relaxed.gpu` memory ordering semantics. The load operations in `cp.reduce.async.bulk.tensor` are treated as weak memory operations and the *complete-tx* operation on the mbarrier has `.release` semantics at the `.cluster` scope as described in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
cp.reduce.async.bulk.tensor.1d.global.shared::cta.add.tile.bulk_group
                                                [tensorMap0, {tc0}], [sMem0];

cp.reduce.async.bulk.tensor.2d.global.shared::cta.and.bulk_group.L2::cache_hint
                                                [tensorMap1, {tc0, tc1}], [sMem1] ,
↪policy;

cp.reduce.async.bulk.tensor.3d.global.shared::cta.xor.im2col.bulk_group
                                                [tensorMap2, {tc0, tc1, tc2}], [sMem2]
```

9.7.9.25.5.4 Data Movement and Conversion Instructions: `cp.async.bulk.prefetch.tensor`

`cp.async.bulk.prefetch.tensor`

Provides a hint to the system to initiate the asynchronous prefetch of tensor data to the cache.

Syntax

```
// global -> shared::cluster:
cp.async.bulk.prefetch.tensor.dim.L2.src{.load_mode}{.level::cache_hint} [tensorMap,
↪tensorCoords]
                                                                    {, im2colInfo } {, cache-
↪policy}

.src =                  { .global }
.dim =                  { .1d, .2d, .3d, .4d, .5d }
.load_mode =            { .tile, .tile::gather4, .im2col, .im2col::w, .im2col::w::128 }
.level::cache_hint =    { .L2::cache_hint }
```

Description

`cp.async.bulk.prefetch.tensor` is a non-blocking instruction which may initiate an asynchronous prefetch of tensor data from the location in `.src` statespace to the L2 cache.

The operand `tensorMap` is the generic address of the opaque tensor-map object which resides in `.param` space or `.const` space or `.global` space. The operand `tensorMap` specifies the properties of the tensor copy operation, as described in *Tensor-map*. The `tensorMap` is accessed in tensormap proxy. Refer to the *CUDA programming guide* for creating the tensor-map objects on the host side.

The dimension of the tensor data is specified by the `.dim` modifier.

The vector operand `tensorCoords` specifies the starting coordinates in the tensor data in the global memory from which the copy operation has to be performed. The individual tensor coordinates in `tensorCoords` are of type `.s32`. The format of vector argument `tensorCoords` is dependent on `.load_mode` specified and is as follows:

.load_mode	tensorCoords	Semantics
`.tile::gather4`	{col_idx, row_idx0, row_idx1, row_idx2, row_idx3}	Fixed length vector of size 5. The five elements together specify the start coordinates of the four rows.
Rest all	{d0, .., dn} for n = .dim	Vector of n elements where n = .dim. The elements indicate the offset in each of the dimension.

The qualifier `.load_mode` specifies how the data in the source location is copied into the destination location. If `.load_mode` is not specified, it defaults to `.tile`.

In `.tile` mode, the multi-dimensional layout of the source tensor is preserved at the destination. In `.tile::gather4` mode, four rows in the 2-dimnesional source tensor are fetched to L2 cache. Details of `.tile::gather4` modes are described in *.tile::scatter4 and .tile::gather4 modes*.

In `.im2col` and `.im2col::*` modes, some dimensions of the source tensors are unrolled in a single dimensional column at the destination. Details of the `im2col` and `.im2col::*` modes are described in *im2col mode* and *im2col::w and im2col::w::128 modes* respectively. In `.im2col` and `.im2col::*`

modes, the tensor has to be at least 3-dimensional. The vector operand `im2colInfo` can be specified only when `.load_mode` is `.im2col` or `.im2col::w` or `.im2col::w::128`. The format of the vector argument `im2colInfo` is dependent on the exact im2col mode and is as follows:

Exact im2col mode	im2colInfo argument	Semantics
`.im2col`	{ i2cOffW , i2cOffH , i2cOffD } for `.dim` = `.5d`	A vector of im2col offsets whose vector size is two less than number of dimensions .dim.
`.im2col::w`	{ wHalo, wOffset }	A vector of 2 arguments containing *wHalo* and *wOffset* arguments.
`.im2col::w::128`		

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

`cp.async.bulk.prefetch.tensor` is treated as a weak memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Support for qualifier `.tile::gather4` introduced in PTX ISA version 8.6.

Support for qualifiers `.im2col::w` and `.im2col::w::128` introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_90` or higher.

Qualifier `.tile::gather4` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifiers `.im2col::w` and `.im2col::w::128` are supported on following architectures:

- `sm_100a`
- `sm_101a`
- And are supported on following family-specific architectures from PTX ISA version 8.8:

- sm_100f or higher in the same family
- sm_101f or higher in the same family

Examples

```
.reg .b16 ctaMask, im2colwHalo, im2colOff;
.reg .u16 i2cOffW, i2cOffH, i2cOffD;
.reg .b64 l2CachePolicy;

cp.async.bulk.prefetch.tensor.1d.L2.global.tile  [tensorMap0, {tc0}];

@p cp.async.bulk.prefetch.tensor.2d.L2.global    [tensorMap1, {tc0, tc1}];

@p cp.async.bulk.prefetch.tensor.5d.L2.global.im2col
                     [tensorMap2, {tc0, tc1, tc2, tc3, tc4}], {i2cOffW, i2cOffH,
↪i2cOffD};

@p cp.async.bulk.prefetch.tensor.3d.L2.global.im2col.L2::cache_hint
                     [tensorMap3, {tc0, tc1, tc2}], {i2cOffW}, policy;

cp.async.bulk.prefetch.tensor.2d.L2.global.tile::gather4 [tensorMap5, {col_idx, row_
↪idx0, row_idx1, row_idx2, row_idx3}];

cp.async.bulk.prefetch.tensor.4d.L2.global.im2col::w::128
                     [tensorMap4, {t0, t1, t2, t3}], {im2colwHalo, im2colOff};
```

9.7.9.25.6 Data Movement and Conversion Instructions: Bulk and Tensor copy completion instructions

9.7.9.25.6.1 Data Movement and Conversion Instructions: cp.async.bulk.commit_group

cp.async.bulk.commit_group

Commits all prior initiated but uncommitted cp.async.bulk instructions into a *cp.async.bulk-group*.

Syntax

```
cp.async.bulk.commit_group;
```

Description

cp.async.bulk.commit_group instruction creates a new per-thread *bulk async-group* and batches all prior cp{.reduce}.async.bulk.{.prefetch}{.tensor} instructions satisfying the following conditions into the new *bulk async-group*:

- The prior cp{.reduce}.async.bulk.{.prefetch}{.tensor} instructions use *bulk_group* based completion mechanism, and
- They are initiated by the executing thread but not committed to any *bulk async-group*.

If there are no uncommitted `cp{.reduce}.async.bulk.{.prefetch}{.tensor}` instructions then `cp.async.bulk.commit_group` results in an empty *bulk async-group*.

An executing thread can wait for the completion of all `cp{.reduce}.async.bulk.{.prefetch}{.tensor}` operations in a *bulk async-group* using `cp.async.bulk.wait_group`.

There is no memory ordering guarantee provided between any two `cp{.reduce}.async.bulk.{.prefetch}{.tensor}` operations within the same *bulk async-group*.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
cp.async.bulk.commit_group;
```

9.7.9.25.6.2 Data Movement and Conversion Instructions: `cp.async.bulk.wait_group`

`cp.async.bulk.wait_group`

Wait for completion of *bulk async-groups*.

Syntax

```
cp.async.bulk.wait_group{.read} N;
```

Description

`cp.async.bulk.wait_group` instruction will cause the executing thread to wait until only N or fewer of the most recent *bulk async-groups* are pending and all the prior *bulk async-groups* committed by the executing threads are complete. For example, when N is 0, the executing thread waits on all the prior *bulk async-groups* to complete. Operand N is an integer constant.

By default, `cp.async.bulk.wait_group` instruction will cause the executing thread to wait until completion of all the bulk async operations in the specified *bulk async-group*. A bulk async operation includes the following:

- Optionally, reading from the tensormap.
- Reading from the source locations.
- Writing to their respective destination locations.
- Writes being made visible to the executing thread.

The optional `.read` modifier indicates that the waiting has to be done until all the bulk async operations in the specified *bulk async-group* have completed:

1. reading from the tensormap
2. the reading from their source locations.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
cp.async.bulk.wait_group.read   0;
cp.async.bulk.wait_group        2;
```

9.7.9.26 Data Movement and Conversion Instructions: `tensormap.replace`

`tensormap.replace`

Modifies the field of a tensor-map object.

Syntax

```
tensormap.replace.mode.field1{.ss}.b1024.type  [addr], new_val;
tensormap.replace.mode.field2{.ss}.b1024.type  [addr], ord, new_val;
tensormap.replace.mode.field3{.ss}.b1024.type  [addr], new_val;

.mode    = { .tile }
.field1  = { .global_address, .rank }
.field2  = { .box_dim, .global_dim, .global_stride, .element_stride  }
.field3  = { .elemtype,  .interleave_layout, .swizzle_mode, .swizzle_atomicity, .fill_
↪mode }
.ss      = { .global, .shared::cta }
.type    = { .b32, .b64 }
```

Description

The `tensormap.replace` instruction replaces the field, specified by `.field` qualifier, of the tensor-map object at the location specified by the address operand `addr` with a new value. The new value is specified by the argument `new_val`.

Qualifier `.mode` specifies the mode of the *tensor-map* object located at the address operand `addr`.

Instruction type `.b1024` indicates the size of the *tensor-map* object, which is 1024 bits.

Operand `new_val` has the type `.type`. When `.field` is specified as `.global_address` or `.global_stride`, `.type` must be `.b64`. Otherwise, `.type` must be `.b32`.

The immediate integer operand `ord` specifies the ordinal of the field across the rank of the tensor which needs to be replaced in the *tensor-map* object.

For field `.rank`, the operand `new_val` must be ones less than the desired tensor rank as this field uses zero-based numbering.

When `.field3` is specified, the operand `new_val` must be an immediate and the Table 34 shows the mapping of the operand `new_val` across various fields.

Table 34: Tensormap new_val validity

new_val	**.field3**				
	.elemtype	**.interleave_layout**	**.swizzle_mode**	**.swizzle_atomicity**	**.fill_mode**
0	.u8	No interleave	No swizzling	16B	Zero fill
1	.u16	16B interleave	32B swizzling	32B	OOB-NaN fill
2	.u32	32B interleave	64B swizzling	32B + 8B flip	x
3	.s32	x	128B swizzling	64B	x
4	.u64	x	96B swizzling	x	x
5	.s64	x	x	x	x
6	.f16	x	x	x	x
7	.f32	x	x	x	x
8	.f32.ftz	x	x	x	x
9	.f64	x	x	x	x
10	.bf16	x	x	x	x
11	.tf32	x	x	x	x
12	.tf32.ftz	x	x	x	x
13	.b4x16	x	x	x	x
14	.b4x16_p64	x	x	x	x
15	.b6x16_p32 or .b6p2x16	x	x	x	x

Note: The values of `.elemtype` do not correspond to the values of the `CUtensorMapDataType` enum used in the driver API.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.global` or `.shared::cta` state space then the behavior is undefined.

`tensormap.replace` is treated as a weak memory operation, on the entire 1024-bit opaque *tensormap* object, in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.3.

Qualifier `.swizzle_atomicity` introduced in PTX ISA version 8.6.

Qualifier `.elemtype` with values from 13 to 15, both inclusive, is supported in PTX ISA version 8.7 onwards.

Qualifier `.swizzle_mode` with value 4 is supported from PTX ISA version 8.8 onwards.

Target ISA Notes

Supported on following architectures:

- `sm_90a`
- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Qualifier `.swizzle_atomicity` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a` (refer to *section* for restrictions on sm_120a)
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

`.field3` variant `.elemtype` corresponding to `new_val` values 13, 14 and 15 is supported on following architectures:

- `sm_100a`

- sm_101a
- sm_120a (refer to *section* for restrictions on sm_120a)
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

.field3 variant .swizzle_mode corresponding to new_val value 4 is supported on following architectures:

- sm_103a (refer to *section* for restrictions on sm_103a)

Examples

```
tensormap.replace.tile.global_address.shared::cta.b1024.b64   [sMem], new_val;
```

9.7.10. Texture Instructions

This section describes PTX instructions for accessing textures and samplers. PTX supports the following operations on texture and sampler descriptors:

- Static initialization of texture and sampler descriptors.
- Module-scope and per-entry scope definitions of texture and sampler descriptors.
- Ability to query fields within texture and sampler descriptors.

9.7.10.1 Texturing Modes

For working with textures and samplers, PTX has two modes of operation. In the *unified mode,* texture and sampler information is accessed through a single .texref handle. In the *independent mode*, texture and sampler information each have their own handle, allowing them to be defined separately and combined at the site of usage in the program.

The advantage of unified mode is that it allows 256 samplers per kernel (128 for architectures prior to sm_3x), with the restriction that they correspond 1-to-1 with the 256 possible textures per kernel (128 for architectures prior to sm_3x). The advantage of independent mode is that textures and samplers can be mixed and matched, but the number of samplers is greatly restricted to 32 per kernel (16 for architectures prior to sm_3x).

Table 35 summarizes the number of textures, samplers and surfaces available in different texturing modes.

Table 35: Texture, sampler and surface limits

Texturing mode	Resource	sm_1x, sm_2x	sm_3x+
Unified mode	Textures	128	256
	Samplers	128	256
	Surfaces	8	16
Independent mode	Textures	128	256
	Samplers	16	32
	Surfaces	8	16

The texturing mode is selected using `.target` options `texmode_unified` and `texmode_independent`. A PTX module may declare only one texturing mode. If no texturing mode is declared, the module is assumed to use unified mode.

Example: calculate an element's power contribution as element's power/total number of elements.

```
.target texmode_independent
.global .samplerref tsamp1 = { addr_mode_0 = clamp_to_border,
                               filter_mode = nearest
                             };
...
.entry compute_power
  ( .param .texref tex1 )
{
  txq.width.b32  r6, [tex1]; // get tex1's width
  txq.height.b32 r5, [tex1]; // get tex1's height
  tex.2d.v4.f32.f32  {r1,r2,r3,r4}, [tex1, tsamp1, {f1,f2}];
  mul.u32 r5, r5, r6;
  add.f32 r1, r1, r2;
  add.f32 r3, r3, r4;
  add.f32 r1, r1, r3;
  cvt.f32.u32 r5, r5;
  div.f32 r1, r1, r5;
}
```

9.7.10.2 Mipmaps

A *mipmap* is a sequence of textures, each of which is a progressively lower resolution representation of the same image. The height and width of each image, or level of detail (LOD), in the mipmap is a power of two smaller than the previous level. Mipmaps are used in graphics applications to improve rendering speed and reduce aliasing artifacts. For example, a high-resolution mipmap image is used for objects that are close to the user; lower-resolution images are used as the object appears farther away. Mipmap filtering modes are provided when switching between two levels of detail (LODs) in order to avoid abrupt changes in visual fidelity.

Example: If the texture has a basic size of 256 by 256 pixels, then the associated mipmap set may contain a series of eight images, each one-fourth the total area of the previous one: 128x128 pixels, 64x64, 32x32, 16x16, 8x8, 4x4, 2x2, 1x1 (a single pixel). If, for example, a scene is rendering this texture in a space of 40x40 pixels, then either a scaled up version of the 32x32 (without trilinear interpolation) or an interpolation of the 64x64 and the 32x32 mipmaps (with trilinear interpolation) would be used.

The total number of LODs in a complete mipmap pyramid is calculated through the following equation:

```
numLODs = 1 + floor(log2(max(w, h, d)))
```

The finest LOD is called the base level and is the 0th level. The next (coarser) level is the 1st level, and so on. The coarsest level is the level of size (1 x 1 x 1). Each successively smaller mipmap level has half the {width, height, depth} of the previous level, but if this half value is a fractional value, it's rounded down to the next largest integer. Essentially, the size of a mipmap level can be specified as:

```
max(1, floor(w_b / 2^i)) x
max(1, floor(h_b / 2^i)) x
max(1, floor(d_b / 2^i))
```

where *i* is the ith level beyond the 0th level (the base level). And *w_b*, *h_b* and *d_b* are the width, height and depth of the base level respectively.

PTX support for mipmaps

The PTX `tex` instruction supports three modes for specifying the LOD: *base*, *level*, and *grad*ient. In base mode, the instruction always picks level 0. In level mode, an additional argument is provided to specify the LOD to fetch from. In gradmode, two floating-point vector arguments provide *partials* (e.g., `{ds/dx, dt/dx}` and `{ds/dy, dt/dy}` for a 2d texture), which the `tex` instruction uses to compute the LOD.

These instructions provide access to texture memory.

- `tex`
- `tld4`
- `txq`

9.7.10.3 Texture Instructions: `tex`

`tex`

Perform a texture memory lookup.

Syntax

```
tex.geom.v4.dtype.ctype  d, [a, c] {, e} {, f};
tex.geom.v4.dtype.ctype  d[|p], [a, b, c] {, e} {, f};  // explicit sampler

tex.geom.v2.f16x2.ctype  d[|p], [a, c] {, e} {, f};
tex.geom.v2.f16x2.ctype  d[|p], [a, b, c] {, e} {, f};  // explicit sampler

// mipmaps
tex.base.geom.v4.dtype.ctype   d[|p], [a, {b,} c] {, e} {, f};
tex.level.geom.v4.dtype.ctype  d[|p], [a, {b,} c], lod {, e} {, f};
tex.grad.geom.v4.dtype.ctype   d[|p], [a, {b,} c], dPdx, dPdy {, e} {, f};

tex.base.geom.v2.f16x2.ctype   d[|p], [a, {b,} c] {, e} {, f};
tex.level.geom.v2.f16x2.ctype  d[|p], [a, {b,} c], lod {, e} {, f};
tex.grad.geom.v2.f16x2.ctype   d[|p], [a, {b,} c], dPdx, dPdy {, e} {, f};
```

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```
.geom  = { .1d, .2d, .3d, .a1d, .a2d, .cube, .acube, .2dms, .a2dms };
.dtype = { .u32, .s32, .f16,  .f32 };
.ctype = {       .s32, .f32 };          // .cube, .acube require .f32
                                        // .2dms, .a2dms require .s32
```

Description

`tex.{1d,2d,3d}`

Texture lookup using a texture coordinate vector. The instruction loads data from the texture named by operand `a` at coordinates given by operand `c` into destination `d`. Operand `c` is a scalar or singleton tuple for `1d` textures; is a two-element vector for `2d` textures; and is a four-element vector for `3d` textures, where the fourth element is ignored. An optional texture sampler `b` may be specified. If no sampler is specified, the sampler behavior is a property of the named texture. The optional destination predicate `p` is set to `True` if data from texture at specified coordinates is resident in memory, `False` otherwise. When optional destination predicate `p` is set to `False`, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

An optional operand `e` may be specified. Operand `e` is a vector of `.s32` values that specifies coordinate offset. Offset is applied to coordinates before doing texture lookup. Offset value is in the range of -8 to +7. Operand `e` is a singleton tuple for `1d` textures; is a two element vector `2d` textures; and is four-element vector for `3d` textures, where the fourth element is ignored.

An optional operand `f` may be specified for `depth textures`. Depth textures are special type of textures which hold data from the depth buffer. Depth buffer contains depth information of each pixel. Operand `f` is `.f32` scalar value that specifies depth compare value for depth textures. Each element fetched from texture is compared against value given in `f` operand. If comparison passes, result is 1.0; otherwise result is 0.0. These per-element comparison results are used for the filtering. When using depth compare operand, the elements in texture coordinate vector `c` have `.f32` type.

Depth compare operand is not supported for `3d` textures.

The instruction returns a two-element vector for destination type `.f16x2`. For all other destination types, the instruction returns a four-element vector. Coordinates may be given in either signed 32-bit integer or 32-bit floating point form.

A texture base address is assumed to be aligned to a 16 byte boundary, and the address given by the coordinate vector must be naturally aligned to a multiple of the access size. If an address is not properly aligned, the resulting behavior is undefined; i.e., the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

`tex.{a1d,a2d}`

Texture array selection, followed by texture lookup. The instruction first selects a texture from the texture array named by operand `a` using the index given by the first element of the array coordinate vector `c`. The instruction then loads data from the selected texture at coordinates given by the remaining elements of operand `c` into destination `d`. Operand `c` is a bit-size type vector or tuple containing an index into the array of textures followed by coordinates within the selected texture, as follows:

- For `1d` texture arrays, operand `c` has type `.v2.b32`. The first element is interpreted as an unsigned integer index (`.u32`) into the texture array, and the second element is interpreted as a `1d` texture coordinate of type `.ctype`.

- For 2d texture arrays, operand c has type .v4.b32. The first element is interpreted as an unsigned integer index (.u32) into the texture array, and the next two elements are interpreted as 2d texture coordinates of type .ctype. The fourth element is ignored.

An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

An optional operand e may be specified. Operand e is a vector of .s32 values that specifies coordinate offset. Offset is applied to coordinates before doing texture lookup. Offset value is in the range of -8 to +7. Operand e is a singleton tuple for 1d texture arrays; and is a two element vector 2d texture arrays.

An optional operand f may be specified for depth textures arrays. Operand f is .f32 scalar value that specifies depth compare value for depth textures. When using depth compare operand, the coordinates in texture coordinate vector c have .f32 type.

The instruction returns a two-element vector for destination type .f16x2. For all other destination types, the instruction returns a four-element vector. The texture array index is a 32-bit unsigned integer, and texture coordinate elements are 32-bit signed integer or floating point values.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

tex.cube

Cubemap texture lookup. The instruction loads data from the cubemap texture named by operand a at coordinates given by operand c into destination d. Cubemap textures are special two-dimensional layered textures consisting of six layers that represent the faces of a cube. All layers in a cubemap are of the same size and are square (i.e., width equals height).

When accessing a cubemap, the texture coordinate vector c has type .v4.f32, and comprises three floating-point coordinates (s, t, r) and a fourth padding argument which is ignored. Coordinates (s, t, r) are projected onto one of the six cube faces. The (s, t, r) coordinates can be thought of as a direction vector emanating from the center of the cube. Of the three coordinates (s, t, r), the coordinate of the largest magnitude (the major axis) selects the cube face. Then, the other two coordinates (the minor axes) are divided by the absolute value of the major axis to produce a new (s, t) coordinate pair to lookup into the selected cube face.

An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

Offset vector operand e is not supported for cubemap textures.

an optional operand f may be specified for cubemap depth textures. operand f is .f32 scalar value that specifies depth compare value for cubemap depth textures.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

tex.acube

Cubemap array selection, followed by cubemap lookup. The instruction first selects a cubemap texture from the cubemap array named by operand a using the index given by the first element of the array coordinate vector c. The instruction then loads data from the selected cubemap texture at coordinates given by the remaining elements of operand c into destination d.

Cubemap array textures consist of an array of cubemaps, i.e., the total number of layers is a multiple of six. When accessing a cubemap array texture, the coordinate vector c has type .v4.b32. The first element is interpreted as an unsigned integer index (.u32) into the cubemap array, and the remaining three elements are interpreted as floating-point cubemap coordinates (s, t, r), used to lookup in the selected cubemap as described above.

An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

Offset vector operand e is not supported for cubemap texture arrays.

An optional operand f may be specified for cubemap depth texture arrays. Operand f is .f32 scalar value that specifies depth compare value for cubemap depth textures.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

tex.2dms

Multi-sample texture lookup using a texture coordinate vector. Multi-sample textures consist of multiple samples per data element. The instruction loads data from the texture named by operand a from sample number given by first element of the operand c, at coordinates given by remaining elements of operand c into destination d. When accessing a multi-sample texture, texture coordinate vector c has type .v4.b32. The first element in operand c is interpreted as unsigned integer sample number (.u32), and the next two elements are interpreted as signed integer (.s32) 2d texture coordinates. The fourth element is ignored. An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

An optional operand e may be specified. Operand e is a vector of type .v2.s32 that specifies coordinate offset. Offset is applied to coordinates before doing texture lookup. Offset value is in the range of -8 to +7.

Depth compare operand f is not supported for multi-sample textures.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

tex.a2dms

Multi-sample texture array selection, followed by multi-sample texture lookup. The instruction first selects a multi-sample texture from the multi-sample texture array named by operand a using the index given by the first element of the array coordinate vector c. The instruction then loads data from the selected multi-sample texture from sample number given by second element of the operand c, at coordinates given by remaining elements of operand c into destination d. When accessing a multi-sample texture array, texture coordinate vector c has type .v4.b32. The first element in operand c is interpreted as unsigned integer sampler number, the second element is interpreted as unsigned integer index (.u32) into the multi-sample texture array and the next two elements are interpreted as signed integer (.s32) 2d texture coordinates. An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

An optional operand e may be specified. Operand e is a vector of type .v2.s32 values that specifies coordinate offset. Offset is applied to coordinates before doing texture lookup. Offset value is in the range of -8 to +7.

Depth compare operand f is not supported for multi-sample texture arrays.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

Mipmaps

.base (lod zero)
Pick level 0 (base level). This is the default if no mipmap mode is specified. No additional arguments.

.level (lod explicit)
Requires an additional 32-bit scalar argument, lod, which contains the LOD to fetch from. The type of lod follows .ctype (either .s32 or .f32). Geometries .2dms and .a2dms are not supported in this mode.

.grad (lod gradient)
Requires two .f32 vectors, dPdx and dPdy, that specify the partials. The vectors are singletons for 1d and a1d textures; are two-element vectors for 2d and a2d textures; and are four-element vectors for 3d, cube and acube textures, where the fourth element is ignored for 3d and cube geometries. Geometries .2dms and .a2dms are not supported in this mode.

For mipmap texture lookup, an optional operand e may be specified. Operand e is a vector of .s32 that specifies coordinate offset. Offset is applied to coordinates before doing texture lookup. Offset value is in the range of -8 to +7. Offset vector operand is not supported for cube and cubemap geometries.

An optional operand f may be specified for mipmap textures. Operand f is .f32 scalar value that specifies depth compare value for depth textures. When using depth compare operand, the coordinates in texture coordinate vector c have .f32 type.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

Depth compare operand is not supported for 3d textures.

Indirect texture access

Beginning with PTX ISA version 3.1, indirect texture access is supported in unified mode for target architecture sm_20 or higher. In indirect access, operand a is a .u64 register holding the address of a .texref variable.

Notes

For compatibility with prior versions of PTX, the square brackets are not required and `.v4` coordinate vectors are allowed for any geometry, with the extra elements being ignored.

PTX ISA Notes

Unified mode texturing introduced in PTX ISA version 1.0. Extension using opaque `.texref` and `.samplerref` types and independent mode texturing introduced in PTX ISA version 1.5.

Texture arrays `tex.{a1d,a2d}` introduced in PTX ISA version 2.3.

Cubemaps and cubemap arrays introduced in PTX ISA version 3.0.

Support for mipmaps introduced in PTX ISA version 3.1.

Indirect texture access introduced in PTX ISA version 3.1.

Multi-sample textures and multi-sample texture arrays introduced in PTX ISA version 3.2.

Support for textures returning `.f16` and `.f16x2` data introduced in PTX ISA version 4.2.

Support for `tex.grad.{cube, acube}` introduced in PTX ISA version 4.3.

Offset vector operand introduced in PTX ISA version 4.3.

Depth compare operand introduced in PTX ISA version 4.3.

Support for optional destination predicate introduced in PTX ISA version 7.1.

Target ISA Notes

Supported on all target architectures.

The cubemap array geometry (`.acube`) requires `sm_20` or higher.

Mipmaps require `sm_20` or higher.

Indirect texture access requires `sm_20` or higher.

Multi-sample textures and multi-sample texture arrays require `sm_30` or higher.

Texture fetch returning `.f16` and `.f16x2` data require `sm_53` or higher.

`tex.grad.{cube, acube}` requires `sm_20` or higher.

Offset vector operand requires `sm_30` or higher.

Depth compare operand requires `sm_30` or higher.

Support for optional destination predicate requires `sm_60` or higher.

Examples

```
// Example of unified mode texturing
// - f4 is required to pad four-element tuple and is ignored
tex.3d.v4.s32.s32  {r1,r2,r3,r4}, [tex_a,{f1,f2,f3,f4}];

// Example of independent mode texturing
tex.1d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a,smpl_x,{f1}];

// Example of 1D texture array, independent texturing mode
tex.a1d.v4.s32.s32 {r1,r2,r3,r4}, [tex_a,smpl_x,{idx,s1}];

// Example of 2D texture array, unified texturing mode
// - f3 is required to pad four-element tuple and is ignored
tex.a2d.v4.s32.f32 {r1,r2,r3,r4}, [tex_a,{idx,f1,f2,f3}];

// Example of cubemap array, unified textureing mode
tex.acube.v4.f32.f32 {r0,r1,r2,r3}, [tex_cuarray,{idx,f1,f2,f3}];

// Example of multi-sample texture, unified texturing mode
tex.2dms.v4.s32.s32 {r0,r1,r2,r3}, [tex_ms,{sample,r6,r7,r8}];

// Example of multi-sample texture, independent texturing mode
tex.2dms.v4.s32.s32 {r0,r1,r2,r3}, [tex_ms, smpl_x,{sample,r6,r7,r8}];

// Example of multi-sample texture array, unified texturing mode
tex.a2dms.v4.s32.s32 {r0,r1,r2,r3}, [tex_ams,{idx,sample,r6,r7}];

// Example of texture returning .f16 data
tex.1d.v4.f16.f32  {h1,h2,h3,h4}, [tex_a,smpl_x,{f1}];

// Example of texture returning .f16x2 data
tex.1d.v2.f16x2.f32  {h1,h2}, [tex_a,smpl_x,{f1}];

// Example of 3d texture array access with tex.grad,unified texturing mode
tex.grad.3d.v4.f32.f32 {%f4,%f5,%f6,%f7},[tex_3d,{%f0,%f0,%f0,%f0}],
                {fl0,fl1,fl2,fl3},{fl0,fl1,fl2,fl3};

// Example of cube texture array access with tex.grad,unified texturing mode
tex.grad.cube.v4.f32.f32{%f4,%f5,%f6,%f7},[tex_cube,{%f0,%f0,%f0,%f0}],
                {fl0,fl1,fl2,fl3},{fl0,fl1,fl2,fl3};

// Example of 1d texture lookup with offset, unified texturing mode
tex.1d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a, {f1}], {r5};

// Example of 2d texture array lookup with offset, unified texturing mode
tex.a2d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a,{idx,f1,f2}], {f5,f6};

// Example of 2d mipmap texture lookup with offset, unified texturing mode
tex.level.2d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a,{f1,f2}],
                         flvl, {r7, r8};

// Example of 2d depth texture lookup with compare, unified texturing mode
tex.1d.v4.f32.f32  {f1,f2,f3,f4}, [tex_a, {f1}], f0;

// Example of depth 2d texture array lookup with offset, compare
tex.a2d.v4.s32.f32  {f0,f1,f2,f3}, [tex_a,{idx,f4,f5}], {r5,r6}, f6;
```

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```
// Example of destination predicate use
tex.3d.v4.s32.s32 {r1,r2,r3,r4}|p, [tex_a,{f1,f2,f3,f4}];
```

9.7.10.4 Texture Instructions: tld4

tld4

Perform a texture fetch of the 4-texel bilerp footprint.

Syntax

```
tld4.comp.2d.v4.dtype.f32    d[|p], [a, c] {, e} {, f};
tld4.comp.geom.v4.dtype.f32  d[|p], [a, b, c] {, e} {, f};  // explicit sampler

.comp  = { .r, .g, .b, .a };
.geom  = { .2d, .a2d, .cube, .acube };
.dtype = { .u32, .s32, .f32 };
```

Description

Texture fetch of the 4-texel bilerp footprint using a texture coordinate vector. The instruction loads the bilerp footprint from the texture named by operand a at coordinates given by operand c into vector destination d. The texture component fetched for each texel sample is specified by .comp. The four texel samples are placed into destination vector d in counter-clockwise order starting at lower left.

An optional texture sampler b may be specified. If no sampler is specified, the sampler behavior is a property of the named texture.

The optional destination predicate p is set to True if data from texture at specified coordinates is resident in memory, False otherwise. When optional destination predicate p is set to False, data loaded will be all zeros. Memory residency of Texture Data at specified coordinates is dependent on execution environment setup using Driver API calls, prior to kernel launch. Refer to Driver API documentation for more details including any system/implementation specific behavior.

An optional operand f may be specified for *depth textures*. Depth textures are special type of textures which hold data from the depth buffer. Depth buffer contains depth information of each pixel. Operand f is .f32 scalar value that specifies depth compare value for depth textures. Each element fetched from texture is compared against value given in f operand. If comparison passes, result is 1.0; otherwise result is 0.0. These per-element comparison results are used for the filtering.

A texture base address is assumed to be aligned to a 16 byte boundary, and the address given by the coordinate vector must be naturally aligned to a multiple of the access size. If an address is not properly aligned, the resulting behavior is undefined; i.e., the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

tld4.2d

For 2D textures, operand c specifies coordinates as a two-element, 32-bit floating-point vector.

An optional operand e may be specified. Operand e is a vector of type .v2.s32 that specifies coordinate offset. Offset is applied to coordinates before doing texture fetch. Offset value is in the range of -8 to +7.

`tld4.a2d`

Texture array selection, followed by `tld4` texture fetch of 2d texture. For 2d texture arrays operand `c` is a four element, 32-bit vector. The first element in operand `c` is interpreted as an unsigned integer index (`.u32`) into the texture array, and the next two elements are interpreted as 32-bit floating point coordinates of 2d texture. The fourth element is ignored.

An optional operand `e` may be specified. Operand `e` is a vector of type `.v2.s32` that specifies coordinate offset. Offset is applied to coordinates before doing texture fetch. Offset value is in the range of -8 to +7.

`tld4.cube`

For cubemap textures, operand `c` specifies four-element vector which comprises three floating-point coordinates (s, t, r) and a fourth padding argument which is ignored.

Cubemap textures are special two-dimensional layered textures consisting of six layers that represent the faces of a cube. All layers in a cubemap are of the same size and are square (i.e., width equals height).

Coordinates (s, t, r) are projected onto one of the six cube faces. The (s, t, r) coordinates can be thought of as a direction vector emanating from the center of the cube. Of the three coordinates (s, t, r), the coordinate of the largest magnitude (the major axis) selects the cube face. Then, the other two coordinates (the minor axes) are divided by the absolute value of the major axis to produce a new (s, t) coordinate pair to lookup into the selected cube face.

Offset vector operand `e` is not supported for cubemap textures.

`tld4.acube`

Cubemap array selection, followed by `tld4` texture fetch of cubemap texture. The first element in operand `c` is interpreted as an unsigned integer index (`.u32`) into the cubemap texture array, and the remaining three elements are interpreted as floating-point cubemap coordinates (s, t, r), used to lookup in the selected cubemap.

Offset vector operand `e` is not supported for cubemap texture arrays.

Indirect texture access

Beginning with PTX ISA version 3.1, indirect texture access is supported in unified mode for target architecture `sm_20` or higher. In indirect access, operand `a` is a `.u64` register holding the address of a `.texref` variable.

PTX ISA Notes

Introduced in PTX ISA version 2.2.

Indirect texture access introduced in PTX ISA version 3.1.

`tld4.{a2d,cube,acube}` introduced in PTX ISA version 4.3.

Offset vector operand introduced in PTX ISA version 4.3.

Depth compare operand introduced in PTX ISA version 4.3.

Support for optional destination predicate introduced in PTX ISA version 7.1.

Target ISA Notes

`tld4` requires `sm_20` or higher.

Indirect texture access requires `sm_20` or higher.

`tld4.{a2d,cube,acube}` requires `sm_30` or higher.

Offset vector operand requires `sm_30` or higher.

Depth compare operand requires `sm_30` or higher.

Support for optional destination predicate requires `sm_60` or higher.

Examples

```
//Example of unified mode texturing
tld4.r.2d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a,{f1,f2}];

// Example of independent mode texturing
tld4.r.2d.v4.u32.f32  {u1,u2,u3,u4}, [tex_a,smpl_x,{f1,f2}];

// Example of unified mode texturing using offset
tld4.r.2d.v4.s32.f32  {r1,r2,r3,r4}, [tex_a,{f1,f2}], {r5, r6};

// Example of unified mode texturing using compare
tld4.r.2d.v4.f32.f32  {f1,f2,f3,f4}, [tex_a,{f5,f6}], f7;

// Example of optional destination predicate
tld4.r.2d.v4.f32.f32 {f1,f2,f3,f4}|p, [tex_a,{f5,f6}], f7;
```

9.7.10.5 Texture Instructions: `txq`

`txq`

Query texture and sampler attributes.

Syntax

```
txq.tquery.b32         d, [a];       // texture attributes
txq.level.tlquery.b32  d, [a], lod;  // texture attributes
txq.squery.b32         d, [a];       // sampler attributes

.tquery  = { .width, .height, .depth,
             .channel_data_type, .channel_order,
             .normalized_coords, .array_size,
             .num_mipmap_levels, .num_samples};

.tlquery = { .width, .height, .depth };

.squery  = { .force_unnormalized_coords, .filter_mode,
             .addr_mode_0, addr_mode_1, addr_mode_2 };
```

Description

Query an attribute of a texture or sampler. Operand a is either a `.texref` or `.samplerref` variable, or a `.u64` register.

Query	Returns

`.width`
`.height`
`.depth`
	value in elements

`.channel_data_type`	Unsigned integer corresponding to source language's channel data type enumeration. If the source language combines channel data type and channel order into a single enumeration type, that value is returned for both `channel_data_type` and channel_order queries.
`.channel_order`	Unsigned integer corresponding to source language's channel order enumeration. If the source language combines channel data type and channel order into a single enumeration type, that value is returned for both `channel_data_type` and `channel_order` queries.
`.normalized_coords`	1 (`True`) or `0` (`False`).
`.force_unnormalized_coords`	1 (`True`) or `0` (`False`). Defined only for `.samplerref` variables in independent texture mode. Overrides the `normalized_coords` field of a `.texref` variable used with a `.samplerref` in a `tex` instruction.
`.filter_mode`	Integer from `enum { nearest, linear }`

`.addr_mode_0`
`.addr_mode_1`
`.addr_mode_2`
	Integer from `enum { wrap, mirror, clamp_ogl, clamp_to_edge, clamp_to_border }`

`.array_size`	For a texture array, number of textures in array, 0 otherwise.
`.num_mipmap_levels`	For a mipmapped texture, number of levels of details (LOD), 0 otherwise.
`.num_samples`	For a multi-sample texture, number of samples, 0 otherwise.

Texture attributes are queried by supplying a `.texref` argument to `txq`. In unified mode, sampler attributes are also accessed via a `.texref` argument, and in independent mode sampler attributes are accessed via a separate `.samplerref` argument.

`txq.level`

`txq.level` requires an additional 32bit integer argument, `lod`, which specifies LOD and queries requested attribute for the specified LOD.

Indirect texture access

Beginning with PTX ISA version 3.1, indirect texture access is supported in unified mode for target architecture `sm_20` or higher. In indirect access, operand `a` is a `.u64` register holding the address of a `.texref` variable.

PTX ISA Notes

Introduced in PTX ISA version 1.5.

Channel data type and channel order queries were added in PTX ISA version 2.1.

The `.force_unnormalized_coords` query was added in PTX ISA version 2.2.

Indirect texture access introduced in PTX ISA version 3.1.

`.array_size`, `.num_mipmap_levels`, `.num_samples` samples queries were added in PTX ISA version 4.1.

`txq.level` introduced in PTX ISA version 4.3.

Target ISA Notes

Supported on all target architectures.

Indirect texture access requires `sm_20` or higher.

Querying the number of mipmap levels requires `sm_20` or higher.

Querying the number of samples requires `sm_30` or higher.

`txq.level` requires `sm_30` or higher.

Examples

```
txq.width.b32       %r1, [tex_A];
txq.filter_mode.b32 %r1, [tex_A];   // unified mode
txq.addr_mode_0.b32 %r1, [smpl_B];  // independent mode
txq.level.width.b32 %r1, [tex_A], %r_lod;
```

9.7.10.6 Texture Instructions: `istypep`

`istypep`

Query whether a register points to an opaque variable of a specified type.

Syntax

```
istypep.type   p, a;  // result is .pred

.type = { .texref, .samplerref, .surfref };
```

Description

Write predicate register p with 1 if register a points to an opaque variable of the specified type, and with 0 otherwise. Destination p has type `.pred`; the source address operand must be of type `.u64`.

PTX ISA Notes

Introduced in PTX ISA version 4.0.

Target ISA Notes

istypep requires `sm_30` or higher.

Examples

```
istypep.texref istex, tptr;
istypep.samplerref issampler, sptr;
istypep.surfref issurface, surfptr;
```

9.7.11. Surface Instructions

This section describes PTX instructions for accessing surfaces. PTX supports the following operations on surface descriptors:

- Static initialization of surface descriptors.
- Module-scope and per-entry scope definitions of surface descriptors.
- Ability to query fields within surface descriptors.

These instructions provide access to surface memory.

- `suld`
- `sust`
- `sured`
- `suq`

9.7.11.1 Surface Instructions: suld

suld

Load from surface memory.

Syntax

```
suld.b.geom{.cop}.vec.dtype.clamp  d, [a, b];  // unformatted

.geom  = { .1d, .2d, .3d, .a1d, .a2d };
.cop   = { .ca, .cg, .cs, .cv };               // cache operation
.vec   = { none, .v2, .v4 };
.dtype = { .b8 , .b16, .b32, .b64 };
.clamp = { .trap, .clamp, .zero };
```

Description

`suld.b.{1d,2d,3d}`

Load from surface memory using a surface coordinate vector. The instruction loads data from the surface named by operand `a` at coordinates given by operand `b` into destination `d`. Operand `a` is a `.surfref` variable or `.u64` register. Operand `b` is a scalar or singleton tuple for `1d` surfaces; is a two-element vector for `2d` surfaces; and is a four-element vector for `3d` surfaces, where the fourth element is ignored. Coordinate elements are of type `.s32`.

`suld.b` performs an unformatted load of binary data. The lowest dimension coordinate represents a byte offset into the surface and is not scaled, and the size of the data transfer matches the size of destination operand `d`.

`suld.b.{a1d,a2d}`

Surface layer selection, followed by a load from the selected surface. The instruction first selects a surface layer from the surface array named by operand `a` using the index given by the first element of the array coordinate vector `b`. The instruction then loads data from the selected surface at coordinates given by the remaining elements of operand `b` into destination `d`. Operand `a` is a `.surfref` variable or `.u64` register. Operand `b` is a bit-size type vector or tuple containing an index into the array of surfaces followed by coordinates within the selected surface, as follows:

For `1d` surface arrays, operand `b` has type `.v2.b32`. The first element is interpreted as an unsigned integer index (`.u32`) into the surface array, and the second element is interpreted as a `1d` surface coordinate of type `.s32`.

For `2d` surface arrays, operand `b` has type `.v4.b32`. The first element is interpreted as an unsigned integer index (`.u32`) into the surface array, and the next two elements are interpreted as `2d` surface coordinates of type `.s32`. The fourth element is ignored.

A surface base address is assumed to be aligned to a 16 byte boundary, and the address given by the coordinate vector must be naturally aligned to a multiple of the access size. If an address is not properly aligned, the resulting behavior is undefined; i.e., the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

The `.clamp` field specifies how to handle out-of-bounds addresses:

`.trap`
causes an execution trap on out-of-bounds addresses

.clamp
loads data at the nearest surface location (sized appropriately)

.zero
loads zero for out-of-bounds addresses

Indirect surface access

Beginning with PTX ISA version 3.1, indirect surface access is supported for target architecture `sm_20` or higher. In indirect access, operand a is a `.u64` register holding the address of a `.surfref` variable.

PTX ISA Notes

`suld.b.trap` introduced in PTX ISA version 1.5.

Additional clamp modifiers and cache operations introduced in PTX ISA version 2.0.

`suld.b.3d` and `suld.b.{a1d,a2d}` introduced in PTX ISA version 3.0.

Indirect surface access introduced in PTX ISA version 3.1.

Target ISA Notes

`suld.b` supported on all target architectures.

`sm_1x` targets support only the `.trap` clamping modifier.

`suld.3d` and `suld.{a1d,a2d}` require `sm_20` or higher.

Indirect surface access requires `sm_20` or higher.

Cache operations require `sm_20` or higher.

Examples

```
suld.b.1d.v4.b32.trap  {s1,s2,s3,s4}, [surf_B, {x}];
suld.b.3d.v2.b64.trap  {r1,r2}, [surf_A, {x,y,z,w}];
suld.b.a1d.v2.b32      {r0,r1}, [surf_C, {idx,x}];
suld.b.a2d.b32         r0, [surf_D, {idx,x,y,z}];  // z ignored
```

9.7.11.2 Surface Instructions: sust

sust

Store to surface memory.

Syntax

```
sust.b.{1d,2d,3d}{.cop}.vec.ctype.clamp  [a, b], c;  // unformatted
sust.p.{1d,2d,3d}.vec.b32.clamp          [a, b], c;  // formatted

sust.b.{a1d,a2d}{.cop}.vec.ctype.clamp   [a, b], c;  // unformatted

.cop   = { .wb, .cg, .cs, .wt };                     // cache operation
.vec   = { none, .v2, .v4 };
.ctype = { .b8 , .b16, .b32, .b64 };
.clamp = { .trap, .clamp, .zero };
```

Description

`sust.{1d,2d,3d}`

Store to surface memory using a surface coordinate vector. The instruction stores data from operand `c` to the surface named by operand `a` at coordinates given by operand `b`. Operand `a` is a `.surfref` variable or `.u64` register. Operand `b` is a scalar or singleton tuple for `1d` surfaces; is a two-element vector for `2d` surfaces; and is a four-element vector for `3d` surfaces, where the fourth element is ignored. Coordinate elements are of type `.s32`.

`sust.b` performs an unformatted store of binary data. The lowest dimension coordinate represents a byte offset into the surface and is not scaled. The size of the data transfer matches the size of source operand `c`.

`sust.p` performs a formatted store of a vector of 32-bit data values to a surface sample. The source vector elements are interpreted left-to-right as `R`, `G`, `B`, and `A` surface components. These elements are written to the corresponding surface sample components. Source elements that do not occur in the surface sample are ignored. Surface sample components that do not occur in the source vector will be written with an unpredictable value. The lowest dimension coordinate represents a sample offset rather than a byte offset.

The source data interpretation is based on the surface sample format as follows: If the surface format contains `UNORM`, `SNORM`, or `FLOAT` data, then `.f32` is assumed; if the surface format contains `UINT` data, then `.u32` is assumed; if the surface format contains `SINT` data, then `.s32` is assumed. The source data is then converted from this type to the surface sample format.

`sust.b.{a1d,a2d}`

Surface layer selection, followed by an unformatted store to the selected surface. The instruction first selects a surface layer from the surface array named by operand `a` using the index given by the first element of the array coordinate vector `b`. The instruction then stores the data in operand `c` to the selected surface at coordinates given by the remaining elements of operand `b`. Operand `a` is a .surfref variable or `.u64` register. Operand `b` is a bit-size type vector or tuple containing an index into the array of surfaces followed by coordinates within the selected surface, as follows:

- For `1d` surface arrays, operand `b` has type `.v2.b32`. The first element is interpreted as an unsigned integer index (`.u32`) into the surface array, and the second element is interpreted as a `1d` surface coordinate of type `.s32`.
- For `2d` surface arrays, operand `b` has type `.v4.b32`. The first element is interpreted as an unsigned integer index (`.u32`) into the surface array, and the next two elements are interpreted as `2d` surface coordinates of type `.s32`. The fourth element is ignored.

A surface base address is assumed to be aligned to a 16 byte boundary, and the address given by the coordinate vector must be naturally aligned to a multiple of the access size. If an address is not

properly aligned, the resulting behavior is undefined; i.e., the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

The `.clamp` field specifies how to handle out-of-bounds addresses:

`.trap`
causes an execution trap on out-of-bounds addresses

`.clamp`
stores data at the nearest surface location (sized appropriately)

`.zero`
drops stores to out-of-bounds addresses

Indirect surface access

Beginning with PTX ISA version 3.1, indirect surface access is supported for target architecture `sm_20` or higher. In indirect access, operand a is a `.u64` register holding the address of a `.surfref` variable.

PTX ISA Notes

`sust.b.trap` introduced in PTX ISA version 1.5. `sust.p`, additional clamp modifiers, and cache operations introduced in PTX ISA version 2.0.

`sust.b.3d` and `sust.b.{a1d,a2d}` introduced in PTX ISA version 3.0.

Indirect surface access introduced in PTX ISA version 3.1.

Target ISA Notes

`sust.b` supported on all target architectures.

`sm_1x` targets support only the `.trap` clamping modifier.

`sust.3d` and `sust.{a1d,a2d}` require `sm_20` or higher.

`sust.p` requires `sm_20` or higher.

Indirect surface access requires `sm_20` or higher.

Cache operations require `sm_20` or higher.

Examples

```
sust.p.1d.v4.b32.trap  [surf_B, {x}], {f1,f2,f3,f4};
sust.b.3d.v2.b64.trap  [surf_A, {x,y,z,w}], {r1,r2};
sust.b.a1d.v2.b64      [surf_C, {idx,x}], {r1,r2};
sust.b.a2d.b32         [surf_D, {idx,x,y,z}], r0;  // z ignored
```

9.7.11.3 Surface Instructions: sured

sured

Reduce surface memory.

Syntax

```
sured.b.op.geom.ctype.clamp  [a,b],c; // byte addressing
sured.p.op.geom.ctype.clamp  [a,b],c; // sample addressing

.op    = { .add, .min, .max, .and, .or };
.geom  = { .1d, .2d, .3d };
.ctype = { .u32, .u64, .s32, .b32, .s64 };  // for sured.b
.ctype = { .b32, .b64 };                    // for sured.p
.clamp = { .trap, .clamp, .zero };
```

Description

Reduction to surface memory using a surface coordinate vector. The instruction performs a reduction operation with data from operand c to the surface named by operand a at coordinates given by operand b. Operand a is a `.surfref` variable or `.u64` register. Operand b is a scalar or singleton tuple for 1d surfaces; is a two-element vector for 2d surfaces; and is a four-element vector for 3d surfaces, where the fourth element is ignored. Coordinate elements are of type `.s32`.

`sured.b` performs an unformatted reduction on `.u32`, `.s32`, `.b32`, `.u64`, or `.s64` data. The lowest dimension coordinate represents a byte offset into the surface and is not scaled. Operation `add` applies to `.u32`, `.u64`, and `.s32` types; `min` and `max` apply to `.u32`, `.s32`, `.u64` and `.s64` types; operations `and` and `or` apply to `.b32` type.

`sured.p` performs a reduction on sample-addressed data. The lowest dimension coordinate represents a sample offset rather than a byte offset. The instruction type `.b64` is restricted to `min` and `max` operations. For type `.b32`, the data is interpreted as `.u32` or `.s32` based on the surface sample format as follows: if the surface format contains `UINT` data, then `.u32` is assumed; if the surface format contains `SINT` data, then `.s32` is assumed. For type `.b64`, if the surface format contains `UINT` data, then `.u64` is assumed; if the surface format contains `SINT` data, then `.s64` is assumed.

A surface base address is assumed to be aligned to a 16 byte boundary, and the address given by the coordinate vector must be naturally aligned to a multiple of the access size. If an address is not properly aligned, the resulting behavior is undefined; i.e., the access may proceed by silently masking off low-order address bits to achieve proper rounding, or the instruction may fault.

The `.clamp` field specifies how to handle out-of-bounds addresses:

`.trap`
causes an execution trap on out-of-bounds addresses

`.clamp`
stores data at the nearest surface location (sized appropriately)

`.zero`
drops stores to out-of-bounds addresses

Indirect surface access

Beginning with PTX ISA version 3.1, indirect surface access is supported for target architecture `sm_20` or higher. In indirect access, operand a is a `.u64` register holding the address of a `.surfref` variable.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Indirect surface access introduced in PTX ISA version 3.1.

`.u64/.s64/.b64` types with `.min/.max` operations introduced in PTX ISA version 8.1.

Target ISA Notes

sured requires `sm_20` or higher.

Indirect surface access requires `sm_20` or higher.

`.u64/.s64/.b64` types with `.min/.max` operations requires `sm_50` or higher.

Examples

```
sured.b.add.2d.u32.trap  [surf_A, {x,y}], r1;
sured.p.min.1d.u32.trap  [surf_B, {x}], r1;
sured.b.max.1d.u64.trap  [surf_C, {x}], r1;
sured.p.min.1d.b64.trap  [surf_D, {x}], r1;
```

9.7.11.4 Surface Instructions: suq

suq

Query a surface attribute.

Syntax

```
suq.query.b32   d, [a];

.query = { .width, .height, .depth,
           .channel_data_type, .channel_order,
           .array_size, .memory_layout };
```

Description

Query an attribute of a surface. Operand a is a `.surfref` variable or a `.u64` register.

Query	Returns

`.width`
`.height`
`.depth`
	value in elements

`.channel_data_type`	Unsigned integer corresponding to source language's channel data type enumeration. If the source language combines channel data type and channel order into a single enumeration type, that value is returned for both `channel_data_type` and `channel_order` queries.
`.channel_order`	Unsigned integer corresponding to source language's channel order enumeration. If the source language combines channel data type and channel order into a single enumeration type, that value is returned for both `channel_data_type` and `channel_order` queries.
`.array_size`	For a surface array, number of surfaces in array, 0 otherwise.
`.memory_layout`	1 for surface with linear memory layout; `0` otherwise

Indirect surface access

Beginning with PTX ISA version 3.1, indirect surface access is supported for target architecture `sm_20` or higher. In indirect access, operand a is a `.u64` register holding the address of a `.surfref` variable.

PTX ISA Notes

Introduced in PTX ISA version 1.5.

Channel data type and channel order queries added in PTX ISA version 2.1.

Indirect surface access introduced in PTX ISA version 3.1.

The `.array_size` query was added in PTX ISA version 4.1.

The `.memory_layout` query was added in PTX ISA version 4.2.

Target ISA Notes

Supported on all target architectures.

Indirect surface access requires `sm_20` or higher.

Examples

```
suq.width.b32       %r1, [surf_A];
```

9.7.12. Control Flow Instructions

The following PTX instructions and syntax are for controlling execution in a PTX program:

- {}
- @
- bra
- call
- ret
- exit

9.7.12.1 Control Flow Instructions: {}

{}

Instruction grouping.

Syntax

```
{ instructionList }
```

Description

The curly braces create a group of instructions, used primarily for defining a function body. The curly braces also provide a mechanism for determining the scope of a variable: any variable declared within a scope is not available outside the scope.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
{ add.s32  a,b,c; mov.s32  d,a; }
```

9.7.12.2 Control Flow Instructions: @

@

Predicated execution.

Syntax

```
@{!}p    instruction;
```

Description

Execute an instruction or instruction block for threads that have the guard predicate `True`. Threads with a `False` guard predicate do nothing.

Semantics

If `{!}p` then instruction

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
    setp.eq.f32  p,y,0;     // is y zero?
@!p div.f32      ratio,x,y  // avoid division by zero

@q  bra L23;                // conditional branch
```

9.7.12.3 Control Flow Instructions: bra

bra

Branch to a target and continue execution there.

Syntax

```
@p   bra{.uni}  tgt;           // tgt is a label
     bra{.uni}  tgt;           // unconditional branch
```

Description

Continue execution at the target. Conditional branches are specified by using a guard predicate. The branch target must be a label.

`bra.uni` is guaranteed to be non-divergent, i.e. all active threads in a warp that are currently executing this instruction have identical values for the guard predicate and branch target.

Semantics

```
if (p) {
    pc = tgt;
}
```

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Unimplemented indirect branch introduced in PTX ISA version 2.1 has been removed from the spec.

Target ISA Notes

Supported on all target architectures.

Examples

```
bra.uni  L_exit;    // uniform unconditional jump
@q  bra      L23;   // conditional branch
```

9.7.12.4 Control Flow Instructions: `brx.idx`

`brx.idx`

Branch to a label indexed from a list of potential branch targets.

Syntax

```
@p    brx.idx{.uni} index, tlist;
      brx.idx{.uni} index, tlist;
```

Description

Index into a list of possible destination labels, and continue execution from the chosen label. Conditional branches are specified by using a guard predicate.

`brx.idx.uni` guarantees that the branch is non-divergent, i.e. all active threads in a warp that are currently executing this instruction have identical values for the guard predicate and the `index` argument.

The `index` operand is a `.u32` register. The `tlist` operand must be the label of a `.branchtargets` directive. It is accessed as a zero-based sequence using `index`. Behaviour is undefined if the value of `index` is greater than or equal to the length of `tlist`.

The `.branchtargets` directive must be defined in the local function scope before it is used. It must refer to labels within the current function.

Semantics

```
if (p) {
    if (index < length(tlist)) {
      pc = tlist[index];
    } else {
      pc = undefined;
    }
}
```

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
.function foo () {
    .reg .u32 %r0;
    ...
    L1:
    ...
    L2:
    ...
    L3:
    ...
    ts: .branchtargets L1, L2, L3;
    @p brx.idx %r0, ts;
    ...
}
```

9.7.12.5 Control Flow Instructions: `call`

`call`

Call a function, recording the return location.

Syntax

```
// direct call to named function, func is a symbol
call{.uni} (ret-param), func, (param-list);
call{.uni} func, (param-list);
call{.uni} func;

// indirect call via pointer, with full list of call targets
call{.uni} (ret-param), fptr, (param-list), flist;
call{.uni} fptr, (param-list), flist;
call{.uni} fptr, flist;

// indirect call via pointer, with no knowledge of call targets
call{.uni} (ret-param), fptr, (param-list), fproto;
call{.uni} fptr, (param-list), fproto;
call{.uni} fptr, fproto;
```

Description

The `call` instruction stores the address of the next instruction, so execution can resume at that point after executing a `ret` instruction. A `call` is assumed to be divergent unless the `.uni` suffix is present. The `.uni` suffix indicates that the `call` is guaranteed to be non-divergent, i.e. all active threads in a warp that are currently executing this instruction have identical values for the guard predicate and `call` target.

For direct calls, the called location `func` must be a symbolic function name; for indirect calls, the called location `fptr` must be an address of a function held in a register. Input arguments and return values are optional. Arguments may be registers, immediate constants, or variables in `.param` space. Arguments are pass-by-value.

Indirect calls require an additional operand, `flist` or `fproto`, to communicate the list of potential `call` targets or the common function prototype of all `call` targets, respectively. In the first case, `flist` gives a complete list of potential `call` targets and the optimizing backend is free to optimize the calling convention. In the second case, where the complete list of potential `call` targets may not be known, the common function prototype is given and the `call` must obey the ABI's calling convention.

The `flist` operand is either the name of an array (call table) initialized to a list of function names; or a label associated with a `.calltargets` directive, which declares a list of potential `call` targets. In both cases the fptr register holds the address of a function listed in the call table or `.calltargets` list, and the `call` operands are type-checked against the type signature of the functions indicated by `flist`.

The fproto operand is the name of a label associated with a `.callprototype` directive. This operand is used when a complete list of potential targets is not known. The `call` operands are type-checked against the prototype, and code generation will follow the ABI calling convention. If a function that doesn't match the prototype is called, the behavior is undefined.

Call tables may be declared at module scope or local scope, in either the constant or global state space. The `.calltargets` and `.callprototype` directives must be declared within a function body. All functions must be declared prior to being referenced in a `call` table initializer or `.calltargets` directive.

PTX ISA Notes

Direct `call` introduced in PTX ISA version 1.0. Indirect `call` introduced in PTX ISA version 2.1.

Target ISA Notes

Direct `call` supported on all target architectures. Indirect `call` requires `sm_20` or higher.

Examples

```
// examples of direct call
    call     init;    // call function 'init'
    call.uni g, (a);  // call function 'g' with parameter 'a'
@p  call     (d), h, (a, b);  // return value into register d

// call-via-pointer using jump table
.func (.reg .u32 rv) foo (.reg .u32 a, .reg .u32 b) ...
.func (.reg .u32 rv) bar (.reg .u32 a, .reg .u32 b) ...
.func (.reg .u32 rv) baz (.reg .u32 a, .reg .u32 b) ...

.global .u32 jmptbl[5] = { foo, bar, baz };
      ...
@p    ld.global.u32  %r0, [jmptbl+4];
@p    ld.global.u32  %r0, [jmptbl+8];
      call  (retval), %r0, (x, y), jmptbl;

// call-via-pointer using .calltargets directive
.func (.reg .u32 rv) foo (.reg .u32 a, .reg .u32 b) ...
.func (.reg .u32 rv) bar (.reg .u32 a, .reg .u32 b) ...
.func (.reg .u32 rv) baz (.reg .u32 a, .reg .u32 b) ...
      ...
@p    mov.u32  %r0, foo;
@q    mov.u32  %r0, baz;
Ftgt: .calltargets foo, bar, baz;
      call  (retval), %r0, (x, y), Ftgt;

// call-via-pointer using .callprototype directive
.func dispatch (.reg .u32 fptr, .reg .u32 idx)
{
...
Fproto: .callprototype _ (.param .u32 _, .param .u32 _);
      call  %fptr, (x, y), Fproto;
...
```

9.7.12.6 Control Flow Instructions: `ret`

`ret`

Return from function to instruction after call.

Syntax

```
ret{.uni};
```

Description

Return execution to caller's environment. A divergent return suspends threads until all threads are ready to return to the caller. This allows multiple divergent `ret` instructions.

A `ret` is assumed to be divergent unless the `.uni` suffix is present, indicating that the return is guaranteed to be non-divergent.

Any values returned from a function should be moved into the return parameter variables prior to executing the `ret` instruction.

A return instruction executed in a top-level entry routine will terminate thread execution.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
    ret;
@p  ret;
```

9.7.12.7 Control Flow Instructions: `exit`

`exit`

Terminate a thread.

Syntax

```
exit;
```

Description

Ends execution of a thread.

As threads exit, barriers waiting on all threads are checked to see if the exiting threads are the only threads that have not yet made it to a barrier{.cta} for all threads in the CTA or to a `barrier.cluster` for all threads in the cluster. If the exiting threads are holding up the barrier, the barrier is released.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
    exit;
@p  exit;
```

9.7.13. Parallel Synchronization and Communication Instructions

These instructions are:

- `bar{.cta}, barrier{.cta}`
- `bar.warp.sync`
- `barrier.cluster`
- `membar`
- `atom`
- `red`
- `red.async`
- `vote`
- `match.sync`
- `activemask`
- `redux.sync`
- `griddepcontrol`
- `elect.sync`
- `mbarrier.init`
- `mbarrier.inval`
- `mbarrier.arrive`
- `mbarrier.arrive_drop`
- `mbarrier.test_wait`
- `mbarrier.try_wait`
- `mbarrier.pending_count`
- `cp.async.mbarrier.arrive`

- `tensormap.cp_fenceproxy`
- `clusterlaunchcontrol.try_cancel`
- `clusterlaunchcontrol.query_cancel`

9.7.13.1 Parallel Synchronization and Communication Instructions: `bar`, `barrier`

`bar`, `bar.cta`, `barrier`, `barrier.cta`

Barrier synchronization.

Syntax

```
barrier{.cta}.sync{.aligned}      a{, b};
barrier{.cta}.arrive{.aligned}    a, b;

barrier{.cta}.red.popc{.aligned}.u32  d, a{, b}, {!}c;
barrier{.cta}.red.op{.aligned}.pred   p, a{, b}, {!}c;

bar{.cta}.sync      a{, b};
bar{.cta}.arrive    a, b;

bar{.cta}.red.popc.u32  d, a{, b}, {!}c;
bar{.cta}.red.op.pred   p, a{, b}, {!}c;

.op = { .and, .or };
```

Description

Performs barrier synchronization and communication within a CTA. Each CTA instance has sixteen barriers numbered `0..15`.

`barrier{.cta}` instructions can be used by the threads within the CTA for synchronization and communication.

Operands `a`, `b`, and `d` have type `.u32`; operands `p` and `c` are predicates. Source operand `a` specifies a logical barrier resource as an immediate constant or register with value `0` through `15`. Operand `b` specifies the number of threads participating in the barrier. If no thread count is specified, all threads in the CTA participate in the barrier. When specifying a thread count, the value must be a multiple of the warp size. Note that a non-zero thread count is required for `barrier{.cta}.arrive`.

Depending on operand `b`, either specified number of threads (in multiple of warp size) or all threads in the CTA participate in `barrier{.cta}` instruction. The `barrier{.cta}` instructions signal the arrival of the executing threads at the named barrier.

`barrier{.cta}` instruction causes executing thread to wait for all non-exited threads from its warp and marks warps' arrival at barrier. In addition to signaling its arrival at the barrier, the `barrier{.cta}.red` and `barrier{.cta}.sync` instructions causes executing thread to wait for non-exited threads of all other warps participating in the barrier to arrive. `barrier{.cta}.arrive` does not cause executing thread to wait for threads of other participating warps.

When a barrier completes, the waiting threads are restarted without delay, and the barrier is reinitialized so that it can be immediately reused.

The barrier{.cta}.sync or barrier{.cta}.red or barrier{.cta}.arrive instruction guarantees that when the barrier completes, prior memory accesses requested by this thread are performed relative to all threads participating in the barrier. The barrier{.cta}.sync and barrier{.cta}.red instruction further guarantees that no new memory access is requested by this thread before the barrier completes.

A memory read (e.g., by ld or atom) has been performed when the value read has been transmitted from memory and cannot be modified by another thread participating in the barrier. A memory write (e.g., by st, red or atom) has been performed when the value written has become visible to other threads participating in the barrier, that is, when the previous value can no longer be read.

barrier{.cta}.red performs a reduction operation across threads. The c predicate (or its complement) from all threads in the CTA are combined using the specified reduction operator. Once the barrier count is reached, the final value is written to the destination register in all threads waiting at the barrier.

The reduction operations for barrier{.cta}.red are population-count (.popc), all-threads-True (.and), and any-thread-True (.or). The result of .popc is the number of threads with a True predicate, while .and and .or indicate if all the threads had a True predicate or if any of the threads had a True predicate.

Instruction barrier{.cta} has optional .aligned modifier. When specified, it indicates that all threads in CTA will execute the same barrier{.cta} instruction. In conditionally executed code, an aligned barrier{.cta} instruction should only be used if it is known that all threads in CTA evaluate the condition identically, otherwise behavior is undefined.

Different warps may execute different forms of the barrier{.cta} instruction using the same barrier name and thread count. One example mixes barrier{.cta}.sync and barrier{.cta}.arrive to implement producer/consumer models. The producer threads execute barrier{.cta}.arrive to announce their arrival at the barrier and continue execution without delay to produce the next value, while the consumer threads execute the barrier{.cta}.sync to wait for a resource to be produced. The roles are then reversed, using a different barrier, where the producer threads execute a barrier{.cta}.sync to wait for a resource to consumed, while the consumer threads announce that the resource has been consumed with barrier{.cta}.arrive. Care must be taken to keep a warp from executing more barrier{.cta} instructions than intended (barrier{.cta}.arrive followed by any other barrier{.cta} instruction to the same barrier) prior to the reset of the barrier. barrier{.cta}.red should not be intermixed with barrier{.cta}.sync or barrier{.cta}.arrive using the same active barrier. Execution in this case is unpredictable.

The optional .cta qualifier simply indicates CTA-level applicability of the barrier and it doesn't change the semantics of the instruction.

bar{.cta}.sync is equivalent to barrier{.cta}.sync.aligned. bar{.cta}.arrive is equivalent to barrier{.cta}.arrive.aligned. bar{.cta}.red is equivalent to barrier{.cta}.red.aligned.

Note: For .target sm_6x or below,

1. barrier{.cta} instruction without .aligned modifier is equivalent to .aligned variant and has the same restrictions as of .aligned variant.
2. All threads in warp (except for those have exited) must execute barrier{.cta} instruction in convergence.

PTX ISA Notes

`bar.sync` without a thread count introduced in PTX ISA version 1.0.

Register operands, thread count, and `bar.{arrive,red}` introduced in PTX ISA version 2.0.

`barrier` instruction introduced in PTX ISA version 6.0.

`.cta` qualifier introduced in PTX ISA version 7.8.

Target ISA Notes

Register operands, thread count, and `bar{.cta}.{arrive,red}` require `sm_20` or higher.

Only `bar{.cta}.sync` with an immediate barrier number is supported for `sm_1x` targets.

`barrier{.cta}` instruction requires `sm_30` or higher.

Examples

```
// Use bar.sync to arrive at a pre-computed barrier number and
// wait for all threads in CTA to also arrive:
    st.shared [r0],r1;  // write my result to shared memory
    bar.cta.sync  1;    // arrive, wait for others to arrive
    ld.shared r2,[r3];  // use shared results from other threads

// Use bar.sync to arrive at a pre-computed barrier number and
// wait for fixed number of cooperating threads to arrive:
    #define CNT1 (8*12) // Number of cooperating threads

    st.shared [r0],r1;     // write my result to shared memory
    bar.cta.sync  1, CNT1; // arrive, wait for others to arrive
    ld.shared r2,[r3];     // use shared results from other threads

// Use bar.red.and to compare results across the entire CTA:
    setp.eq.u32 p,r1,r2;         // p is True if r1==r2
    bar.cta.red.and.pred r3,1,p; // r3=AND(p) forall threads in CTA

// Use bar.red.popc to compute the size of a group of threads
// that have a specific condition True:
    setp.eq.u32 p,r1,r2;         // p is True if r1==r2
    bar.cta.red.popc.u32 r3,1,p; // r3=SUM(p) forall threads in CTA

// Examples of barrier.cta.sync
    st.shared         [r0],r1;
    barrier.cta.sync  0;
    ld.shared         r1, [r0];

/* Producer/consumer model. The producer deposits a value in
 * shared memory, signals that it is complete but does not wait
 * using bar.arrive, and begins fetching more data from memory.
 * Once the data returns from memory, the producer must wait
 * until the consumer signals that it has read the value from
 * the shared memory location. In the meantime, a consumer
 * thread waits until the data is stored by the producer, reads
 * it, and then signals that it is done (without waiting).
```

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```
*/
   // Producer code places produced value in shared memory.
   st.shared   [r0],r1;
   bar.arrive  0,64;
   ld.global   r1,[r2];
   bar.sync    1,64;
   ...

   // Consumer code, reads value from shared memory
   bar.sync   0,64;
   ld.shared  r1,[r0];
   bar.arrive 1,64;
   ...
```

9.7.13.2 Parallel Synchronization and Communication Instructions: `bar.warp.sync`

`bar.warp.sync`

Barrier synchronization for threads in a warp.

Syntax

```
bar.warp.sync      membermask;
```

Description

`bar.warp.sync` will cause executing thread to wait until all threads corresponding to `membermask` have executed a `bar.warp.sync` with the same `membermask` value before resuming execution.

Operand `membermask` specifies a 32-bit integer which is a mask indicating threads participating in barrier where the bit position corresponds to thread's `laneid`.

The behavior of `bar.warp.sync` is undefined if the executing thread is not in the `membermask`.

`bar.warp.sync` also guarantee memory ordering among threads participating in barrier. Thus, threads within warp that wish to communicate via memory can store to memory, execute `bar.warp.sync`, and then safely read values stored by other threads in warp.

Note: For .target `sm_6x` or below, all threads in `membermask` must execute the same `bar.warp.sync` instruction in convergence, and only threads belonging to some `membermask` can be active when the `bar.warp.sync` instruction is executed. Otherwise, the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
st.shared.u32 [r0],r1;         // write my result to shared memory
bar.warp.sync  0xffffffff;     // arrive, wait for others to arrive
ld.shared.u32 r2,[r3];         // read results written by other threads
```

9.7.13.3 Parallel Synchronization and Communication Instructions: `barrier.cluster`

`barrier.cluster`

Barrier synchronization within a cluster.

Syntax

```
barrier.cluster.arrive{.sem}{.aligned};
barrier.cluster.wait{.acquire}{.aligned};

.sem = {.release, .relaxed}
```

Description

Performs barrier synchronization and communication within a cluster.

`barrier.cluster` instructions can be used by the threads within the cluster for synchronization and communication.

`barrier.cluster.arrive` instruction marks warps' arrival at barrier without causing executing thread to wait for threads of other participating warps.

`barrier.cluster.wait` instruction causes the executing thread to wait for all non-exited threads of the cluster to perform `barrier.cluster.arrive`.

In addition, `barrier.cluster` instructions cause the executing thread to wait for all non-exited threads from its warp.

When all non-exited threads that executed `barrier.cluster.arrive` have executed `barrier.cluster.wait`, the barrier completes and is reinitialized so it can be reused immediately. Each thread must arrive at the barrier only once before the barrier completes.

The `barrier.cluster.wait` instruction guarantees that when it completes the execution, memory accesses (except asynchronous operations) requested, in program order, prior to the preceding `barrier.cluster.arrive` by all threads in the cluster are complete and visible to the executing thread.

There is no memory ordering and visibility guarantee for memory accesses requested by the executing thread, in program order, after `barrier.cluster.arrive` and prior to `barrier.cluster.wait`.

The optional `.relaxed` qualifier on `barrier.cluster.arrive` specifies that there are no memory ordering and visibility guarantees provided for the memory accesses performed prior to `barrier.cluster.arrive`.

The optional `.sem` and `.acquire` qualifiers on instructions `barrier.cluster.arrive` and `barrier.cluster.wait` specify the memory synchronization as described in the *Memory Consistency Model*. If the optional `.sem` qualifier is absent for `barrier.cluster.arrive`, `.release` is assumed by default. If the optional `.acquire` qualifier is absent for `barrier.cluster.wait`, `.acquire` is assumed by default.

The optional `.aligned` qualifier indicates that all threads in the warp must execute the same `barrier.cluster` instruction. In conditionally executed code, an aligned `barrier.cluster` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Support for `.acquire`, `.relaxed`, `.release` qualifiers introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
// use of arrive followed by wait
ld.shared::cluster.u32 r0, [addr];
barrier.cluster.arrive.aligned;
...
barrier.cluster.wait.aligned;
st.shared::cluster.u32 [addr], r1;

// use memory fence prior to arrive for relaxed barrier
@cta0 ld.shared::cluster.u32 r0, [addr];
fence.cluster.acq_rel;
barrier.cluster.arrive.relaxed.aligned;
...
barrier.cluster.wait.aligned;
@cta1 st.shared::cluster.u32 [addr], r1;
```

9.7.13.4 Parallel Synchronization and Communication Instructions: membar / fence

membar, fence

Enforce an ordering of memory operations.

Syntax

```
// Thread fence:
fence{.sem}.scope;

// Thread fence (uni-directional):
fence.acquire.sync_restrict::shared::cluster.cluster;
fence.release.sync_restrict::shared::cta.cluster;

// Operation fence (uni-directional):
fence.op_restrict.release.cluster;

// Proxy fence (bi-directional):
fence.proxy.proxykind;

// Proxy fence (uni-directional):
fence.proxy.to_proxykind::from_proxykind.release.scope;
fence.proxy.to_proxykind::from_proxykind.acquire.scope  [addr], size;
fence.proxy.async::generic.acquire.sync_restrict::shared::cluster.cluster;
fence.proxy.async::generic.release.sync_restrict::shared::cta.cluster;

// Old style membar:
membar.level;
membar.proxy.proxykind;

.sem       = { .sc, .acq_rel, .acquire, .release };
.scope     = { .cta, .cluster, .gpu, .sys };
.level     = { .cta, .gl, .sys };
.proxykind = { .alias, .async, .async.global, .async.shared::{cta, cluster} };
.op_restrict = { .mbarrier_init };
.to_proxykind::from_proxykind = {.tensormap::generic};
```

Description

The `membar` instruction guarantees that prior memory accesses requested by this thread (`ld`, `st`, `atom` and `red` instructions) are performed at the specified `level`, before later memory operations requested by this thread following the `membar` instruction. The `level` qualifier specifies the set of threads that may observe the ordering effect of this operation.

A memory read (e.g., by `ld` or `atom`) has been performed when the value read has been transmitted from memory and cannot be modified by another thread at the indicated level. A memory write (e.g., by `st`, `red` or `atom`) has been performed when the value written has become visible to other threads at the specified level, that is, when the previous value can no longer be read.

The `fence` instruction establishes an ordering between memory accesses requested by this thread (`ld`, `st`, `atom` and `red` instructions) as described in the *Memory Consistency Model*. The scope qualifier specifies the set of threads that may observe the ordering effect of this operation.

`fence.acq_rel` is a light-weight fence that is sufficient for memory synchronization in most programs. Instances of `fence.acq_rel` synchronize when combined with additional memory operations as described in `acquire` and `release` patterns in the *Memory Consistency Model*. If the optional `.sem` qualifier is absent, `.acq_rel` is assumed by default.

`fence.sc` is a slower fence that can restore *sequential consistency* when used in sufficient places, at the cost of performance. Instances of `fence.sc` with sufficient scope always synchronize by forming a total order per scope, determined at runtime. This total order can be constrained further by other synchronization in the program.

Qualifiers `.op_restrict` and `.sync_restrict` restrict the class of memory operations for which the `fence` instruction provides the memory ordering guarantees. When `.op_restrict` is `.mbarrier_init`, the synchronizing effect of the fence only applies to the prior `mbarrier.init` operations executed by the same thread on *mbarrier objects* in `.shared::cta` state space. When `.sync_restrict` is `.sync_restrict::shared::cta`, `.sem` must be `.release`, and the effect of the fence only applies to operations performed on objects in `.shared::cta` state space. Likewise, when `.sync_restrict` is `.sync_restrict::shared::cluster`, `.sem` must be `.acquire`, and the effect of the fence only applies to operations performed on objects in `.shared::cluster` state space. When either `.sync_restrict::shared::cta` or `.sync_restrict::shared::cluster` is present, the `.scope` must be specified as `.cluster`.

The address operand `addr` and the operand `size` together specify the memory range `[addr, addr+size-1]` on which the ordering guarantees on the memory accesses across the proxies is to be provided. The only supported value for the `size` operand is `128`, which must be a constant integer literal. *Generic Addressing* is used unconditionally, and the address specified by the operand `addr` must fall within the `.global` state space. Otherwise, the behavior is undefined.

On `sm_70` and higher `membar` is a synonym for `fence.sc`[1], and the `membar` levels `cta`, `gl` and `sys` are synonymous with the `fence` scopes `cta`, `gpu` and `sys` respectively.

`membar.proxy` and `fence.proxy` instructions establish an ordering between memory accesses that may happen through different *proxies*.

A *uni-directional* proxy ordering from the *from-proxykind* to the *to-proxykind* establishes ordering between a prior memory access performed via the *from-proxykind* and a subsequent memory access performed via the *to-proxykind*.

A *bi-directional* proxy ordering between two proxykinds establishes two *uni-directional* proxy orderings : one from the first proxykind to the second proxykind and the other from the second proxykind to the first proxykind.

The `.proxykind` qualifier indicates the *bi-directional* proxy ordering that is established between the memory accesses done between the generic proxy and the proxy specified by `.proxykind`.

Value `.alias` of the `.proxykind` qualifier refers to memory accesses performed using virtually aliased addresses to the same memory location. Value `.async` of the `.proxykind` qualifier specifies that the memory ordering is established between the async proxy and the generic proxy. The memory ordering is limited only to operations performed on objects in the state space specified. If no state space is specified, then the memory ordering applies on all state spaces.

A `.release` proxy fence can form a release sequence that synchronizes with an acquire sequence that contains a `.acquire` proxy fence. The `.to_proxykind` and `.from_proxykind` qualifiers indicate the *uni-directional* proxy ordering that is established.

On `sm_70` and higher, `membar.proxy` is a synonym for `fence.proxy`.

[1] The semantics of `fence.sc` introduced with `sm_70` is a superset of the semantics of `membar` and the two are compatible; when executing on `sm_70` or later architectures, `membar` acquires the full semantics of `fence.sc`.

PTX ISA Notes

`membar.{cta,gl}` introduced in PTX ISA version 1.4.

`membar.sys` introduced in PTX ISA version 2.0.

`fence` introduced in PTX ISA version 6.0.

`membar.proxy` and `fence.proxy` introduced in PTX ISA version 7.5.

`.cluster` scope qualifier introduced in PTX ISA version 7.8.

`.op_restrict` qualifier introduced in PTX ISA version 8.0.

`fence.proxy.async` is introduced in PTX ISA version 8.0.

`.to_proxykind::from_proxykind` qualifier introduced in PTX ISA version 8.3.

`.acquire` and `.release` qualifiers for `fence` instruction introduced in PTX ISA version 8.6.

`.sync_restrict` qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

`membar.{cta,gl}` supported on all target architectures.

`membar.sys` requires `sm_20` or higher.

`fence` requires `sm_70` or higher.

`membar.proxy` requires `sm_60` or higher.

`fence.proxy` requires `sm_70` or higher.

`.cluster` scope qualifier requires `sm_90` or higher.

`.op_restrict` qualifier requires `sm_90` or higher.

`fence.proxy.async` requires `sm_90` or higher.

`.to_proxykind::from_proxykind` qualifier requires `sm_90` or higher.

`.acquire` and `.release` qualifiers for `fence` instruction require `sm_90` or higher..

`.sync_restrict` qualifier requires `sm_90` or higher..

Examples

```
membar.gl;
membar.cta;
membar.sys;
fence.sc.cta;
fence.sc.cluster;
fence.proxy.alias;
membar.proxy.alias;
fence.mbarrier_init.release.cluster;
fence.proxy.async;
fence.proxy.async.shared::cta;
fence.proxy.async.shared::cluster;
fence.proxy.async.global;
```

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```
tensormap.replace.tile.global_address.global.b1024.b64   [gbl], new_addr;
fence.proxy.tensormap::generic.release.gpu;
cvta.global.u64  tmap, gbl;
fence.proxy.tensormap::generic.acquire.gpu [tmap], 128;
cp.async.bulk.tensor.1d.shared::cluster.global.tile  [addr0], [tmap, {tc0}], [mbar0];

// Acquire remote barrier state via async proxy.
barrier.cluster.wait.acquire;
fence.proxy.async::generic.acquire.sync_restrict::shared::cluster.cluster;

// Release local barrier state via async proxy.
mbarrier.init [bar];
fence.mbarrier_init.release.cluster;
fence.proxy.async::generic.release.sync_restrict::shared::cta.cluster;
barrier.cluster.arrive.relaxed;

// Acquire local shared memory via generic proxy.
mbarrier.try_wait.relaxed.cluster.shared::cta.b64 complete, [addr], parity;
fence.acquire.sync_restrict::shared::cluster.cluster;

// Release local shared memory via generic proxy.
fence.release.sync_restrict::shared::cta.cluster;
mbarrier.arrive.relaxed.cluster.shared::cluster.b64 state, [bar];
```

9.7.13.5 Parallel Synchronization and Communication Instructions: `atom`

`atom`

Atomic reduction operations for thread-to-thread communication.

Syntax

Atomic operation with scalar type:

```
atom{.sem}{.scope}{.space}.op{.level::cache_hint}.type d, [a], b{, cache-policy};
atom{.sem}{.scope}{.space}.op.type d, [a], b, c;

atom{.sem}{.scope}{.space}.cas.b16 d, [a], b, c;

atom{.sem}{.scope}{.space}.cas.b128 d, [a], b, c;
atom{.sem}{.scope}{.space}.exch{.level::cache_hint}.b128 d, [a], b {, cache-policy};

atom{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.f16     d, [a], b{, cache-
↪policy};
atom{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.f16x2   d, [a], b{, cache-
↪policy};

atom{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.bf16    d, [a], b{, cache-
↪policy};
atom{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.bf16x2  d, [a], b{, cache-
↪policy};

.space =              { .global, .shared{::cta, ::cluster} };
```

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```
.sem =                { .relaxed, .acquire, .release, .acq_rel };
.scope =              { .cta, .cluster, .gpu, .sys };

.op =                 { .and, .or, .xor,
                        .cas, .exch,
                        .add, .inc, .dec,
                        .min, .max };
.level::cache_hint =  { .L2::cache_hint };
.type =               { .b32, .b64, .u32, .u64, .s32, .s64, .f32, .f64 };
```

Atomic operation with vector type:

```
atom{.sem}{.scope}{.global}.add{.level::cache_hint}.vec_32_bit.f32                d,
↪ [a], b{, cache-policy};
atom{.sem}{.scope}{.global}.op.noftz{.level::cache_hint}.vec_16_bit.half_word_type  d,
↪ [a], b{, cache-policy};
atom{.sem}{.scope}{.global}.op.noftz{.level::cache_hint}.vec_32_bit.packed_type     d,
↪ [a], b{, cache-policy};

.sem =               { .relaxed, .acquire, .release, .acq_rel };
.scope =             { .cta, .cluster, .gpu, .sys };
.op =                { .add, .min, .max };
.half_word_type =    { .f16, .bf16 };
.packed_type =       { .f16x2, .bf16x2 };
.vec_16_bit =        { .v2, .v4, .v8 }
.vec_32_bit =        { .v2, .v4 };
.level::cache_hint = { .L2::cache_hint }
```

Description

Atomically loads the original value at location a into destination register d, performs a reduction operation with operand b and the value in location a, and stores the result of the specified operation at location a, overwriting the original value. Operand a specifies a location in the specified state space. If no state space is given, perform the memory accesses using *Generic Addressing*. `atom` with scalar type may be used only with `.global` and `.shared` spaces and with generic addressing, where the address points to `.global` or `.shared` space. `atom` with vector type may be used only with `.global` space and with generic addressing where the address points to `.global` space.

For `atom` with vector type, operands d and b are brace-enclosed vector expressions, size of which is equal to the size of vector qualifier.

If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

The optional `.sem` qualifier specifies a memory synchronizing effect as described in the *Memory Consistency Model*. If the `.sem` qualifier is absent, `.relaxed` is assumed by default.

The optional `.scope` qualifier specifies the set of threads that can directly observe the memory synchronizing effect of this operation, as described in the *Memory Consistency Model*. If the `.scope` qualifier is absent, `.gpu` scope is assumed by default.

For `atom` with vector type, the supported combinations of vector qualifier and types, and atomic operations supported on these combinations are depicted in the following table:

Vector qualifier	Types		
	.f16/ bf16	.f16x2/ bf16x2	.f32
.v2	.add, .min, .max	.add, .min, .max	.add
.v4	.add, .min, .max	.add, .min, .max	.add
.v8	.add, .min, .max	Not supported	Not Supported

Two atomic operations (atom or red) are performed atomically with respect to each other only if each operation specifies a scope that includes the other. When this condition is not met, each operation observes the other operation being performed as if it were split into a read followed by a dependent write.

atom instruction on packed type or vector type, accesses adjacent scalar elements in memory. In such cases, the atomicity is guaranteed separately for each of the individual scalar elements; the entire atom is not guaranteed to be atomic as a single access.

For sm_6x and earlier architectures, atom operations on .shared state space do not guarantee atomicity with respect to normal store instructions to the same address. It is the programmer's responsibility to guarantee correctness of programs that use shared memory atomic instructions, e.g., by inserting barriers between normal stores and atomic operations to a common address, or by using atom.exch to store to locations accessed by other atomic operations.

Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*

The bit-size operations are .and, .or, .xor, .cas (compare-and-swap), and .exch (exchange).

The integer operations are .add, .inc, .dec, .min, .max. The .inc and .dec operations return a result in the range [0..b].

The floating-point operation .add operation rounds to nearest even. Current implementation of atom.add.f32 on global memory flushes subnormal inputs and results to sign-preserving zero; whereas atom.add.f32 on shared memory supports subnormal inputs and results and doesn't flush them to zero.

atom.add.f16, atom.add.f16x2, atom.add.bf16 and atom.add.bf16x2 operation requires the .noftz qualifier; it preserves subnormal inputs and results, and does not flush them to zero.

When the optional argument cache-policy is specified, the qualifier .level::cache_hint is required. The 64-bit operand cache-policy specifies the cache eviction policy that may be used during the memory access.

The qualifier .level::cache_hint is only supported for .global state space and for generic addressing where the address points to the .global state space.

cache-policy is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

Semantics

```
atomic {
    d = *a;
    *a = (operation == cas) ? operation(*a, b, c)
                            : operation(*a, b);
}
where
    inc(r, s)  = (r >= s) ? 0 : r+1;
    dec(r, s)  = (r==0 || r > s)  ? s : r-1;
    exch(r, s) =  s;
    cas(r,s,t) = (r == s) ? t : r;
```

Notes

Simple reductions may be specified by using the *bit bucket* destination operand _.

PTX ISA Notes

32-bit atom.global introduced in PTX ISA version 1.1.

`atom.shared` and 64-bit `atom.global.{add,cas,exch}` introduced in PTX ISA 1.2.

`atom.add.f32` and 64-bit `atom.shared.{add,cas,exch}` introduced in PTX ISA 2.0.

64-bit `atom.{and,or,xor,min,max}` introduced in PTX ISA 3.1.

`atom.add.f64` introduced in PTX ISA 5.0.

`.scope` qualifier introduced in PTX ISA 5.0.

`.sem` qualifier introduced in PTX ISA version 6.0.

`atom.add.noftz.f16x2` introduced in PTX ISA 6.2.

`atom.add.noftz.f16` and `atom.cas.b16` introduced in PTX ISA 6.3.

Per-element atomicity of `atom.f16x2` clarified in PTX ISA version 6.3, with retrospective effect from PTX ISA version 6.2.

Support for `.level::cache_hint` qualifier introduced in PTX ISA version 7.4.

`atom.add.noftz.bf16` and `atom.add.noftz.bf16x2` introduced in PTX ISA 7.8.

Support for `.cluster` scope qualifier introduced in PTX ISA version 7.8.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for vector types introduced in PTX ISA version 8.1.

Support for `.b128` type introduced in PTX ISA version 8.3.

Support for `.sys` scope with `.b128` type introduced in PTX ISA version 8.4.

Target ISA Notes

`atom.global` requires `sm_11` or higher.

`atom.shared` requires `sm_12` or higher.

64-bit `atom.global.{add,cas,exch}` require `sm_12` or higher.

64-bit `atom.shared.{add,cas,exch}` require `sm_20` or higher.

64-bit `atom.{and,or,xor,min,max}` require `sm_32` or higher.

`atom.add.f32` requires `sm_20` or higher.

`atom.add.f64` requires `sm_60` or higher.

`.scope` qualifier requires `sm_60` or higher.

`.sem` qualifier requires `sm_70` or higher.

Use of generic addressing requires `sm_20` or higher.

`atom.add.noftz.f16x2` requires `sm_60` or higher.

`atom.add.noftz.f16` and `atom.cas.b16` requires `sm_70` or higher.

Support for `.level::cache_hint` qualifier requires `sm_80` or higher.

`atom.add.noftz.bf16` and `atom.add.noftz.bf16x2` require `sm_90` or higher.

Support for `.cluster` scope qualifier requires `sm_90` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for vector types requires `sm_90` or higher.

Support for `.b128` type requires `sm_90` or higher.

Examples

```
atom.global.add.s32  d,[a],1;
atom.shared::cta.max.u32  d,[x+4],0;
@p  atom.global.cas.b32  d,[p],my_val,my_new_val;
atom.global.sys.add.u32 d, [a], 1;
atom.global.acquire.sys.inc.u32 ans, [gbl], %r0;
atom.add.noftz.f16x2 d, [a], b;
atom.add.noftz.f16   hd, [ha], hb;
atom.global.cas.b16  hd, [ha], hb, hc;
atom.add.noftz.bf16   hd, [a], hb;
atom.add.noftz.bf16x2 bd, [b], bb;
atom.add.shared::cluster.noftz.f16   hd, [ha], hb;
atom.shared.b128.cas d, a, b, c; // 128-bit atom
atom.global.b128.exch d, a, b;   // 128-bit atom

atom.global.cluster.relaxed.add.u32 d, [a], 1;

createpolicy.fractional.L2::evict_last.b64 cache-policy, 0.25;
atom.global.add.L2::cache_hint.s32  d, [a], 1, cache-policy;

atom.global.v8.f16.max.noftz  {%hd0, %hd1, %hd2, %hd3, %hd4, %hd5, %hd6, %hd7}, [gbl],
```

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```
                                                {%h0, %h1, %h2, %h3, %h4, %h5, %h6, %h7}
↪;
atom.global.v8.bf16.add.noftz  {%hd0, %hd1, %hd2, %hd3, %hd4, %hd5, %hd6, %hd7},
↪[gbl],
                                                {%h0, %h1, %h2, %h3, %h4, %h5, %h6, %h7}
↪;
atom.global.v2.f16.add.noftz  {%hd0, %hd1}, [gbl], {%h0, %h1};
atom.global.v2.bf16.add.noftz  {%hd0, %hd1}, [gbl], {%h0, %h1};
atom.global.v4.b16x2.min.noftz  {%hd0, %hd1, %hd2, %hd3}, [gbl], {%h0, %h1, %h2, %h3};
atom.global.v4.f32.add  {%f0, %f1, %f2, %f3}, [gbl], {%f0, %f1, %f2, %f3};
atom.global.v2.f16x2.min.noftz  {%bd0, %bd1}, [g], {%b0, %b1};
atom.global.v2.bf16x2.max.noftz  {%bd0, %bd1}, [g], {%b0, %b1};
atom.global.v2.f32.add  {%f0, %f1}, [g], {%f0, %f1};
```

9.7.13.6 Parallel Synchronization and Communication Instructions: red

red

Reduction operations on global and shared memory.

Syntax

Reduction operation with scalar type:

```
red{.sem}{.scope}{.space}.op{.level::cache_hint}.type          [a], b{, cache-policy};

red{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.f16    [a], b{, cache-policy};

red{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.f16x2  [a], b{, cache-policy};

red{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.bf16
                                                       [a], b {, cache-policy};

red{.sem}{.scope}{.space}.add.noftz{.level::cache_hint}.bf16x2
                                                       [a], b {, cache-policy};

.space =              { .global, .shared{::cta, ::cluster} };
.sem =                {.relaxed, .release};
.scope =              {.cta, .cluster, .gpu, .sys};

.op =                 { .and, .or, .xor,
                        .add, .inc, .dec,
                        .min, .max };
.level::cache_hint =  { .L2::cache_hint };
.type =               { .b32, .b64, .u32, .u64, .s32, .s64, .f32, .f64 };
```

Reduction operation with vector type:

```
red{.sem}{.scope}{.global}.add{.level::cache_hint}.vec_32_bit.f32 [a], b{, cache-
↪policy};
red{.sem}{.scope}{.global}.op.noftz{.level::cache_hint}. vec_16_bit.half_word_type
↪[a], b{, cache-policy};
red{.sem}{.scope}{.global}.op.noftz{.level::cache_hint}.vec_32_bit.packed_type [a], b
↪{, cache-policy};
```

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```
.sem =                { .relaxed, .release };
.scope =              { .cta, .cluster, .gpu, .sys };
.op =                 { .add, .min, .max };
.half_word_type =     { .f16, .bf16 };
.packed_type =        { .f16x2,.bf16x2 };
.vec_16_bit =         { .v2, .v4, .v8 }
.vec_32_bit =         { .v2, .v4 };
.level::cache_hint =  { .L2::cache_hint }
```

Description

Performs a reduction operation with operand `b` and the value in location `a`, and stores the result of the specified operation at location `a`, overwriting the original value. Operand `a` specifies a location in the specified state space. If no state space is given, perform the memory accesses using *Generic Addressing*. `red` with scalar type may be used only with `.global` and `.shared` spaces and with generic addressing, where the address points to `.global` or `.shared` space. `red` with vector type may be used only with `.global` space and with generic addressing where the address points to `.global` space.

For `red` with vector type, operand `b` is brace-enclosed vector expressions, size of which is equal to the size of vector qualifier.

If no sub-qualifier is specified with `.shared` state space, then `::cta` is assumed by default.

The optional `.sem` qualifier specifies a memory synchronizing effect as described in the *Memory Consistency Model*. If the `.sem` qualifier is absent, `.relaxed` is assumed by default.

The optional `.scope` qualifier specifies the set of threads that can directly observe the memory synchronizing effect of this operation, as described in the *Memory Consistency Model*. If the `.scope` qualifier is absent, `.gpu` scope is assumed by default.

For `red` with vector type, the supported combinations of vector qualifier, types and reduction operations supported on these combinations are depicted in following table:

Vector qualifier	Types		
	.f16/ bf16	**.f16x2/ bf16x2**	**.f32**
.v2	.add, .min, .max	.add, .min, .max	.add
.v4	.add, .min, .max	.add, .min, .max	.add
.v8	.add, .min, .max	Not supported	Not Supported

Two atomic operations (`atom` or `red`) are performed atomically with respect to each other only if each operation specifies a scope that includes the other. When this condition is not met, each operation observes the other operation being performed as if it were split into a read followed by a dependent write.

`red` instruction on packed type or vector type, accesses adjacent scalar elements in memory. In such case, the atomicity is guaranteed separately for each of the individual scalar elements; the entire `red` is not guaranteed to be atomic as a single access.

For `sm_6x` and earlier architectures, `red` operations on `.shared` state space do not guarantee atomicity with respect to normal store instructions to the same address. It is the programmer's responsibility to guarantee correctness of programs that use shared memory reduction instructions, e.g., by

inserting barriers between normal stores and reduction operations to a common address, or by using `atom.exch` to store to locations accessed by other reduction operations.

Supported addressing modes for operand a and alignment requirements are described in *Addresses as Operands*

The bit-size operations are `.and`, `.or`, and `.xor`.

The integer operations are `.add`, `.inc`, `.dec`, `.min`, `.max`. The `.inc` and `.dec` operations return a result in the range `[0..b]`.

The floating-point operation `.add` operation rounds to nearest even. Current implementation of `red.add.f32` on global memory flushes subnormal inputs and results to sign-preserving zero; whereas `red.add.f32` on shared memory supports subnormal inputs and results and doesn't flush them to zero.

`red.add.f16`, `red.add.f16x2`, `red.add.bf16` and `red.add.bf16x2` operation requires the `.noftz` qualifier; it preserves subnormal inputs and results, and does not flush them to zero.

When the optional argument `cache-policy` is specified, the qualifier `.level::cache_hint` is required. The 64-bit operand `cache-policy` specifies the cache eviction policy that may be used during the memory access.

The qualifier `.level::cache_hint` is only supported for `.global` state space and for generic addressing where the address points to the `.global` state space.

`cache-policy` is a hint to the cache subsystem and may not always be respected. It is treated as a performance hint only, and does not change the memory consistency behavior of the program.

Semantics

```
*a = operation(*a, b);

where
    inc(r, s) = (r >= s) ? 0 : r+1;
    dec(r, s) = (r==0 || r > s)  ? s : r-1;
```

PTX ISA Notes

Introduced in PTX ISA version 1.2.

`red.add.f32` and `red.shared.add.u64` introduced in PTX ISA 2.0.

64-bit `red.{and,or,xor,min,max}` introduced in PTX ISA 3.1.

`red.add.f64` introduced in PTX ISA 5.0.

`.scope` qualifier introduced in PTX ISA 5.0.

`.sem` qualifier introduced in PTX ISA version 6.0.

`red.add.noftz.f16x2` introduced in PTX ISA 6.2.

`red.add.noftz.f16` introduced in PTX ISA 6.3.

Per-element atomicity of `red.f16x2` clarified in PTX ISA version 6.3, with retrospective effect from PTX ISA version 6.2

Support for `.level::cache_hint` qualifier introduced in PTX ISA version 7.4.

`red.add.noftz.bf16` and `red.add.noftz.bf16x2` introduced in PTX ISA 7.8.

Support for `.cluster` scope qualifier introduced in PTX ISA version 7.8.

Support for `::cta` and `::cluster` sub-qualifiers introduced in PTX ISA version 7.8.

Support for vector types introduced in PTX ISA version 8.1.

Target ISA Notes

`red.global` requires `sm_11` or higher

`red.shared` requires `sm_12` or higher.

`red.global.add.u64` requires `sm_12` or higher.

`red.shared.add.u64` requires `sm_20` or higher.

64-bit `red.{and,or,xor,min,max}` require `sm_32` or higher.

`red.add.f32` requires `sm_20` or higher.

`red.add.f64` requires `sm_60` or higher.

`.scope` qualifier requires `sm_60` or higher.

`.sem` qualifier requires `sm_70` or higher.

Use of generic addressing requires `sm_20` or higher.

`red.add.noftz.f16x2` requires `sm_60` or higher.

`red.add.noftz.f16` requires `sm_70` or higher.

Support for `.level::cache_hint` qualifier requires `sm_80` or higher.

`red.add.noftz.bf16` and `red.add.noftz.bf16x2` require `sm_90` or higher.

Support for `.cluster` scope qualifier requires `sm_90` or higher.

Sub-qualifier `::cta` requires `sm_30` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for vector types requires `sm_90` or higher.

Examples

```
red.global.add.s32  [a],1;
red.shared::cluster.max.u32  [x+4],0;
@p  red.global.and.b32  [p],my_val;
red.global.sys.add.u32 [a], 1;
red.global.acquire.sys.add.u32 [gbl], 1;
red.add.noftz.f16x2 [a], b;
red.add.noftz.bf16   [a], hb;
red.add.noftz.bf16x2 [b], bb;
red.global.cluster.relaxed.add.u32 [a], 1;
red.shared::cta.min.u32  [x+4],0;

createpolicy.fractional.L2::evict_last.b64 cache-policy, 0.25;
red.global.and.L2::cache_hint.b32 [a], 1, cache-policy;

red.global.v8.f16.add.noftz  [gbl], {%h0, %h1, %h2, %h3, %h4, %h5, %h6, %h7};
red.global.v8.bf16.min.noftz [gbl], {%h0, %h1, %h2, %h3, %h4, %h5, %h6, %h7};
```

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```
red.global.v2.f16.add.noftz [gbl], {%h0, %h1};
red.global.v2.bf16.add.noftz [gbl], {%h0, %h1};
red.global.v4.f16x2.max.noftz [gbl], {%h0, %h1, %h2, %h3};
red.global.v4.f32.add  [gbl], {%f0, %f1, %f2, %f3};
red.global.v2.f16x2.max.noftz {%bd0, %bd1}, [g], {%b0, %b1};
red.global.v2.bf16x2.add.noftz {%bd0, %bd1}, [g], {%b0, %b1};
red.global.v2.f32.add  {%f0, %f1}, [g], {%f0, %f1};
```

9.7.13.7 Parallel Synchronization and Communication Instructions: red.async

red.async

Asynchronous reduction operation.

Syntax

```
// Increment and Decrement reductions
red.async.sem.scope{.ss}.completion_mechanism.op.type [a], b, [mbar];

.sem  =                 { .relaxed };
.scope =                { .cluster };
.ss   =                 { .shared::cluster };
.op   =                 { .inc, .dec };
.type =                 { .u32 };
.completion_mechanism = { .mbarrier::complete_tx::bytes };


// MIN and MAX reductions
red.async.sem.scope{.ss}.completion_mechanism.op.type [a], b, [mbar];

.sem  = { .relaxed };
.scope = { .cluster };
.ss   = { .shared::cluster };
.op   = { .min, .max };
.type = { .u32, .s32 };
.completion_mechanism = { .mbarrier::complete_tx::bytes };

// Bitwise AND, OR and XOR reductions
red.async.sem.scope{.ss}.completion_mechanism.op.type [a], b, [mbar];

.sem  = { .relaxed };
.scope = { .cluster };
.ss   = { .shared::cluster };
.op   = { .and, .or, .xor };
.type = { .b32 };
.completion_mechanism = { .mbarrier::complete_tx::bytes };

// ADD reductions
red.async.sem.scope{.ss}.completion_mechanism.add.type [a], b, [mbar];

.sem  = { .relaxed };
.scope = { .cluster };
.ss   = { .shared::cluster };
```

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```
.type = { .u32, .s32, .u64 };
.completion_mechanism = { .mbarrier::complete_tx::bytes };

red.async{.mmio}.sem.scope{.ss}.add.type [a], b;

.sem  = { .release };
.scope = { .gpu, .cluster };
.ss   = { .global };
.type = { .u32, .s32, .u64, .s64 };
```

Description

`red.async` is a non-blocking instruction which initiates an asynchronous reduction operation specified by `.op`, with the operand `b` and the value at destination shared memory location specified by operand `a`.

Operands

- `a` is a destination address, and must be either a register, or of the form `register + immOff`, as described in *Addresses as Operands*.
- `b` is a source value, of the type indicated by qualifier `.type`.
- `mbar` is an mbarrier object address.

Qualifiers

- `.mmio` indicates whether this is an *mmio Operation*.
- `.sem` specifies the memory ordering semantics as described in the *Memory Consistency Model*.
- `.scope` specifies the set of threads with which this instruction can directly synchronize.
- `.ss` specifies the state space of the destination operand `a` and the mbarrier operand `mbar`.
  - If `.ss` is not specified, *Generic Addressing* is used.
- `.completion_mechanism` specifies the mechanism for observing the completion of the asynchronous operation.
  - When `.completion_mechanism` is `.mbarrier::complete_tx::bytes`: upon completion of the asynchronous operation, a *complete-tx* operation will be performed on the mbarrier object specified by the operand `mbar`, with `completeCount` argument equal to the amount of data stored in bytes.
  - When `.completion_mechanism` is not specified: the completion of the store synchronizes with the end of the CTA.
- `.op` specifies the reduction operation.
  - The `.inc` and `.dec` operations return a result in the range `[0..b]`.
- `.type` specifies the type of the source operand `b`.

Conditions

When `.sem` is `.relaxed`:

- The reduce operation is a relaxed memory operation.
- The complete-tx operation on the mbarrier has `.release` semantics at `.cluster` scope.
- The shared-memory addresses of the destination operand `a` and the mbarrier operand `mbar` must meet all of the following conditions:
  - They belong to the same CTA.
  - The CTA to which they belong is different from the CTA of the executing thread, but must be within the same cluster.

  Otherwise, the behavior is undefined.
- `.mmio` must not be specified.
- If `.scope` is specified, it must be `.cluster`.
- If `.scope` is not specified, it defaults to `.cluster`.
- If `.ss` is specified, it must be `.shared::cluster`.
- If `.ss` is not specified, generic addressing is used for operands `a` and `mbar`. If the generic addresses specified do not fall within the address window of `.shared::cluster` state space, the behavior is undefined.
- If `.completion_mechanism` is specified, it must be `.mbarrier::complete_tx::bytes`.
- If `.completion_mechanism` is not specified, it defaults to `.mbarrier::complete_tx::bytes`.

When `.sem` is `.release`:

- The reduce operation is a strong memory operation with `.release` semantics at the scope specified by `.scope`.
- If `.mmio` is specified, `.scope` must be `.sys`.
- If `.scope` is specified, it may be `.gpu` or `.sys`.
- If `.scope` is not specified, it defaults to `.sys`.
- If `.ss` is specified, it must be `.global`.
- If `.ss` is not specified, generic addressing is used for operand `a`. If the generic address specified does not fall within the address window of `.global` state space, the behavior is undefined.
- `.completion_mechanism` must not be specified.

PTX ISA Notes

Introduced in PTX ISA version 8.1.

Support for `.mmio` qualifier, `.release` semantics, `.global` state space, and `.gpu` and `.sys` scopes introduced in PTX ISA version 8.7.

Target ISA Notes

Requires sm_90 or higher.

.mmio qualifier, .release semantics, .global state space, and .gpu and .sys scopes require sm_100 or higher.

Examples

```
red.async.relaxed.cluster.shared::cluster.mbarrier::complete_tx::bytes.min.u32 [addr],
↪ b, [mbar_addr];

red.async.release.sys.global.add.u32 [addr], b;
```

9.7.13.8 Parallel Synchronization and Communication Instructions: vote (deprecated)

vote (deprecated)

Vote across thread group.

Syntax

```
vote.mode.pred  d, {!}a;
vote.ballot.b32 d, {!}a;  // 'ballot' form, returns bitmask

.mode = { .all, .any, .uni };
```

Deprecation Note

The vote instruction without a .sync qualifier is deprecated in PTX ISA version 6.0.

- Support for this instruction with .target lower than sm_70 may be removed in a future PTX ISA version.

Removal Note

Support for vote instruction without a .sync qualifier is removed in PTX ISA version 6.4 for .target sm_70 or higher.

Description

Performs a reduction of the source predicate across all active threads in a warp. The destination predicate value is the same across all threads in the warp.

The reduction modes are:

.all
: True if source predicate is True for all active threads in warp. Negate the source predicate to compute .none.

.any
: True if source predicate is True for some active thread in warp. Negate the source predicate to compute .not_all.

.uni
: True if source predicate has the same value in all active threads in warp. Negating the source predicate also computes .uni.

In the *ballot* form, vote.ballot.b32 simply copies the predicate from each thread in a warp into the corresponding bit position of destination register d, where the bit position corresponds to the thread's lane id.

An inactive thread in warp will contribute a 0 for its entry when participating in vote.ballot.b32.

PTX ISA Notes

Introduced in PTX ISA version 1.2.

Deprecated in PTX ISA version 6.0 in favor of vote.sync.

Not supported in PTX ISA version 6.4 for .target sm_70 or higher.

Target ISA Notes

vote requires sm_12 or higher.

vote.ballot.b32 requires sm_20 or higher.

vote is not supported on sm_70 or higher starting PTX ISA version 6.4.

Release Notes

Note that vote applies to threads in a single warp, not across an entire CTA.

Examples

```
vote.all.pred    p,q;
vote.uni.pred    p,q;
vote.ballot.b32  r1,p;  // get 'ballot' across warp
```

9.7.13.9 Parallel Synchronization and Communication Instructions: vote.sync

vote.sync

Vote across thread group.

Syntax

```
vote.sync.mode.pred  d, {!}a, membermask;
vote.sync.ballot.b32 d, {!}a, membermask;  // 'ballot' form, returns bitmask

.mode = { .all, .any, .uni };
```

Description

`vote.sync` will cause executing thread to wait until all non-exited threads corresponding to `membermask` have executed `vote.sync` with the same qualifiers and same `membermask` value before resuming execution.

Operand `membermask` specifies a 32-bit integer which is a mask indicating threads participating in this instruction where the bit position corresponds to thread's `laneid`. Operand `a` is a predicate register.

In the *mode* form, `vote.sync` performs a reduction of the source predicate across all non-exited threads in `membermask`. The destination operand `d` is a predicate register and its value is the same across all threads in `membermask`.

The reduction modes are:

`.all`
: `True` if source predicate is `True` for all non-exited threads in `membermask`. Negate the source predicate to compute `.none`.

`.any`
: `True` if source predicate is `True` for some thread in `membermask`. Negate the source predicate to compute `.not_all`.

`.uni`
: `True` if source predicate has the same value in all non-exited threads in `membermask`. Negating the source predicate also computes `.uni`.

In the *ballot* form, the destination operand `d` is a `.b32` register. In this form, `vote.sync.ballot.b32` simply copies the predicate from each thread in `membermask` into the corresponding bit position of destination register `d`, where the bit position corresponds to the thread's lane id.

A thread not specified in `membermask` will contribute a 0 for its entry in `vote.sync.ballot.b32`.

The behavior of `vote.sync` is undefined if the executing thread is not in the `membermask`.

Note: For .target `sm_6x` or below, all threads in `membermask` must execute the same `vote.sync` instruction in convergence, and only threads belonging to some `membermask` can be active when the `vote.sync` instruction is executed. Otherwise, the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
vote.sync.all.pred    p,q,0xffffffff;
vote.sync.ballot.b32  r1,p,0xffffffff;  // get 'ballot' across warp
```

9.7.13.10 Parallel Synchronization and Communication Instructions: `match.sync`

`match.sync`

Broadcast and compare a value across threads in warp.

Syntax

```
match.any.sync.type  d, a, membermask;
match.all.sync.type  d[|p], a, membermask;

.type = { .b32, .b64 };
```

Description

`match.sync` will cause executing thread to wait until all non-exited threads from `membermask` have executed `match.sync` with the same qualifiers and same `membermask` value before resuming execution.

Operand `membermask` specifies a 32-bit integer which is a mask indicating threads participating in this instruction where the bit position corresponds to thread's laneid.

`match.sync` performs broadcast and compare of operand `a` across all non-exited threads in `membermask` and sets destination `d` and optional predicate `p` based on mode.

Operand `a` has instruction type and `d` has `.b32` type.

Destination `d` is a 32-bit mask where bit position in mask corresponds to thread's laneid.

The matching operation modes are:

`.all`
: `d` is set to mask corresponding to non-exited threads in `membermask` if all non-exited threads in `membermask` have same value of operand `a`; otherwise `d` is set to 0. Optionally predicate `p` is set to true if all non-exited threads in `membermask` have same value of operand `a`; otherwise `p` is set to false. The sink symbol '_' may be used in place of any one of the destination operands.

.any
d is set to mask of non-exited threads in membermask that have same value of operand a.

The behavior of match.sync is undefined if the executing thread is not in the membermask.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

Target ISA Notes

Requires sm_70 or higher.

Release Notes

Note that match.sync applies to threads in a single warp, not across an entire CTA.

Examples

```
match.any.sync.b32    d, a, 0xffffffff;
match.all.sync.b64    d|p, a, mask;
```

9.7.13.11 Parallel Synchronization and Communication Instructions: activemask

activemask

Queries the active threads within a warp.

Syntax

```
activemask.b32 d;
```

Description

activemask queries predicated-on active threads from the executing warp and sets the destination d with 32-bit integer mask where bit position in the mask corresponds to the thread's laneid.

Destination d is a 32-bit destination register.

An active thread will contribute 1 for its entry in the result and exited or inactive or predicated-off thread will contribute 0 for its entry in the result.

PTX ISA Notes

Introduced in PTX ISA version 6.2.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
activemask.b32  %r1;
```

9.7.13.12 Parallel Synchronization and Communication Instructions: `redux.sync`

`redux.sync`

Perform reduction operation on the data from each predicated active thread in the thread group.

Syntax

```
redux.sync.op.type dst, src, membermask;
.op   = {.add, .min, .max}
.type = {.u32, .s32}

redux.sync.op.b32 dst, src, membermask;
.op   = {.and, .or, .xor}

redux.sync.op{.abs.}{.NaN}.f32 dst, src, membermask;
.op   = { .min, .max }
```

Description

`redux.sync` will cause the executing thread to wait until all non-exited threads corresponding to `membermask` have executed `redux.sync` with the same qualifiers and same `membermask` value before resuming execution.

Operand `membermask` specifies a 32-bit integer which is a mask indicating threads participating in this instruction where the bit position corresponds to thread's `laneid`.

`redux.sync` performs a reduction operation `.op` of the 32 bit source register `src` across all non-exited threads in the `membermask`. The result of the reduction operation is written to the 32 bit destination register `dst`.

Reduction operation can be one of the bitwise operation in `.and`, `.or`, `.xor` or arithmetic operation in `.add`, `.min` , `.max`.

For the `.add` operation result is truncated to 32 bits.

For `.f32` instruction type, if the input value is 0.0 then +0.0 > -0.0.

If `.abs` qualifier is specified, then the absolute value of the input is considered for the reduction operation.

If the `.NaN` qualifier is specified, then the result of the reduction operation is canonical NaN if the input to the reduction operation from any participating thread is NaN.

In the absence of `.NaN` qualifier, only non-NaN values are considered for the reduction operation and the result will be canonical NaN when all inputs are NaNs.

The behavior of `redux.sync` is undefined if the executing thread is not in the `membermask`.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for `.f32` type is introduced in PTX ISA version 8.6.

Support for `.abs` and `.NaN` qualifiers is introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_80` or higher.

`.f32` type requires `sm_100a` and is supported on `sm_100f` from PTX ISA version 8.8.

Qualifiers `.abs` and `.NaN` require `sm_100a` and are supported on `sm_100f` or higher in the same family from PTX ISA version 8.8.

Release Notes

Note that `redux.sync` applies to threads in a single warp, not across an entire CTA.

Examples

```
.reg .b32 dst, src, init, mask;
redux.sync.add.s32 dst, src, 0xff;
redux.sync.xor.b32 dst, src, mask;

redux.sync.min.abs.NaN.f32 dst, src, mask;
```

9.7.13.13 Parallel Synchronization and Communication Instructions: `griddepcontrol`

`griddepcontrol`

Control execution of dependent grids.

Syntax

```
griddepcontrol.action;

.action   = { .launch_dependents, .wait }
```

Description

The `griddepcontrol` instruction allows the dependent grids and prerequisite grids as defined by the runtime, to control execution in the following way:

`.launch_dependents` modifier signals that specific dependents the runtime system designated to react to this instruction can be scheduled as soon as all other CTAs in the grid issue the same instruction or have completed. The dependent may launch before the completion of the current grid. There is no guarantee that the dependent will launch before the completion of the current grid. Repeated invocations of this instruction by threads in the current CTA will have no additional side effects past that of the first invocation.

`.wait` modifier causes the executing thread to wait until all prerequisite grids in flight have completed and all the memory operations from the prerequisite grids are performed and made visible to the current grid.

Note: If the prerequisite grid is using `griddepcontrol.launch_dependents`, then the dependent grid must use `griddepcontrol.wait` to ensure correct functional execution.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
griddepcontrol.launch_dependents;
griddepcontrol.wait;
```

9.7.13.14 Parallel Synchronization and Communication Instructions: `elect.sync`

`elect.sync`

Elect a leader thread from a set of threads.

Syntax

```
elect.sync d|p, membermask;
```

Description

`elect.sync` elects one predicated active leader thread from among a set of threads specified by `membermask`. `laneid` of the elected thread is returned in the 32-bit destination operand `d`. The sink symbol '_' can be used for destination operand `d`. The predicate destination `p` is set to `True` for the leader thread, and `False` for all other threads.

Operand `membermask` specifies a 32-bit integer indicating the set of threads from which a leader is to be elected. The behavior is undefined if the executing thread is not in `membermask`.

Election of a leader thread happens deterministically, i.e. the same leader thread is elected for the same `membermask` every time.

The mandatory `.sync` qualifier indicates that `elect` causes the executing thread to wait until all threads in the `membermask` execute the `elect` instruction before resuming execution.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
elect.sync    %r0|%p0, 0xffffffff;
```

9.7.13.15 Parallel Synchronization and Communication Instructions: `mbarrier`

`mbarrier` is a barrier created in shared memory that supports :

- Synchronizing any subset of threads within a CTA
- One-way synchronization of threads across CTAs of a cluster. As noted in *mbarrier support with shared memory*, threads can perform only *arrive* operations but not **_wait* on an mbarrier located in `shared::cluster` space.

- Waiting for completion of asynchronous memory operations initiated by a thread and making them visible to other threads.

An *mbarrier object* is an opaque object in memory which can be initialized and invalidated using :

- `mbarrier.init`
- `mbarrier.inval`

Operations supported on *mbarrier object*s are :

- `mbarrier.expect_tx`
- `mbarrier.complete_tx`
- `mbarrier.arrive`
- `mbarrier.arrive_drop`
- `mbarrier.test_wait`
- `mbarrier.try_wait`
- `mbarrier.pending_count`
- `cp.async.mbarrier.arrive`

Performing any *mbarrier* operation except `mbarrier.init` on an uninitialized *mbarrier object* results in undefined behavior. Performing any *non-mbarrier* or `mbarrier.init` operations on an initialized *mbarrier object* results in undefined behavior.

Unlike `bar{.cta}/barrier{.cta}` instructions which can access a limited number of barriers per CTA, *mbarrier objects* are user defined and are only limited by the total shared memory size available.

mbarrier operations enable threads to perform useful work after the arrival at the *mbarrier* and before waiting for the *mbarrier* to complete.

9.7.13.15.1 Size and alignment of mbarrier object

An mbarrier object is an opaque object with the following type and alignment requirements :

Type	Alignment (bytes)	Memory space
`.b64`	8	`.shared`

9.7.13.15.2 Contents of the mbarrier object

An opaque *mbarrier object* keeps track of the following information :

- Current phase of the *mbarrier object*
- Count of pending arrivals for the current phase of the *mbarrier object*
- Count of expected arrivals for the next phase of the *mbarrier object*
- Count of pending asynchronous memory operations (or transactions) tracked by the current phase of the *mbarrier object*. This is also referred to as *tx-count*.

An *mbarrier object* progresses through a sequence of phases where each phase is defined by threads performing an expected number of *arrive-on* operations.

The valid range of each of the counts is as shown below:

Count name	Minimum value	Maximum value
Expected arrival count	1	2^{20} - 1
Pending arrival count	0	2^{20} - 1
tx-count	-(2^{20} - 1)	2^{20} - 1

9.7.13.15.3 Lifecycle of the mbarrier object

The *mbarrier object* must be initialized prior to use.

An *mbarrier object* is used to synchronize threads and asynchronous memory operations.

An *mbarrier object* may be used to perform a sequence of such synchronizations.

An *mbarrier object* must be invalidated to repurpose its memory for any purpose, including repurposing it for another mbarrier object.

9.7.13.15.4 Phase of the mbarrier object

The phase of an *mbarrier object* is the number of times the *mbarrier object* has been used to synchronize threads and *cp.async* operations. In each phase {0, 1, 2, ...}, threads perform in program order :

- *arrive-on* operations to complete the current phase and
- *test_wait* / *try_wait* operations to check for the completion of the current phase.

An *mbarrier object* is automatically reinitialized upon completion of the current phase for immediate use in the next phase. The current phase is incomplete and all prior phases are complete.

For each phase of the mbarrier object, at least one *test_wait* or *try_wait* operation must be performed which returns `True` for `waitComplete` before an *arrive-on* operation in the subsequent phase.

9.7.13.15.5 Tracking asynchronous operations by the mbarrier object

Starting with the Hopper architecture (`sm_9x`), *mbarrier object* supports a new count, called *tx-count*, which is used for tracking the completion of asynchronous memory operations or transactions. *tx-count* tracks the number of asynchronous transactions, in units specified by the asynchronous memory operation, that are outstanding and yet to be complete.

The *tx-count* of an *mbarrier object* must be set to the total amount of asynchronous memory operations, in units as specified by the asynchronous operations, to be tracked by the current phase. Upon completion of each of the asynchronous operations, the *complete-tx* operation will be performed on the *mbarrier object* and thus progress the mbarrier towards the completion of the current phase.

9.7.13.15.5.1 expect-tx operation

The *expect-tx* operation, with an `expectCount` argument, increases the *tx-count* of an *mbarrier object* by the value specified by `expectCount`. This makes the current phase of the *mbarrier object* to expect and track the completion of additional asynchronous transactions.

9.7.13.15.5.2 complete-tx operation

The *complete-tx* operation, with an `completeCount` argument, on an *mbarrier object* consists of the following:

mbarrier signaling
Signals the completion of asynchronous transactions that were tracked by the current phase. As a result of this, *tx-count* is decremented by `completeCount`.

mbarrier potentially completing the current phase
If the current phase has been completed then the mbarrier transitions to the next phase. Refer to *Phase Completion of the mbarrier object* for details on phase completion requirements and phase transition process.

9.7.13.15.6 Phase Completion of the mbarrier object

The requirements for completion of the current phase are described below. Upon completion of the current phase, the phase transitions to the subsequent phase as described below.

Current phase completion requirements
An *mbarrier object* completes the current phase when all of the following conditions are met:

- The count of the pending arrivals has reached zero.
- The *tx-count* has reached zero.

Phase transition
When an *mbarrier* object completes the current phase, the following actions are performed atomically:

- The *mbarrier object* transitions to the next phase.
- The pending arrival count is reinitialized to the expected arrival count.

9.7.13.15.7 Arrive-on operation on mbarrier object

An *arrive-on* operation, with an optional *count* argument, on an *mbarrier object* consists of the following 2 steps :

- mbarrier signalling:

  Signals the arrival of the executing thread OR completion of the `cp.async` instruction which signals the arrive-on operation initiated by the executing thread on the *mbarrier object*. As a result of this, the pending arrival count is decremented by *count*. If the *count* argument is not specified, then it defaults to 1.

- mbarrier potentially completing the current phase:

If the current phase has been completed then the mbarrier transitions to the next phase. Refer to *Phase Completion of the mbarrier object* for details on phase completion requirements and phase transition process.

9.7.13.15.8 mbarrier support with shared memory

The following table summarizes the support of various mbarrier operations on *mbarrier objects* located at different shared memory locations:

mbarrier operations	`.shared::cta`	`.shared::cluster`
`mbarrier.arrive`	Supported	Supported, cannot return result
`mbarrier.expect_tx`	Supported	Supported
`mbarrier.complete_tx`	Supported	Supported
Other mbarrier operations	Supported	Not supported

9.7.13.15.9 Parallel Synchronization and Communication Instructions: `mbarrier.init`

`mbarrier.init`

Initialize the *mbarrier object*.

Syntax

```
mbarrier.init{.shared{::cta}}.b64 [addr], count;
```

Description

`mbarrier.init` initializes the *mbarrier object* at the location specified by the address operand `addr` with the unsigned 32-bit integer `count`. The value of operand count must be in the range as specified in *Contents of the mbarrier object*.

Initialization of the *mbarrier object* involves :

- Initializing the current phase to 0.
- Initializing the expected arrival count to `count`.
- Initializing the pending arrival count to `count`.
- Initializing the *tx-count* to 0.

The valid range of values for the operand `count` is [1, ..., 2^{20} - 1]. Refer *Contents of the mbarrier object* for the valid range of values for the various constituents of the mbarrier.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` state space then the behavior is undefined.

Supported addressing modes for operand `addr` is as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

The behavior of performing an `mbarrier.init` operation on a memory location containing a valid *mbarrier object* is undefined; invalidate the *mbarrier object* using `mbarrier.inval` first, before repurposing the memory location for any other purpose, including another *mbarrier object*.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
.shared .b64 shMem, shMem2;
.reg    .b64 addr;
.reg    .b32 %r1;

cvta.shared.u64          addr, shMem2;
mbarrier.init.b64        [addr],   %r1;
bar.cta.sync             0;
// ... other mbarrier operations on addr

mbarrier.init.shared::cta.b64 [shMem], 12;
bar.sync                 0;
// ... other mbarrier operations on shMem
```

9.7.13.15.10 Parallel Synchronization and Communication Instructions: `mbarrier.inval`

`mbarrier.inval`

Invalidates the *mbarrier object*.

Syntax

```
mbarrier.inval{.shared{::cta}}.b64 [addr];
```

Description

`mbarrier.inval` invalidates the *mbarrier object* at the location specified by the address operand `addr`.

An *mbarrier object* must be invalidated before using its memory location for any other purpose.

Performing any *mbarrier* operation except `mbarrier.init` on a memory location that does not contain a valid *mbarrier object*, results in undefined behaviour.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` state space then the behavior is undefined.

Supported addressing modes for operand `addr` is as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
.shared .b64 shmem;
.reg    .b64 addr;
.reg    .b32 %r1;
.reg    .pred t0;

// Example 1 :
bar.sync                    0;
@t0 mbarrier.init.b64     [addr], %r1;
// ... other mbarrier operations on addr
bar.sync                    0;
@t0 mbarrier.inval.b64    [addr];


// Example 2 :
bar.cta.sync                  0;
mbarrier.init.shared.b64          [shmem], 12;
// ... other mbarrier operations on shmem
bar.cta.sync                  0;
@t0 mbarrier.inval.shared.b64     [shmem];

// shmem can be reused here for unrelated use :
bar.cta.sync                  0;
st.shared.b64                     [shmem], ...;

// shmem can be re-initialized as mbarrier object :
bar.cta.sync                  0;
```

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```
@t0 mbarrier.init.shared.b64       [shmem], 24;
// ... other mbarrier operations on shmem
bar.cta.sync                  0;
@t0 mbarrier.inval.shared::cta.b64 [shmem];
```

9.7.13.15.11 Parallel Synchronization and Communication Instructions: `mbarrier.expect_tx`

`mbarrier.expect_tx`

Perfoms *expect-tx* operation on the *mbarrier object*.

Syntax

```
mbarrier.expect_tx{.sem}{.scope}{.space}.b64 [addr], txCount;

.sem   = { .relaxed }
.scope = { .cta, .cluster }
.space = { .shared{::cta}, .shared::cluster }
```

Description

A thread executing `mbarrier.expect_tx` performs an *expect-tx* operation on the *mbarrier object* at the location specified by the address operand `addr`. The 32-bit unsigned integer operand `txCount` specifies the `expectCount` argument to the *expect-tx* operation.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` or `.shared::cluster` state space then the behavior is undefined.

Supported addressing modes for operand `addr` are as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

This operation does not provide any memory ordering semantics and thus is a *relaxed* operation.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
mbarrier.expect_tx.b64                          [addr], 32;
mbarrier.expect_tx.relaxed.cta.shared.b64    [mbarObj1], 512;
mbarrier.expect_tx.relaxed.cta.shared.b64    [mbarObj2], 512;
```

9.7.13.15.12 Parallel Synchronization and Communication Instructions: `mbarrier.complete_tx`

`mbarrier.complete_tx`

Perfoms *complete-tx* operation on the *mbarrier object*.

Syntax

```
mbarrier.complete_tx{.sem}{.scope}{.space}.b64 [addr], txCount;

.sem   = { .relaxed }
.scope = { .cta, .cluster }
.space = { .shared{::cta}, .shared::cluster }
```

Description

A thread executing `mbarrier.complete_tx` performs a *complete-tx* operation on the *mbarrier object* at the location specified by the address operand `addr`. The 32-bit unsigned integer operand `txCount` specifies the `completeCount` argument to the *complete-tx* operation.

`mbarrier.complete_tx` does not involve any asynchronous memory operations and only simulates the completion of an asynchronous memory operation and its side effect of signaling to the *mbarrier object*.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` or `.shared::cluster` state space then the behavior is undefined.

Supported addressing modes for operand `addr` are as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

This operation does not provide any memory ordering semantics and thus is a *relaxed* operation.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires sm_90 or higher.

Examples

```
mbarrier.complete_tx.b64              [addr],     32;
mbarrier.complete_tx.shared.b64       [mbarObj1], 512;
mbarrier.complete_tx.relaxed.cta.b64 [addr2],     32;
```

9.7.13.15.13 Parallel Synchronization and Communication Instructions: mbarrier.arrive

mbarrier.arrive

Performs *arrive-on operation* on the *mbarrier object*.

Syntax

```
mbarrier.arrive{.sem}{.scope}{.shared{::cta}}.b64           state, [addr]{, count};
mbarrier.arrive{.sem}{.scope}{.shared::cluster}.b64         _, [addr] {,count}
mbarrier.arrive.expect_tx{.sem}{.scope}{.shared{::cta}}.b64 state, [addr], txCount;
mbarrier.arrive.expect_tx{.sem}{.scope}{.shared::cluster}.b64   _, [addr], txCount;
mbarrier.arrive.noComplete{.release}{.cta}{.shared{::cta}}.b64  state, [addr], count;

.sem   = { .release, .relaxed }
.scope = { .cta, .cluster }
```

Description

A thread executing mbarrier.arrive performs an *arrive-on* operation on the *mbarrier object* at the location specified by the address operand addr. The 32-bit unsigned integer operand count specifies the *count* argument to the *arrive-on* operation.

If no state space is specified then *Generic Addressing* is used. If the address specified by addr does not fall within the address window of .shared::cta state space then the behavior is undefined.

Supported addressing modes for operand addr is as described in *Addresses as Operands*. Alignment for operand addr is as described in the *Size and alignment of mbarrier object*.

The optional qualifier .expect_tx specifies that an *expect-tx* operation is performed prior to the *arrive-on* operation. The 32-bit unsigned integer operand txCount specifies the *expectCount* argument to the *expect-tx* operation. When both qualifiers .arrive and .expect_tx are specified, then the count argument of the *arrive-on* operation is assumed to be 1.

A mbarrier.arrive operation with .noComplete qualifier must not cause the mbarrier to complete its current phase, otherwise the behavior is undefined.

The value of the operand count must be in the range as specified in *Contents of the mbarrier object*.

Note: for sm_8x, when the argument count is specified, the modifier .noComplete is required.

mbarrier.arrive operation on an *mbarrier object* located in .shared::cta returns an opaque 64-bit register capturing the phase of the *mbarrier object* prior to the *arrive-on operation* in the destination

operand `state`. Contents of the `state` operand are implementation specific. Optionally, sink symbol '_' can be used for the `state` argument.

`mbarrier.arrive` operation on an *mbarrier object* located in `.shared::cluster` but not in `.shared::cta` cannot return a value. Sink symbol '_' is mandatory for the destination operand for such cases.

The optional `.sem` qualifier specifies a memory synchronizing effect as described in the *Memory Consistency Model*. If the `.sem` qualifier is absent, `.release` is assumed by default.

The `.relaxed` qualifier does not provide any memory ordering semantics and visibility guarantees.

The optional `.scope` qualifier indicates the set of threads that directly observe the memory synchronizing effect of this operation, as described in the *Memory Consistency Model*. If the `.scope` qualifier is not specified then it defaults to `.cta`. In contrast, the `.shared::<scope>` indicates the state space where the mbarrier resides.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for sink symbol '_' as the destination operand is introduced in PTX ISA version 7.1.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Support for `count` argument without the modifier `.noComplete` introduced in PTX ISA version 7.8.

Support for sub-qualifier `::cluster` introduced in PTX ISA version 8.0.

Support for qualifier `.expect_tx` is introduced in PTX ISA version 8.0.

Support for `.scope` and `.sem` qualifiers introduced in PTX ISA version 8.0

Support for `.relaxed` qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_80` or higher.

Support for `count` argument without the modifier `.noComplete` requires `sm_90` or higher.

Qualifier `.expect_tx` requires `sm_90` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for `.cluster` scope requires `sm_90` or higher.

Examples

```
.reg .b32 cnt, remoteAddr32, remoteCTAId, addr32;
.reg .b64 %r<5>, addr, remoteAddr64;
.shared .b64 shMem, shMem2;

cvta.shared.u64            addr, shMem2;
mov.b32                    addr32, shMem2;
mapa.shared::cluster.u32   remoteAddr32, addr32, remoteCTAId;
mapa.u64                   remoteAddr64, addr,   remoteCTAId;
```

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```
cvta.shared.u64          addr, shMem2;

mbarrier.arrive.shared.b64                          %r0, [shMem];
mbarrier.arrive.shared::cta.b64                     %r0, [shMem2];
mbarrier.arrive.release.cta.shared::cluster.b64     _, [remoteAddr32];
mbarrier.arrive.release.cluster.b64                 _, [remoteAddr64], cnt;
mbarrier.arrive.expect_tx.release.cluster.b64       _, [remoteAddr64], tx_count;
mbarrier.arrive.noComplete.b64                      %r1, [addr], 2;
mbarrier.arrive.relaxed.cta.b64                     %r2, [addr], 4;
mbarrier.arrive.b64                                 %r2, [addr], cnt;
```

9.7.13.15.14 Parallel Synchronization and Communication Instructions: `mbarrier.arrive_drop`

`mbarrier.arrive_drop`

Decrements the expected count of the *mbarrier object* and performs *arrive-on operation*.

Syntax

```
mbarrier.arrive_drop{.sem}{.scope}{.shared{::cta}}.b64 state,           [addr]{,
↪count};
mbarrier.arrive_drop{.sem}{.scope}{.shared::cluster}.b64           _,   [addr] {,
↪count};
mbarrier.arrive_drop.expect_tx{.shared{::cta}}{.sem}{.scope}.b64 state, [addr], tx_
↪count;
mbarrier.arrive_drop.expect_tx{.shared::cluster}{.sem}{.scope}.b64   _, [addr], tx_
↪count;
mbarrier.arrive_drop.noComplete{.release}{.cta}{.shared{::cta}}.b64 state,  [addr],
↪count;

.sem   = { .release, .relaxed }
.scope = { .cta, .cluster }
```

Description

A thread executing `mbarrier.arrive_drop` on the *mbarrier object* at the location specified by the address operand `addr` performs the following steps:

- Decrements the expected arrival count of the *mbarrier object* by the value specified by the 32-bit integer operand `count`. If `count` operand is not specified, it defaults to 1.
- Performs an *arrive-on operation* on the *mbarrier object*. The operand `count` specifies the *count* argument to the *arrive-on operation*.

The decrement done in the expected arrivals count of the *mbarrier object* will be for all the subsequent phases of the *mbarrier object*.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` or `.shared::cluster` state space then the behavior is undefined.

Supported addressing modes for operand `addr` is as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

The optional qualifier `.expect_tx` specifies that an *expect-tx* operation is performed prior to the *arrive-on* operation. The 32-bit unsigned integer operand `txCount` specifies the *expectCount* argument to the *expect-tx* operation. When both qualifiers `.arrive` and `.expect_tx` are specified, then the count argument of the *arrive-on* operation is assumed to be 1.

`mbarrier.arrive_drop` operation with `.release` qualifier forms the *release* pattern as described in the Memory Consistency Model and synchronizes with the *acquire* patterns.

The optional `.sem` qualifier specifies a memory synchronizing effect as described in the *Memory Consistency Model*. If the `.sem` qualifier is absent, `.release` is assumed by default. The `.relaxed` qualifier does not provide any memory ordering semantics and visibility guarantees.

The optional `.scope` qualifier indicates the set of threads that an `mbarrier.arrive_drop` instruction can directly synchronize. If the `.scope` qualifier is not specified then it defaults to `.cta`. In contrast, the `.shared::<scope>` indicates the state space where the mbarrier resides.

A `mbarrier.arrive_drop` with `.noComplete` qualifier must not complete the `mbarrier`, otherwise the behavior is undefined.

The value of the operand `count` must be in the range as specified in *Contents of the mbarrier object*.

Note: for `sm_8x`, when the argument `count` is specified, the modifier `.noComplete` is required.

A thread that wants to either exit or opt out of participating in the *arrive-on operation* can use `mbarrier.arrive_drop` to drop itself from the `mbarrier`.

`mbarrier.arrive_drop` operation on an *mbarrier object* located in `.shared::cta` returns an opaque 64-bit register capturing the phase of the *mbarrier object* prior to the *arrive-on operation* in the destination operand `state`. Contents of the returned state are implementation specific. Optionally, sink symbol '`_`' can be used for the `state` argument.

`mbarrier.arrive_drop` operation on an *mbarrier* object located in `.shared::cluster` but not in `.shared::cta` cannot return a value. Sink symbol '_' is mandatory for the destination operand for such cases.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Support for `count` argument without the modifier `.noComplete` introduced in PTX ISA version 7.8.

Support for qualifier `.expect_tx` is introduced in PTX ISA version 8.0.

Support for sub-qualifier `::cluster` introduced in PTX ISA version 8.0.

Support for `.scope` and `.sem` qualifiers introduced in PTX ISA version 8.0

Support for `.relaxed` qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_80` or higher.

Support for `count` argument without the modifier `.noComplete` requires `sm_90` or higher.

Qualifier `.expect_tx` requires `sm_90` or higher.

Sub-qualifier `::cluster` requires `sm_90` or higher.

Support for `.cluster` scope requires `sm_90` or higher.

Examples

```
.reg .b32 cnt;
.reg .b64 %r1;
.shared .b64 shMem;

// Example 1
@p mbarrier.arrive_drop.shared.b64 _, [shMem];
@p exit;
@p2 mbarrier.arrive_drop.noComplete.shared.b64 _, [shMem], %a;
@p2 exit;
..
@!p mbarrier.arrive.shared.b64   %r1, [shMem];
@!p mbarrier.test_wait.shared.b64  q, [shMem], %r1;

// Example 2
mbarrier.arrive_drop.shared::cluster.b64 _, [addr];
mbarrier.arrive_drop.shared::cta.release.cluster.b64     _, [addr], cnt;

// Example 3
mbarrier.arrive_drop.expect_tx.shared::cta.relaxed.cluster.b64 state, [addr], tx_
↪count;
```

9.7.13.15.15 Parallel Synchronization and Communication Instructions: `cp.async.mbarrier.arrive`

`cp.async.mbarrier.arrive`

Makes the *mbarrier object* track all prior *cp.async* operations initiated by the executing thread.

Syntax

```
cp.async.mbarrier.arrive{.noinc}{.shared{::cta}}.b64 [addr];
```

Description

Causes an *arrive-on operation* to be triggered by the system on the *mbarrier object* upon the completion of all prior *cp.async* operations initiated by the executing thread. The *mbarrier object* is at the location specified by the operand `addr`. The *arrive-on operation* is asynchronous to execution of `cp.async.mbarrier.arrive`.

When `.noinc` modifier is not specified, the pending count of the mbarrier object is incremented by 1 prior to the asynchronous *arrive-on operation*. This results in a zero-net change for the pending count from the asynchronous *arrive-on* operation during the current phase. The pending count of the *mbarrier object* after the increment should not exceed the limit as mentioned in *Contents of the mbarrier object*. Otherwise, the behavior is undefined.

When the `.noinc` modifier is specified, the increment to the pending count of the *mbarrier object* is not performed. Hence the decrement of the pending count done by the asynchronous *arrive-on operation* must be accounted for in the initialization of the *mbarrier object*.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` state space then the behavior is undefined.

Supported addressing modes for operand `addr` is as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
// Example 1: no .noinc
mbarrier.init.shared.b64 [shMem], threadCount;
....
cp.async.ca.shared.global [shard1], [gbl1], 4;
cp.async.cg.shared.global [shard2], [gbl2], 16;
....
// Absence of .noinc accounts for arrive-on from completion of prior cp.async
↪operations.
// So mbarrier.init must only account for arrive-on from mbarrier.arrive.
cp.async.mbarrier.arrive.shared.b64 [shMem];
....
mbarrier.arrive.shared.b64 state, [shMem];

waitLoop:
mbarrier.test_wait.shared.b64 p, [shMem], state;
@!p bra waitLoop;
```

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```
// Example 2: with .noinc

// Tracks arrive-on from mbarrier.arrive and cp.async.mbarrier.arrive.

// All threads participating in the mbarrier perform cp.async
mov.b32 copyOperationCnt, threadCount;

// 3 arrive-on operations will be triggered per-thread
mul.lo.u32 copyArrivalCnt, copyOperationCnt, 3;

add.u32 totalCount, threadCount, copyArrivalCnt;

mbarrier.init.shared.b64 [shMem], totalCount;
....
cp.async.ca.shared.global [shard1], [gbl1], 4;
cp.async.cg.shared.global [shard2], [gbl2], 16;
...
// Presence of .noinc requires mbarrier initalization to have accounted for arrive-on
↪from cp.async
cp.async.mbarrier.arrive.noinc.shared.b64 [shMem]; // 1st instance
....
cp.async.ca.shared.global [shard3], [gbl3], 4;
cp.async.ca.shared.global [shard4], [gbl4], 16;
cp.async.mbarrier.arrive.noinc.shared::cta.b64 [shMem]; // 2nd instance
....
cp.async.ca.shared.global [shard5], [gbl5], 4;
cp.async.cg.shared.global [shard6], [gbl6], 16;
cp.async.mbarrier.arrive.noinc.shared.b64 [shMem]; // 3rd and last instance
....
mbarrier.arrive.shared.b64 state, [shMem];

waitLoop:
mbarrier.test_wait.shared.b64 p, [shMem], state;
@!p bra waitLoop;
```

9.7.13.15.16 Parallel Synchronization and Communication Instructions: mbarrier.test_wait / mbarrier.try_wait

mbarrier.test_wait, mbarrier.try_wait

Checks whether the *mbarrier object* has completed the phase.

Syntax

```
mbarrier.test_wait{.sem}{.scope}{.shared{::cta}}.b64        waitComplete, [addr],
↪state;
mbarrier.test_wait.parity{.sem}{.scope}{.shared{::cta}}.b64 waitComplete, [addr],
↪phaseParity;

mbarrier.try_wait{.sem}{.scope}{.shared{::cta}}.b64         waitComplete, [addr],
↪state
                                                               {, suspendTimeHint};
```

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```
mbarrier.try_wait.parity{.sem}{.scope}{.shared{::cta}}.b64  waitComplete, [addr],
↪phaseParity
                                                                {, suspendTimeHint};

.sem   = { .acquire, .relaxed }
.scope = { .cta, .cluster }
```

Description

The *test_wait* and *try_wait* operations test for the completion of the current or the immediately preceding phase of an *mbarrier object* at the location specified by the operand `addr`.

`mbarrier.test_wait` is a non-blocking instruction which tests for the completion of the phase.

`mbarrier.try_wait` is a potentially blocking instruction which tests for the completion of the phase. If the phase is not complete, the executing thread may be suspended. Suspended thread resumes execution when the specified phase completes OR before the phase completes following a system-dependent time limit. The optional 32-bit unsigned integer operand `suspendTimeHint` specifies the time limit, in nanoseconds, that may be used for the time limit instead of the system-dependent limit.

`mbarrier.test_wait` and `mbarrier.try_wait` test for completion of the phase :

- Specified by the operand `state`, which was returned by an `mbarrier.arrive` instruction on the same *mbarrier object* during the current or the immediately preceding phase. Or
- Indicated by the operand `phaseParity`, which is the integer parity of either the current phase or the immediately preceding phase of the *mbarrier object*.

The `.parity` variant of the instructions test for the completion of the phase indicated by the operand `phaseParity`, which is the integer parity of either the current phase or the immediately preceding phase of the *mbarrier object*. An even phase has integer parity 0 and an odd phase has integer parity of 1. So the valid values of `phaseParity` operand are 0 and 1.

Note: the use of the `.parity` variants of the instructions requires tracking the phase of an *mbarrier object* throughout its lifetime.

The *test_wait* and *try_wait* operations are valid only for :

- the current incomplete phase, for which `waitComplete` returns `False`.
- the immediately preceding phase, for which `waitComplete` returns `True`.

If no state space is specified then *Generic Addressing* is used. If the address specified by `addr` does not fall within the address window of `.shared::cta` state space then the behavior is undefined.

Supported addressing modes for operand `addr` is as described in *Addresses as Operands*. Alignment for operand `addr` is as described in the *Size and alignment of mbarrier object*.

When `mbarrier.test_wait` and `mbarrier.try_wait` operations with `.acquire` qualifier returns `True`, they form the *acquire* pattern as described in the *Memory Consistency Model*.

The optional `.sem` qualifier specifies a memory synchronizing effect as described in the *Memory Consistency Model*. If the `.sem` qualifier is absent, `.acquire` is assumed by default. The `.relaxed` qualifier does not provide any memory ordering semantics and visibility guarantees.

The optional `.scope` qualifier indicates the set of threads that the `mbarrier.test_wait` and `mbarrier.try_wait` instructions can directly synchronize. If the `.scope` qualifier is not specified

then it defaults to `.cta`. In contrast, the `.shared::<scope>` indicates the state space where the mbarrier resides.

The following ordering of memory operations hold for the executing thread when `mbarrier.test_wait` or `mbarrier.try_wait` having acquire semantics returns `True` :

1. All memory accesses (except *async operations*) requested prior, in program order, to `mbarrier.arrive` having release semantics during the completed phase by the participating threads of the CTA are performed and are visible to the executing thread.
2. All *cp.async* operations requested prior, in program order, to `cp.async.mbarrier.arrive` during the completed phase by the participating threads of the CTA are performed and made visible to the executing thread.
3. All `cp.async.bulk` asynchronous operations using the same *mbarrier object* requested prior, in program order, to `mbarrier.arrive` having release semantics during the completed phase by the participating threads of the CTA are performed and made visible to the executing thread.
4. All memory accesses requested after the `mbarrier.test_wait` or `mbarrier.try_wait`, in program order, are not performed and not visible to memory accesses performed prior to `mbarrier.arrive` having release semantics, in program order, by other threads participating in the `mbarrier`.
5. There is no ordering and visibility guarantee for memory accesses requested by the thread after `mbarrier.arrive` having release semantics and prior to `mbarrier.test_wait`, in program order.

PTX ISA Notes

`mbarrier.test_wait` introduced in PTX ISA version 7.0.

Modifier `.parity` is introduced in PTX ISA version 7.1.

`mbarrier.try_wait` introduced in PTX ISA version 7.8.

Support for sub-qualifier `::cta` on `.shared` introduced in PTX ISA version 7.8.

Support for `.scope` and `.sem` qualifiers introduced in PTX ISA version 8.0

Support for `.relaxed` qualifier introduced in PTX ISA version 8.6.

Target ISA Notes

`mbarrier.test_wait` requires `sm_80` or higher.

`mbarrier.try_wait` requires `sm_90` or higher.

Support for `.cluster` scope requires `sm_90` or higher.

Examples

```
// Example 1a, thread synchronization with test_wait:

.reg .b64 %r1;
.shared .b64 shMem;

mbarrier.init.shared.b64 [shMem], N;  // N threads participating in the mbarrier.
...
mbarrier.arrive.shared.b64  %r1, [shMem]; // N threads executing mbarrier.arrive

// computation not requiring mbarrier synchronization...

waitLoop:
mbarrier.test_wait.shared.b64    complete, [shMem], %r1;
@!complete nanosleep.u32 20;
@!complete bra waitLoop;

// Example 1b, thread synchronization with try_wait :

.reg .b64 %r1;
.shared .b64 shMem;

mbarrier.init.shared.b64 [shMem], N;  // N threads participating in the mbarrier.
...
mbarrier.arrive.shared.b64  %r1, [shMem]; // N threads executing mbarrier.arrive

// computation not requiring mbarrier synchronization...

waitLoop:
mbarrier.try_wait.relaxed.cluster.shared.b64    complete, [shMem], %r1;
@!complete bra waitLoop;


// Example 2, thread synchronization using phase parity :

.reg .b32 i, parArg;
.reg .b64 %r1;
.shared .b64 shMem;

mov.b32 i, 0;
mbarrier.init.shared.b64 [shMem], N;  // N threads participating in the mbarrier.
...
loopStart :                           // One phase per loop iteration
    ...
    mbarrier.arrive.shared.b64  %r1, [shMem]; // N threads
    ...
    and.b32 parArg, i, 1;
    waitLoop:
    mbarrier.test_wait.parity.shared.b64  complete, [shMem], parArg;
    @!complete nanosleep.u32 20;
    @!complete bra waitLoop;
    ...
    add.u32 i, i, 1;
    setp.lt.u32 p, i, IterMax;
@p bra loopStart;
```

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```
// Example 3, Asynchronous copy completion waiting :

.reg .b64 state;
.shared .b64 shMem2;
.shared .b64 shard1, shard2;
.global .b64 gbl1, gbl2;

mbarrier.init.shared.b64 [shMem2], threadCount;
...
cp.async.ca.shared.global [shard1], [gbl1], 4;
cp.async.cg.shared.global [shard2], [gbl2], 16;

// Absence of .noinc accounts for arrive-on from prior cp.async operation
cp.async.mbarrier.arrive.shared.b64 [shMem2];
...
mbarrier.arrive.shared.b64 state, [shMem2];

waitLoop:
mbarrier.test_wait.shared::cta.b64 p, [shMem2], state;
@!p bra waitLoop;

// Example 4, Synchronizing the CTA0 threads with cluster threads
.reg .b64 %r1, addr, remAddr;
.shared .b64 shMem;

cvta.shared.u64          addr, shMem;
mapa.u64                 remAddr, addr, 0;     // CTA0's shMem instance

// One thread from CTA0 executing the below initialization operation
@p0 mbarrier.init.shared::cta.b64 [shMem], N;  // N = no of cluster threads

barrier.cluster.arrive;
barrier.cluster.wait;

// Entire cluster executing the below arrive operation
mbarrier.arrive.release.cluster.b64              _, [remAddr];

// computation not requiring mbarrier synchronization ...

// Only CTA0 threads executing the below wait operation
waitLoop:
mbarrier.try_wait.parity.acquire.cluster.shared::cta.b64  complete, [shMem], 0;
@!complete bra waitLoop;
```

9.7.13.15.17 Parallel Synchronization and Communication Instructions: mbarrier.pending_count

mbarrier.pending_count

Query the pending arrival count from the opaque mbarrier state.

Syntax

```
mbarrier.pending_count.b64 count, state;
```

Description

The pending count can be queried from the opaque mbarrier state using `mbarrier.pending_count`.

The `state` operand is a 64-bit register that must be the result of a prior `mbarrier.arrive.noComplete` or `mbarrier.arrive_drop.noComplete` instruction. Otherwise, the behavior is undefined.

The destination register `count` is a 32-bit unsigned integer representing the pending count of the *mbarrier object* prior to the *arrive-on operation* from which the `state` register was obtained.

PTX ISA Notes

Introduced in PTX ISA version 7.0.

Target ISA Notes

Requires `sm_80` or higher.

Examples

```
.reg .b32 %r1;
.reg .b64 state;
.shared .b64 shMem;

mbarrier.arrive.noComplete.b64 state, [shMem], 1;
mbarrier.pending_count.b64 %r1, state;
```

9.7.13.16 Parallel Synchronization and Communication Instructions: `tensormap.cp_fenceproxy`

`tensormap.cp_fenceproxy`

A fused copy and fence operation.

Syntax

```
tensormap.cp_fenceproxy.cp_qualifiers.fence_qualifiers.sync.aligned  [dst], [src],
↪size;

.cp_qualifiers    = { .global.shared::cta }
.fence_qualifiers = { .to_proxy::from_proxy.release.scope }
.to_proxy::from_proxy  = { .tensormap::generic }
.scope            = { .cta, .cluster, .gpu , .sys }
```

Description

The `tensormap.cp_fenceproxy` instructions perform the following operations in order :

- Copies data of size specified by the `size` argument, in bytes, from the location specified by the address operand `src` in shared memory to the location specified by the address operand `dst` in the global memory, in the generic proxy.
- Establishes a *uni-directional* proxy release pattern on the ordering from the copy operation to the subsequent access performed in the tensormap proxy on the address `dst`.

The valid value of immediate operand `size` is 128.

The operands `src` and `dst` specify non-generic addresses in `shared::cta` and `global` state space respectively.

The `.scope` qualifier specifies the set of threads that can directly observe the proxy synchronizing effect of this operation, as described in *Memory Consistency Model*.

The mandatory `.sync` qualifier indicates that `tensormap.cp_fenceproxy` causes the executing thread to wait until all threads in the warp execute the same `tensormap.cp_fenceproxy` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `tensormap.cp_fenceproxy` instruction. In conditionally executed code, an aligned `tensormap.cp_fenceproxy` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.3.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
// Example: manipulate a tensor-map object and then consume it in cp.async.bulk.tensor

.reg .b64 new_addr;
.global .align 128 .b8 gbl[128];
.shared .align 128 .b8 sMem[128];

cp.async.bulk.shared::cluster.global.mbarrier::complete_tx::bytes [sMem], [gMem], 128,
↪ [mbar];
...
try_wait_loop:
mbarrier.try_wait.shared.b64 p, [mbar], state;
@!p bra try_wait loop;

tensormap.replace.tile.global_address.shared.b1024.b64   [sMem], new_addr;
tensormap.cp_fenceproxy.global.shared::cta.tensormap::generic.release.gpu.sync.aligned
                                                         [gbl], [sMem], 128;
```

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```
fence.proxy.tensormap::generic.acquire.gpu [gbl], 128;
cp.async.bulk.tensor.1d.shared::cluster.global.tile  [addr0], [gbl, {tc0}], [mbar0];
```

9.7.13.17 Parallel Synchronization and Communication Instructions: clusterlaunchcontrol.try_cancel

clusterlaunchcontrol.try_cancel

Requests cancellation of cluster which is not launched yet.

Syntax

```
clusterlaunchcontrol.try_cancel.async{.space}.completion_mechanism{.
↪multicast::cluster::all}.b128 [addr], [mbar];

.completion_mechanism = { .mbarrier::complete_tx::bytes };
.space = { .shared::cta };
```

Description

The `clusterlaunchcontrol.try_cancel` instruction requests atomically cancelling the launch of a cluster that has not started running yet. It asynchronously writes an opaque response to shared memory indicating whether the operation succeeded or failed. The completion of the asynchronous operation is tracked using the mbarrier completion mechanism at `.cluster` scope.

On success, the opaque response contains the `ctaid` of the first CTA of the canceled cluster; no other successful response from other `clusterlaunchcontrol.try_cancel` operations from the same grid will contain that id.

The mandatory `.async` qualifier indicates that the instruction will initiate the cancellation operation asynchronously and control will return to the executing thread before the requested operation is complete.

The `.space` qualifier is specified, both operands `addr` and `mbar` must be in the `.shared::cta` state space. Otherwise, generic addressing will be assumed for both. The result is undefined if any of address operands do not fall within the address window of `.shared::cta`.

The qualifier `.completion_mechanism` specifies that upon completion of the asynchronous operation, *complete-tx* operation, with `completeCount` argument equal to amount of data stored in bytes, will be performed on the mbarrier object specified by the operand `mbar`.

The executing thread can then use *mbarrier instructions* to wait for completion of the asynchronous operation. No other synchronization mechanisms described in *Memory Consistency Model* can be used to guarantee the completion of the asynchronous copy operations.

The `.multicast::cluster::all` qualifier indicates that the response is asynchronously written using weak async-proxy writes to the corresponding local shared memory `addr` of each CTA in the requesting cluster. The completion of the writes to `addr` of a particular CTA is signaled via a complete-tx operation to the mbarrier object on the shared memory of that CTA.

The behavior of instruction with `.multicast::cluster::all` qualifier is undefined if any CTA in the cluster is exited.

Operand `addr` specifies the naturally aligned address of the 16-byte wide shared memory location where the request's response is written.

The response of `clusterlaunchcontrol.try_cancel` instruction will be 16-byte opaque value and will be it available at location specified by operand `addr`. After loading this response into 16-byte register, instruction `clusterlaunchcontrol.query_cancel` can be used to check if request was successful and to retrieve `ctaid` of the first CTA of the canceled cluster.

If the executing CTA has already observed the completion of a `clusterlaunchcontrol.try_cancel` instruction as failed, then the behavior of issuing a subsequent `clusterlaunchcontrol.try_cancel` instruction is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_100` or higher.

Qualifier `.multicast::cluster::all` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Examples

```
// Assumption: 1D cluster (cluster_ctaid.y/.z == 1)
// with 1 thread per CTA.

// Current Cluster to be processed, initially the
// currently launched cluster:

mov.b32 xctaid, %ctaid.x;
barrier.cluster.arrive.relaxed;
processCluster:

// Wait on all cluster CTAs completing initialization or processing of previous
↪cluster:

barrier.cluster.wait.acquire;
mov.u32  %r0, %tid.x;
setp.u32.eq p0, %r0, 0x0;
@!p0 bra asyncWork;
```

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```
// All CTAs in the cluster arrive at their local
// SMEM   barrier and set 16B handle tx count:

mbarrier.arrive.expect_tx.cluster.relaxed.shared::cta.b64 state, [mbar], 16;

// first CTA in Cluster attempts to cancel a
// not-yet-started cluster:

mov.u32  %r0, %cluster_ctaid.x;
setp.u32.eq p0, %r0, 0x0;
@p0 clusterlaunchcontrol.try_cancel.async.mbarrier::complete_tx::bytes.
↪multicast::cluster::all.b128 [addr], [mbar];

asyncWork:
// ...process xctaid while cancellation request completes
// asynchronously...

// All CTAs in Cluster wait on cancellation responses on their local SMEM:

waitLoop:
// .acquire prevents the load of the handle from overtaking this read:

mbarrier.try_wait.cluster.acquire.shared::cta.b64   complete, [mbar], state;
@!complete bra waitLoop;

// Load response into 16-byte wide register after unblocking
// from mbarrier:

ld.shared.b128 handle, [addr];

// Check whether cancellation succeeded:

clusterlaunchcontrol.query_cancel.is_canceled.pred.b128 p, handle;
@!p ret; // If failed, we are don end exit:

// Otherwise, read ctaid of first CTA of cancelled Cluster for next iteration...

@p clusterlaunchcontrol.query_cancel.get_first_ctaid.v4.b32.b128 {xctaid, _, _, _},
↪handle;

// ...and signal CTA0 that we are done reading from handle:
// Fence generic->async

fence.proxy.async.shared::cta;
barrier.cluster.arrive.relaxed;

bra processCluster;
```

9.7.13.18 Parallel Synchronization and Communication Instructions: clusterlaunchcontrol.query_cancel

clusterlaunchcontrol.query_cancel

Queries response of `clusterlaunchcontrol.try_cancel` operation.

Syntax

```
clusterlaunchcontrol.query_cancel.is_canceled.pred.b128 pred, try_cancel_response;

clusterlaunchcontrol.query_cancel.get_first_ctaid.v4.b32.b128 {xdim, ydim, zdim, _},
↪try_cancel_response;

clusterlaunchcontrol.query_cancel.get_first_ctaid{::dimension}.b32.b128 reg, try_
↪cancel_response;

::dimension = { ::x, ::y, ::z };
```

Description

Instruction `clusterlaunchcontrol.query_cancel` can be used to decode opaque response written by instruction `clusterlaunchcontrol.try_cancel`.

After loading response from `clusterlaunchcontrol.try_cancel` instruction into 16-byte register it can be further queried using `clusterlaunchcontrol.query_cancel` instruction as follows:

`clusterlaunchcontrol.query_cancel.is_canceled.pred.b128`: If the cluster is canceled successfully, predicate `p` is set to `true`; otherwise, it is set to `false`.

If the request succeeded, the instruction `clusterlaunchcontrol.query_cancel.get_first_ctaid` extracts the CTA id of the first CTA in the canceled cluster. By default, the instruction returns a `.v4` vector whose first three elements are the `x`, `y` and `z` coordinate of first CTA in canceled cluster. The contents of the 4th element are unspecified. The explicit `.get_first_ctaid::x`, `.get_first_ctaid::y`, or `.get_first_ctaid::z` qualifiers can be used to extract individual `x`, `y` or `z` coordinates into a 32-bit register.

If the request fails the behavior of `clusterlaunchcontrol.query_cancel.get_first_ctaid` is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_100` or higher.

Examples

```
clusterlaunchcontrol.query_cancel.is_canceled pred.b128 p, handle;

@p clusterlaunchcontrol.query_cancel.get_first_ctaid.v4.b32.b128 {xdim, ydim, zdim,
↪ignr}  handle;

clusterlaunchcontrol.query_cancel.get_first_ctaid::x.b32.b128 reg0, handle;

clusterlaunchcontrol.query_cancel.get_first_ctaid::y.b32.b128 reg1, handle;

clusterlaunchcontrol.query_cancel.get_first_ctaid::z.b32.b128 reg2, handle;
```

9.7.14. Warp Level Matrix Multiply-Accumulate Instructions

The matrix multiply and accumulate operation has the following form:

```
D = A * B + C
```

where D and C are called accumulators and may refer to the same matrix.

PTX provides two ways to perform matrix multiply-and-accumulate computation:

- Using `wmma` instructions:
  - This warp-level computation is performed collectively by all threads in the warp as follows:
    - Load matrices A, B and C from memory into registers using the `wmma.load` operation. When the operation completes, the destination registers in each thread hold a fragment of the loaded matrix.
    - Perform the matrix multiply and accumulate operation using the `wmma.mma` operation on the loaded matrices. When the operation completes, the destination registers in each thread hold a fragment of the result matrix returned by the `wmma.mma` operation.
    - Store result Matrix D back to memory using the `wmma.store` operation. Alternately, result matrix D can also be used as argument C for a subsequent `wmma.mma` operation.

    The `wmma.load` and `wmma.store` instructions implicitly handle the organization of matrix elements when loading the input matrices from memory for the `wmma.mma` operation and when storing the result back to memory.
- Using `mma` instruction:
  - Similar to `wmma`, `mma` also requires computation to be performed collectively by all threads in the warp however distribution of matrix elements across different threads in warp needs to be done explicitly before invoking the `mma` operation. The `mma` instruction supports both dense as well as sparse matrix A. The sparse variant can be used when A is a structured sparse matrix as described in *Sparse matrix storage*.

9.7.14.1 Matrix Shape

The matrix multiply and accumulate operations support a limited set of shapes for the operand matrices A, B and C. The shapes of all three matrix operands are collectively described by the tuple `MxNxK`, where A is an `MxK` matrix, B is a `KxN` matrix, while C and D are `MxN` matrices.

The following matrix shapes are supported for the specified types:

Instruction	Scale	Sparsity	Multiplicand Data-type	Shape	PTX ISA version
`wmma`	NA	Dense	Floating-point - `.f16`	`.m16n16k16`, `.m8n32k16`, and `.m32n8k16`	PTX ISA version 6.0
`wmma`		Dense	Alternate floating-point format - `.bf16`	`.m16n16k16`, `.m8n32k16`, and `.m32n8k16`	PTX ISA version 7.0
`wmma`		Dense	Alternate floating-point format - `.tf32`	`.m16n16k8`	PTX ISA version 7.0
`wmma`		Dense	Integer - `.u8/.s8`	`.m16n16k16`, `.m8n32k16`, and `.m32n8k16`	PTX ISA version 6.3
`wmma`		Dense	Sub-byte integer - `.u4/.s4`	`.m8n8k32`	PTX ISA version 6.3 (preview feature)
`wmma`		Dense	Single-bit - `.b1`	`.m8n8k128`	PTX ISA version 6.3 (preview feature)
`mma`	NA	Dense	Floating-point - `.f64`	`.m8n8k4`	PTX ISA version 7.0
				`.m16n8k4`, `.m16n8k8`, and `.m16n8k16`	PTX ISA version 7.8
`mma`		Dense	Floating-point - `.f16`	`.m8n8k4`	PTX ISA version 6.4
				`.m16n8k8`	PTX ISA version 6.5
				`.m16n8k16`	PTX ISA version 7.0
`mma`		Dense	Alternate floating-point format - `.bf16`	`.m16n8k8` and `.m16n8k16`	PTX ISA version 7.0
`mma`		Dense	Alternate floating-point format - `.tf32`	`.m16n8k4` and `.m16n8k8`	PTX ISA version 7.0
`mma`		Dense	Integer - `.u8/.s8`	`.m8n8k16`	PTX ISA version 6.5
				`.m16n8k16` and `.m16n8k32`	PTX ISA version 7.0
`mma`		Dense	Sub-byte integer - `.u4/.s4`	`.m8n8k32`	PTX ISA version 6.5
				`.m16n8k32` and `.m16n8k64`	PTX ISA version 7.0
`mma`		Dense	Single-bit - `.b1`	`.m8n8k128`, `.m16n8k128`, and `.m16n8k256`	PTX ISA version 7.0
`mma`		Dense	Alternate floating-point format - `.e4m3` / `.e5m2`	`.m16n8k32`	PTX ISA version 8.4

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Instruction	Scale	Sparsity	Multiplicand Data-type	Shape	PTX ISA version
mma		Dense	Alternate floating-point format - .e4m3 / .e5m2	.m16n8k16	PTX ISA version 8.7
mma		Dense	Alternate floating-point format - .e3m2 / .e2m3/.e2m1	.m16n8k32	PTX ISA version 8.7
mma	Yes	Dense	Alternate floating-point format - .e4m3 / .e5m2/.e3m2/.e2m3/.e2m1 X (Scale) .ue8m0	.m16n8k32	PTX ISA version 8.7
mma		Dense	Alternate floating-point format - .e2m1 X (Scale) .ue8m0/.ue4m3	.m16n8k64	PTX ISA version 8.7
mma	NA	Sparse	Floating-point - .f16	.m16n8k16 and .m16n8k32	PTX ISA version 7.1
mma		Sparse	Alternate floating-point format - .bf16	.m16n8k16 and .m16n8k32	PTX ISA version 7.1
mma		Sparse	Alternate floating-point format - .tf32	.m16n8k8 and .m16n8k16	PTX ISA version 7.1
mma		Sparse	Integer - .u8/.s8	.m16n8k32 and .m16n8k64	PTX ISA version 7.1
mma		Sparse	Sub-byte integer - .u4/.s4	.m16n8k64 and .m16n8k128	PTX ISA version 7.1
mma		Sparse	Alternate floating-point format - .e4m3 / .e5m2	.m16n8k64	PTX ISA version 8.4
mma		Sparse with ordered meta-data	Floating-point - .f16	.m16n8k16 and .m16n8k32	PTX ISA version 8.5
mma		Sparse with ordered meta-data	Alternate floating-point format - .bf16	.m16n8k16 and .m16n8k32	PTX ISA version 8.5
mma		Sparse with ordered meta-data	Alternate floating-point format - .tf32	.m16n8k8 and .m16n8k16	PTX ISA version 8.5

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Instruction	Scale	Sparsity	Multiplicand Data-type	Shape	PTX ISA version
mma		Sparse with ordered metadata	Integer - .u8/.s8	.m16n8k32 and .m16n8k64	PTX ISA version 8.5
mma		Sparse with ordered metadata	Sub-byte integer - .u4/.s4	.m16n8k64 and .m16n8k128	PTX ISA version 8.5
mma		Sparse with ordered metadata	Alternate floating-point format - .e4m3 / .e5m2	.m16n8k64	PTX ISA version 8.5
mma		Sparse with ordered metadata	Alternate floating-point format - .e3m2 / .e2m3/.e2m1	.m16n8k64	PTX ISA version 8.7
mma	Yes	Sparse with ordered metadata	Alternate floating-point format - .e4m3 / .e5m2/.e3m2/.e2m3/.e2m1 X (Scale) .ue8m0	.m16n8k64	PTX ISA version 8.7
mma		Sparse with ordered metadata	Alternate floating-point format - .e2m1 X (Scale) .ue8m0/.ue4m3	.m16n8k128	PTX ISA version 8.7

9.7.14.2 Matrix Data-types

The matrix multiply and accumulate operation is supported separately on integer, floating-point, sub-byte integer and single bit data-types. All operands must contain the same basic type kind, i.e., integer or floating-point.

For floating-point matrix multiply and accumulate operation, different matrix operands may have different precision, as described later.

Data-type	Multiplicands (A or B)	Accumulators (C or D)
Integer	.u8, .s8	.s32
Floating Point	.f16	.f16, .f32
Alternate floating Point	.bf16	.f32
Alternate floating Point	.tf32	.f32
Alternate floating Point	.e4m3 or .e5m2 or .e3m2 or .e2m3 or .e2m1	.f16, .f32
Alternate floating Point with scale	.e4m3 or .e5m2 or .e3m2 or .e2m3 or .e2m1 X (Scale) .ue8m0	.f32
Alternate floating Point with scale	.e2m1 X (Scale) .ue8m0 or .ue4m3	.f32
Floating Point	.f64	.f64
Sub-byte integer	both .u4 or both .s4	.s32
Single-bit integer	.b1	.s32

9.7.14.3 Block Scaling

The mma instruction with the following .kind qualifier:

- .kind::mxf8f6f4
- .kind::mxf4
- .kind::mxf4nvf4

perform matrix multiplication with block scaling. This operation has the following form: D = (A * scale_A) * (B * scale_B) + C.

For a scale_A matrix of shape *M x SFA_N*, each row of matrix A is divided into *SFA_N* number of chunks and each chunk of a row is multiplied with the corresponding element (henceforth referred as *SF_A*) from the same row of scale_A.

Similarly, for a scale_B matrix of shape *SFB_M x N*, each column of matrix B is divided into the *SFB_M* number of chunks and each chunk of a column is multiplied with the corresponding element (henceforth referred as *SF_B*) from the same column of scale_B.

Figure 42 shows an example of mma with block scaling of scale_vec::2X.

The shapes for scale_A and scale_B matrices depend upon the qualifier .scale_vec_size as shown in Table 37.

Table 37: Shapes for scale matrices depending upon .scale_vec_size qualifier

.scale_vec_size	Shape of scale_A	Shape of scale_B
.scale_vec::1X	M x 1	1 x N
.scale_vec::2X	M x 2	2 x N
.scale_vec::4X	M x 4	4 x N

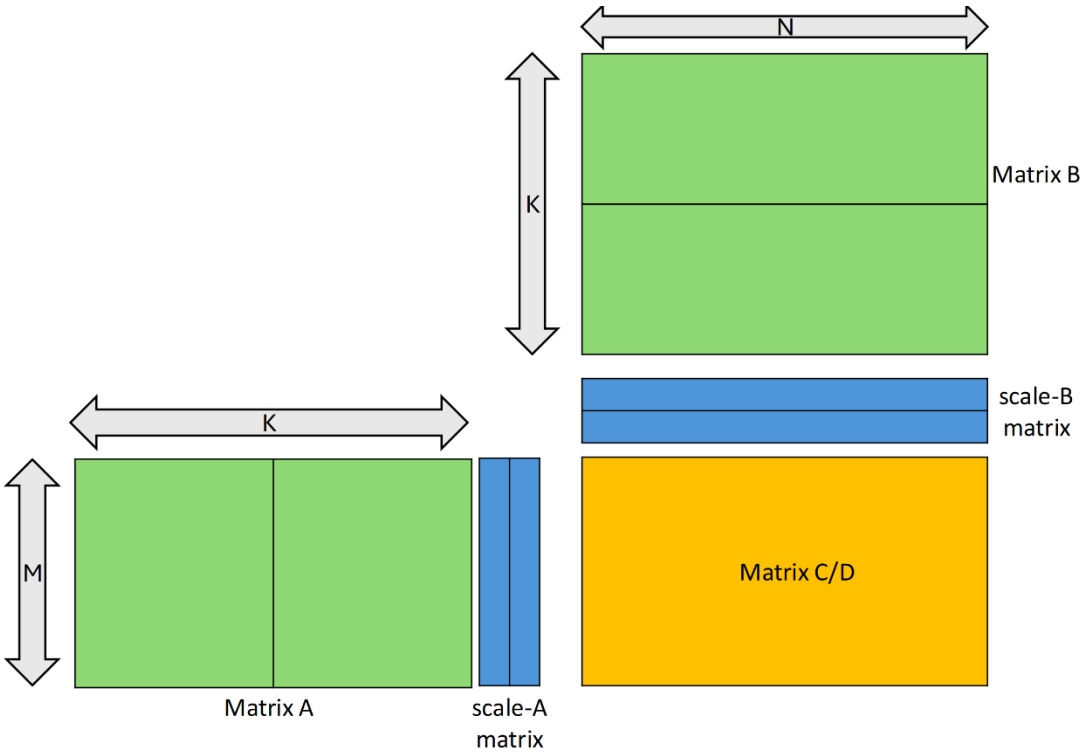

Figure 42: mma with block scaling of .scale_vec::2X

The valid combination of the exact element types and the .scale_vec_size are listed in Table 38.

Table 38: Valid combinations of .scale_vec_size and .kind qualifier

.kind::*	Element Data Type .atype and .btype	Scale Data Type .stype	.scale_vec_size
.kind::mxf8f6f4	.e4m3, .e5m2 .e3m2, .e2m3 .e2m1	.ue8m0	.scale_vec::1X
.kind::mxf4	.e2m1	.ue8m0	.scale_vec::2X
.kind::mxf4nvf4	.e2m1	.ue8m0	.scale_vec::2X
	.e2m1	.ue4m3	.scale_vec::4X

The scale-a-data and scale-b-data argument provides metadata for scale_A and scale_B matrices respectively. The tuple {byte-id-a, thread-id-a} and {byte-id-b, thread-id-b} provides the selector information to choose elements *SF_A* and *SF_B* from corresponding metadata arguments scale-a-data and scale-b-data. The tuple {byte-id-a, thread-id-a} allows to select the scale matrix element *SF_A* from scale-a-data. Similarly, the tuple {byte-id-b, thread-id-b} allows to select the scale matrix element *SF_B* from scale-b-data.

The components thread-id-a, thread-id-b decides which threads among the quad contribute the *SF_A* and *SF_B* values. The following listing describes the impact of thread selector component

`thread-id-a`, `thread-id-b`:

- One thread-pair within the quad determined by `thread-id-a`, contributes the *SF_A* values. The value of 0 selects lower two threads whereas value of 1 selects upper two threads from the quad. In other words, when `thread-id-a` set to 0, thread-pair satisfying: `%laneid` % 4 == 0 or 1 provides the *SF_A*. In contrast when `thread-id-a` set to 1, thread-pair satisfying: `%laneid` % 4 == 2 or 3 provides the *SF_A*. Refer Figure 43 for more details.

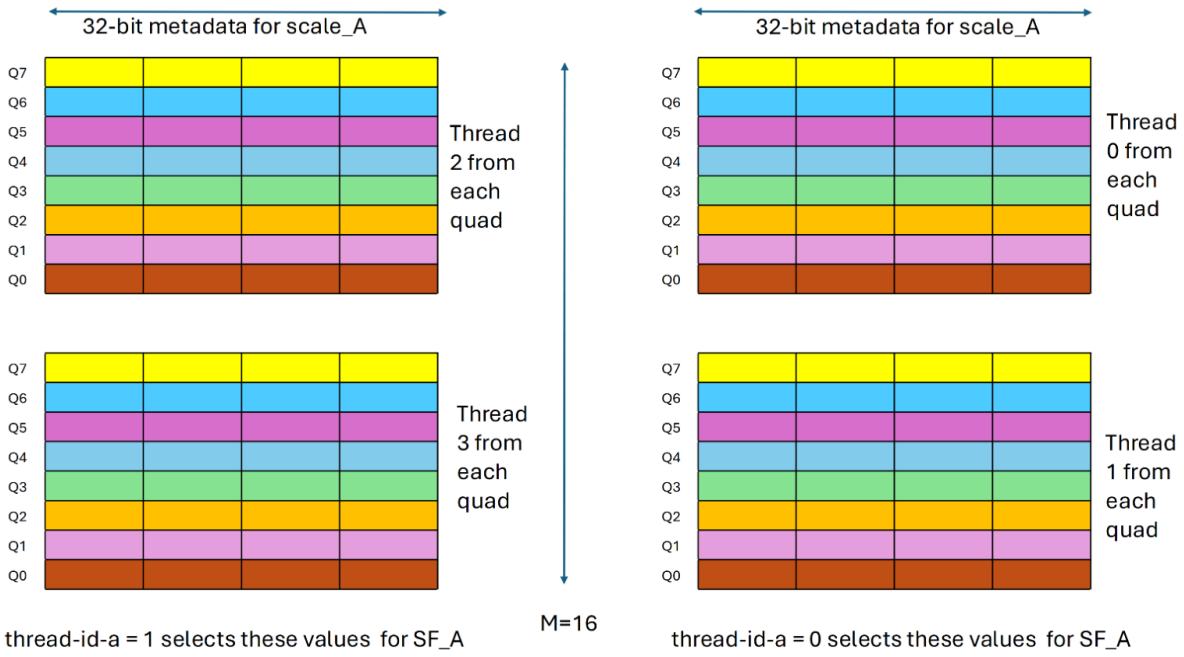

Figure 43: Selection of set of values for *SF_A* based on `thread-id-a`

- One thread within the quad, determined by `thread-id-b`, contributes the *SF_B* value. In other words, each thread satisfying: `%laneid` % 4 == `thread-id-b` provides the *SF_B*. Refer Figure 44 for more details.

The arguments `byte-id-a`, `byte-id-b` selects which bytes from the `scale-a-data`, `scale-b-data` contribute the *SF_A* and *SF_B* values. The following listing describes implications of `.scale_vec_size` qualifier on byte selector component `byte-id-a`, `byte-id-b`:

- When `.scale_vec_size` is `.scale_vec::1X`
  - One byte each within `scale-a-data` and `scale-b-data` determined by `byte-id-a`, `byte-id-b` respectively contributes the *SF_A* and *SF_B* values.
- When `.scale_vec_size` is `.scale_vec::2X`
  - One byte-pair (two bytes) within `scale-a-data` and `scale-b-data` determined by `byte-id-a` and `byte-id-b` contributes the *SF_A* and *SF_B* values. The value of 0 selects lower two bytes whereas value of 2 selects upper two bytes from the corresponding meta-data value.
- When `.scale_vec_size` is `.scale_vec::4X`
  - All four bytes within `scale-a-data` and `scale-b-data` contribute the values. Hence, `byte-id-a`, `byte-id-b` must be zero.

Refer Figure 45 for more details.

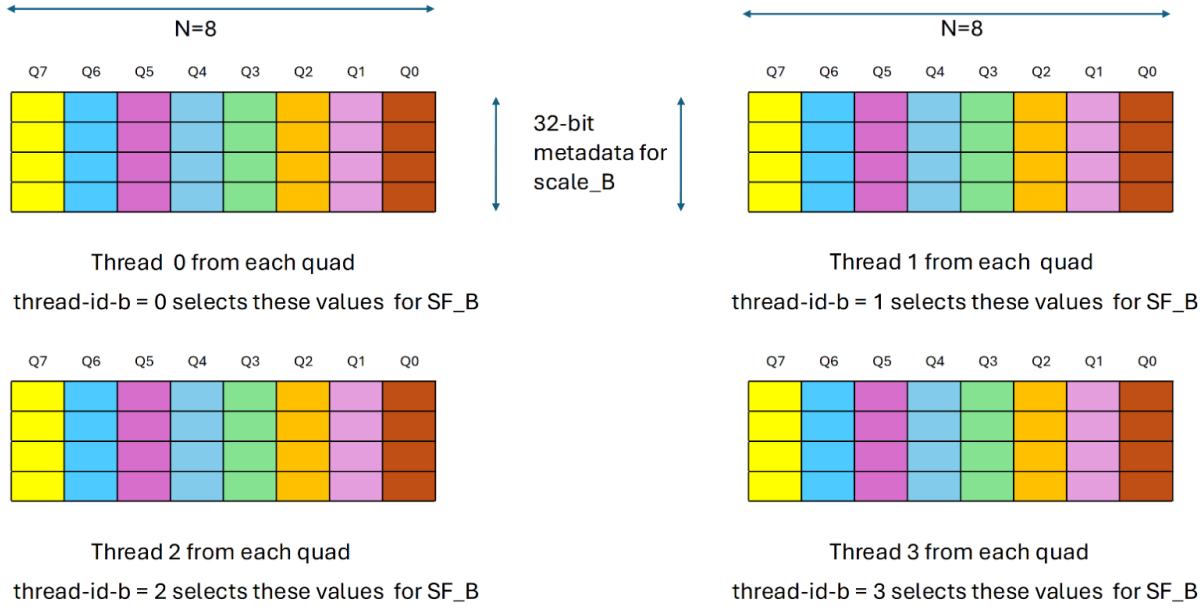

Figure 44: Selection of set of values for *SF_B* based on `thread-id-b`

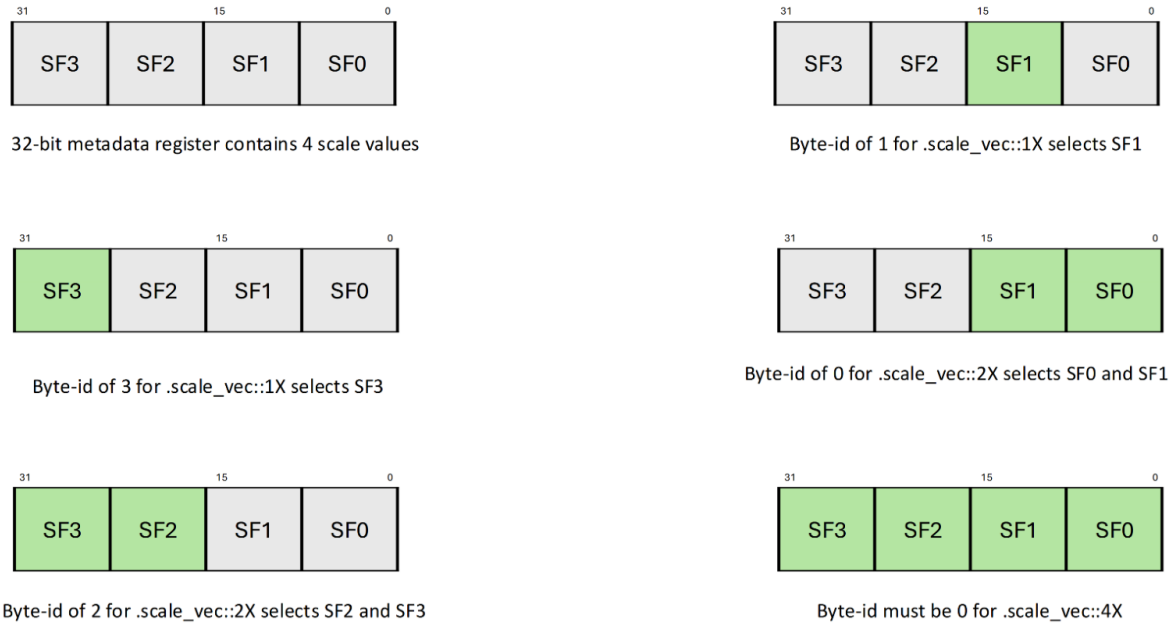

Figure 45: Selection of set of values for *SF_A* or *SF_B* based on `byte-id-a` or `byte-id-b`

Table 39 enumerates the valid values for various selector components. Any other value results in an undefined behavior.

Table 39: Valid values for various selector components

.scale_vec_size	Selector Components			
	byte-id-a	thread-id-a	byte-id-b	thread-id-b
scale_vec::1X	[0, 1, 2, 3]	[0, 1]	[0, 1, 2, 3]	[0, 1, 2, 3]
scale_vec::2X	[0, 2]		[0, 2]	
scale_vec::4X	0		0	

9.7.14.4 Matrix multiply-accumulate operation using wmma instructions

This section describes warp level `wmma.load`, `wmma.mma` and `wmma.store` instructions and the organization of various matrices invovled in these instruction.

9.7.14.4.1 Matrix Fragments for WMMA

Each thread in the warp holds a fragment of the matrix. The distribution of fragments loaded by the threads in a warp is unspecified and is target architecture dependent, and hence the identity of the fragment within the matrix is also unspecified and is target architecture dependent. The fragment returned by a `wmma` operation can be used as an operand for another `wmma` operation if the shape, layout and element type of the underlying matrix matches. Since fragment layout is architecture dependent, using the fragment returned by a `wmma` operation in one function as an operand for a `wmma` operation in a different function may not work as expected if the two functions are linked together but were compiled for different link-compatible SM architectures. Note passing `wmma` fragment to a function having `.weak` linkage is unsafe since at link time references to such function may get resolved to a function in different compilation module.

Each fragment is a vector expression whose contents are determined as follows. The identity of individual matrix elements in the fragment is unspecified.

Integer fragments

Multiplicands (A or B):

Data-type	Shape	Matrix	Fragment
.u8 or .s8	.m16n16k16	A	A vector expression of two .b32 registers, with each register containing four elements from the matrix.
		B	A vector expression of two .b32 registers, with each register containing four elements from the matrix.
	.m8n32k16	A	A vector expression containing a single .b32 register containing four elements from the matrix.
		B	A vector expression of four .b32 registers, with each register containing four elements from the matrix.
	.m32n8k16	A	A vector expression of four .b32 registers, with each register containing four elements from the matrix.
		B	A vector expression containing single .b32 register, with each containing four elements from the matrix.

Accumulators (C or D):

Data-type	Shape	Fragment
.s32	.m16n16k16	A vector expression of eight .s32 registers.
	.m8n32k16	
	.m32n8k16	

Floating point fragments

Data-type	Matrix	Fragment
.f16	A or B	A vector expression of eight .f16x2 registers.
.f16	C or D	A vector expression of four .f16x2 registers.
.f32		A vector expression of eight .f32 registers.

Floating point fragments for .bf16 data format

Multiplicands (A or B):

Data-type	Shape	Matrix	Fragment
.bf16	.m16n16k16	A	A vector expression of four .b32 registers, with each register containing two elements from the matrix.
		B	
	.m8n32k16	A	A vector expression containing a two .b32 registers, with containing two elements from the matrix.
		B	A vector expression of eight .b32 registers, with each register containing two elements from the matrix.
	.m32n8k16	A	A vector expression of eight .b32 registers, with each register containing two elements from the matrix.
		B	A vector expression containing two .b32 registers, with each containing two elements from the matrix.

Accumulators (C or D):

Data-type	Matrix	Fragment
.f32	C or D	A vector expression containing eight .f32 registers.

Floating point fragments for .tf32 data format

Multiplicands (A or B):

Data-type	Shape	Matrix	Fragment
.tf32	.m16n16k8	A	A vector expression of four .b32 registers.
		B	A vector expression of four .b32 registers.

Accumulators (C or D):

Data-type	Shape	Matrix	Fragment
.f32	.m16n16k8	C or D	A vector expression containing eight .f32 registers.

Double precision floating point fragments

Multiplicands (A or B):

Data-type	Shape	Matrix	Fragment
.f64	.m8n8k4	A or B	A vector expression of single .f64 register.

Accumulators (C or D):

Data-type	Shape	Matrix	Fragment
.f64	.m8n8k4	C or D	A vector expression containing single .f64 register.

Sub-byte integer and single-bit fragments

Multiplicands (A or B):

Data-type	Shape	Fragment
.u4 or .s4	.m8n8k32	A vector expression containing a single .b32 register, containing eight elements from the matrix.
.b1	.m8n8k128	A vector expression containing a single .b32 register, containing 32 elements from the matrix.

Accumulators (C or D):

Data-type	Shape	Fragment
.s32	.m8n8k32	A vector expression of two .s32 registers.
	.m8n8k128	A vector expression of two .s32 registers.

Manipulating fragment contents

The contents of a matrix fragment can be manipulated by reading and writing to individual registers in the fragment, provided the following conditions are satisfied:

- All matrix element in the fragment are operated on uniformly across threads, using the same parameters.
- The order of the matrix elements is not changed.

For example, if each register corresponding to a given matrix is multiplied by a uniform constant value, then the resulting matrix is simply the scaled version of the original matrix.

Note that type conversion between .f16 and .f32 accumulator fragments is not supported in either direction. The result is undefined even if the order of elements in the fragment remains unchanged.

9.7.14.4.2 Matrix Storage for WMMA

Each matrix can be stored in memory with a *row-major* or *column-major* layout. In a *row-major* format, consecutive elements of each row are stored in contiguous memory locations, and the row is called the *leading dimension* of the matrix. In a *column-major* format, consecutive elements of each column are stored in contiguous memory locations and the column is called the *leading dimension* of the matrix.

Consecutive instances of the *leading dimension* (rows or columns) need not be stored contiguously in memory. The wmma.load and wmma.store operations accept an optional argument stride that specifies the offset from the beginning of each row (or column) to the next, in terms of matrix elements (and not bytes). For example, the matrix being accessed by a wmma operation may be a submatrix from

a larger matrix stored in memory. This allows the programmer to compose a multiply-and-accumulate operation on matrices that are larger than the shapes supported by the `wmma` operation.

Address Alignment

The starting address of each instance of the leading dimension (row or column) must be aligned with the size of the corresponding fragment in bytes. Note that the starting address is determined by the base pointer and the optional `stride`.

Consider the following instruction as an example:

```
wmma.load.a.sync.aligned.row.m16n16k16.f16 {x0,...,x7}, [p], s;
```

- Fragment size in bytes = 32 (eight elements of type `.f16x2`)
- Actual `stride` in bytes = 2 * `s` (since `stride` is specified in terms of `.f16` elements, not bytes)
- For each row of this matrix to be aligned at fragment size the following must be true:
  1. `p` is a multiple of 32.
  2. `2*s` is a multiple of 32.

Default value for stride

The default value of the `stride` is the size of the *leading dimension* of the matrix. For example, for an `MxK` matrix, the `stride` is `K` for a *row-major* layout and `M` for a *column-major* layout. In particular, the default strides for the supported matrix shapes are as follows:

Shape	A (row)	A (column)	B (row)	B (column)	Accumulator (row)	Accumulator (column)
16x16x16	16	16	16	16	16	16
8x32x16	16	8	32	16	32	8
32x8x16	16	32	8	16	8	32
8x8x32	32	8	8	32	8	8
8x8x128	128	8	8	128	8	8
16x16x8	8	16	16	8	16	16
8x8x4	4	8	8	4	8	8

9.7.14.4.3 Warp-level Matrix Load Instruction: `wmma.load`

`wmma.load`

Collectively load a matrix from memory for WMMA

Syntax

Floating point format `.f16` loads:

```
wmma.load.a.sync.aligned.layout.shape{.ss}.atype r, [p] {, stride};
wmma.load.b.sync.aligned.layout.shape{.ss}.btype r, [p] {, stride};
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride};

.layout = {.row, .col};
.shape  = {.m16n16k16, .m8n32k16, .m32n8k16};
.ss     = {.global, .shared{::cta}};
.atype  = {.f16, .s8, .u8};
.btype  = {.f16, .s8, .u8};
.ctype  = {.f16, .f32, .s32};
```

Alternate floating point format `.bf16` loads:

```
wmma.load.a.sync.aligned.layout.shape{.ss}.atype r, [p] {, stride}
wmma.load.b.sync.aligned.layout.shape{.ss}.btype r, [p] {, stride}
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride}
.layout = {.row, .col};
.shape  = {.m16n16k16, .m8n32k16, .m32n8k16};
.ss     = {.global, .shared{::cta}};
.atype  = {.bf16 };
.btype  = {.bf16 };
.ctype  = {.f32 };
```

Alternate floating point format `.tf32` loads:

```
wmma.load.a.sync.aligned.layout.shape{.ss}.atype r, [p] {, stride}
wmma.load.b.sync.aligned.layout.shape{.ss}.btype r, [p] {, stride}
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride}
.layout = {.row, .col};
.shape  = {.m16n16k8 };
.ss     = {.global, .shared{::cta}};
.atype  = {.tf32 };
.btype  = {.tf32 };
.ctype  = {.f32 };
```

Double precision Floating point `.f64` loads:

```
wmma.load.a.sync.aligned.layout.shape{.ss}.atype r, [p] {, stride}
wmma.load.b.sync.aligned.layout.shape{.ss}.btype r, [p] {, stride}
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride}
.layout = {.row, .col};
.shape  = {.m8n8k4 };
.ss     = {.global, .shared{::cta}};
.atype  = {.f64 };
.btype  = {.f64 };
.ctype  = {.f64 };
```

Sub-byte loads:

```
wmma.load.a.sync.aligned.row.shape{.ss}.atype r, [p] {, stride}
wmma.load.b.sync.aligned.col.shape{.ss}.btype r, [p] {, stride}
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride}
.layout = {.row, .col};
.shape  = {.m8n8k32};
```

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```
.ss     = {.global, .shared{::cta}};
.atype  = {.s4, .u4};
.btype  = {.s4, .u4};
.ctype  = {.s32};
```

Single-bit loads:

```
wmma.load.a.sync.aligned.row.shape{.ss}.atype r, [p] {, stride}
wmma.load.b.sync.aligned.col.shape{.ss}.btype r, [p] {, stride}
wmma.load.c.sync.aligned.layout.shape{.ss}.ctype r, [p] {, stride}
.layout = {.row, .col};
.shape  = {.m8n8k128};
.ss     = {.global, .shared{::cta}};
.atype  = {.b1};
.btype  = {.b1};
.ctype  = {.s32};
```

Description

Collectively load a matrix across all threads in a warp from the location indicated by address operand `p` in the specified state space into destination register `r`.

If no state space is given, perform the memory accesses using *Generic Addressing*. `wmma.load` operation may be used only with `.global` and `.shared` spaces and with generic addressing, where the address points to `.global` or `.shared` space.

The mutually exclusive qualifiers `.a`, `.b` and `.c` indicate whether matrix A, B or C is being loaded respectively for the `wmma` computation.

The destination operand `r` is a brace-enclosed vector expression that can hold the fragment returned by the load operation, as described in *Matrix Fragments for WMMA*.

The `.shape` qualifier indicates the dimensions of all the matrix arguments involved in the intended `wmma` computation.

The `.layout` qualifier indicates whether the matrix to be loaded is stored in *row-major* or *column-major* format.

`stride` is an optional 32-bit integer operand that provides an offset in terms of matrix elements between the start of consecutive instances of the *leading dimension* (rows or columns). The default value of `stride` is described in *Matrix Storage for WMMA* and must be specified if the actual value is larger than the default. For example, if the matrix is a sub-matrix of a larger matrix, then the value of stride is the leading dimension of the larger matrix. Specifying a value lower than the default value results in undefined behavior.

The required alignment for address `p` and `stride` is described in the *Matrix Storage for WMMA*.

The mandatory `.sync` qualifier indicates that `wmma.load` causes the executing thread to wait until all threads in the warp execute the same `wmma.load` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `wmma.load` instruction. In conditionally executed code, a `wmma.load` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of `wmma.load` is undefined if all threads do not use the same qualifiers and the same values of `p` and `stride`, or if any thread in the warp has exited.

`wmma.load` is treated as a *weak* memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

`.m8n32k16` and `.m32n8k16` introduced in PTX ISA version 6.1.

Integer, sub-byte integer and single-bit `wmma` introduced in PTX ISA version 6.3.

`.m8n8k4` and `.m16n16k8` on `wmma` introduced in PTX ISA version 7.0.

Double precision and alternate floating point precision `wmma` introduced in PTX ISA version 7.0.

Modifier `.aligned` is required from PTX ISA version 6.3 onwards, and considered implicit in PTX ISA versions less than 6.3.

Support for `::cta` sub-qualifier introduced in PTX ISA version 7.8.

Preview Feature:

Sub-byte `wmma` and single-bit `wmma` are preview features in PTX ISA version 6.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

Floating point `wmma` requires `sm_70` or higher.

Integer `wmma` requires `sm_72` or higher.

Sub-byte and single-bit `wmma` requires `sm_75` or higher.

Double precision and alternate floating point precision `wmma` requires `sm_80` or higher.

Examples

```
// Load elements from f16 row-major matrix B
.reg .b32 x<8>;

wmma.load.b.sync.aligned.m16n16k16.row.f16 {x0,x1,x2,x3,x4,x5,x,x7}, [ptr];
// Now use {x0, ..., x7} for the actual wmma.mma

// Load elements from f32 column-major matrix C and scale the values:
.reg .b32 x<8>;

wmma.load.c.sync.aligned.m16n16k16.col.f32
                 {x0,x1,x2,x3,x4,x5,x6,x7}, [ptr];

mul.f32 x0, x0, 0.1;
// repeat for all registers x<8>;
...
mul.f32 x7, x7, 0.1;
// Now use {x0, ..., x7} for the actual wmma.mma

// Load elements from integer matrix A:
.reg .b32 x<4>
// destination registers x<4> contain four packed .u8 values each
wmma.load.a.sync.aligned.m32n8k16.row.u8 {x0,x1,x2,x3}, [ptr];

// Load elements from sub-byte integer matrix A:
```

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```
.reg .b32 x0;
// destination register x0 contains eight packed .s4 values
wmma.load.a.sync.aligned.m8n8k32.row.s4 {x0}, [ptr];

// Load elements from .bf16 matrix A:
.reg .b32 x<4>;
wmma.load.a.sync.aligned.m16n16k16.row.bf16
                {x0,x1,x2,x3}, [ptr];

// Load elements from .tf32 matrix A:
.reg .b32 x<4>;
wmma.load.a.sync.aligned.m16n16k8.row.tf32
                {x0,x1,x2,x3}, [ptr];

// Load elements from .f64 matrix A:
.reg .b32 x<4>;
wmma.load.a.sync.aligned.m8n8k4.row.f64
                {x0}, [ptr];
```

9.7.14.4.4 Warp-level Matrix Store Instruction: `wmma.store`

`wmma.store`

Collectively store a matrix into memory for WMMA

Syntax

```
wmma.store.d.sync.aligned.layout.shape{.ss}.type [p], r {, stride};

.layout = {.row, .col};
.shape  = {.m16n16k16, .m8n32k16, .m32n8k16};
.ss     = {.global, .shared{::cta}};
.type   = {.f16, .f32, .s32};

wmma.store.d.sync.aligned.layout.shape{.ss}.type [p], r {, stride}
.layout = {.row, .col};
.shape  = {.m8n8k32, .m8n8k128};
.ss     = {.global, .shared{::cta}};
.type   = {.s32};

wmma.store.d.sync.aligned.layout.shape{.ss}.type [p], r {, stride}
.layout = {.row, .col};
.shape  = {.m16n16k8};
.ss     = {.global, .shared{::cta}};
.type   = {.f32};

wmma.store.d.sync.aligned.layout.shape{.ss}.type [p], r {, stride}
.layout = {.row, .col};
.shape  = {.m8n8k4 };
.ss     = {.global, .shared{::cta}};
.type   = {.f64};
```

Description

Collectively store a matrix across all threads in a warp at the location indicated by address operand p in the specified state space from source register r.

If no state space is given, perform the memory accesses using *Generic Addressing*. wmma.load operation may be used only with .global and .shared spaces and with generic addressing, where the address points to .global or .shared space.

The source operand r is a brace-enclosed vector expression that matches the shape of the fragment expected by the store operation, as described in *Matrix Fragments for WMMA*.

The .shape qualifier indicates the dimensions of all the matrix arguments involved in the intended wmma computation. It must match the .shape qualifier specified on the wmma.mma instruction that produced the D matrix being stored.

The .layout qualifier indicates whether the matrix to be loaded is stored in *row-major* or *column-major* format.

stride is an optional 32-bit integer operand that provides an offset in terms of matrix elements between the start of consecutive instances of the *leading dimension* (rows or columns). The default value of stride is described in *Matrix Storage for WMMA* and must be specified if the actual value is larger than the default. For example, if the matrix is a sub-matrix of a larger matrix, then the value of stride is the leading dimension of the larger matrix. Specifying a value lower than the default value results in undefined behavior.

The required alignment for address p and stride is described in the *Matrix Storage for WMMA*.

The mandatory .sync qualifier indicates that wmma.store causes the executing thread to wait until all threads in the warp execute the same wmma.store instruction before resuming execution.

The mandatory .aligned qualifier indicates that all threads in the warp must execute the same wmma.store instruction. In conditionally executed code, a wmma.store instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of wmma.store is undefined if all threads do not use the same qualifiers and the same values of p and stride, or if any thread in the warp has exited.

wmma.store is treated as a *weak* memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

.m8n32k16 and .m32n8k16 introduced in PTX ISA version 6.1.

Integer, sub-byte integer and single-bit wmma introduced in PTX ISA version 6.3.

.m16n16k8 introduced in PTX ISA version 7.0.

Double precision wmma introduced in PTX ISA version 7.0.

Modifier .aligned is required from PTX ISA version 6.3 onwards, and considered implicit in PTX ISA versions less than 6.3.

Support for ::cta sub-qualifier introduced in PTX ISA version 7.8.

Preview Feature:

Sub-byte wmma and single-bit wmma are preview features in PTX ISA version 6.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

Floating point `wmma` requires `sm_70` or higher.

Integer `wmma` requires `sm_72` or higher.

Sub-byte and single-bit `wmma` requires `sm_75` or higher.

Double precision `wmma` and shape `.m16n16k8` requires `sm_80` or higher.

Examples

```
// Storing f32 elements computed by a wmma.mma
.reg .b32 x<8>;

wmma.mma.sync.m16n16k16.row.col.f32.f32
              {d0, d1, d2, d3, d4, d5, d6, d7}, ...;
wmma.store.d.sync.m16n16k16.row.f32
              [ptr], {d0, d1, d2, d3, d4, d5, d6, d7};

// Store s32 accumulator for m16n16k16 shape:
.reg .b32 d<8>;
wmma.store.d.sync.aligned.m16n16k16.row.s32
              [ptr], {d0, d1, d2, d3, d4, d5, d6, d7};

// Store s32 accumulator for m8n8k128 shape:
.reg .b32 d<2>
wmma.store.d.sync.aligned.m8n8k128.row.s32
[ptr], {d0, d1};

// Store f64 accumulator for m8n8k4 shape:
.reg .f64 d<2>;
wmma.store.d.sync.aligned.m8n8k4.row.f64
              [ptr], {d0, d1};
```

9.7.14.4.5 Warp-level Matrix Multiply-and-Accumulate Instruction: `wmma.mma`

`wmma.mma`

Perform a single matrix multiply-and-accumulate operation across a warp

Syntax

```
// Floating point (.f16 multiplicands) wmma.mma
wmma.mma.sync.aligned.alayout.blayout.shape.dtype.ctype d, a, b, c;

// Integer (.u8/.s8 multiplicands) wmma.mma
wmma.mma.sync.aligned.alayout.blayout.shape.s32.atype.btype.s32{.satfinite} d, a, b,
↪c;

.alayout = {.row, .col};
.blayout = {.row, .col};
.shape  =  {.m16n16k16, .m8n32k16, .m32n8k16};
```

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```
.dtype   = {.f16, .f32};
.atype   = {.s8, .u8};
.btype   = {.s8, .u8};
.ctype   = {.f16, .f32};
```

Floating point format `.bf16` `wmma.mma`:

```
wmma.mma.sync.aligned.alayout.blayout.shape.f32.atype.btype.f32 d, a, b, c;
.alayout = {.row, .col};
.blayout = {.row, .col};
.shape   = {.m16n16k16, .m8n32k16, .m32n8k16};
.atype   = {.bf16 };
.btype   = {.bf16};
```

Floating point format `.tf32` `wmma.mma`:

```
wmma.mma.sync.aligned.alayout.blayout.shape.f32.atype.btype.f32 d, a, b, c;
.alayout = {.row, .col};
.blayout = {.row, .col};
.shape   = {.m16n16k8 };
.atype   = {.tf32 };
.btype   = {.tf32};
```

Floating point Double precision `wmma.mma`:

```
wmma.mma.sync.aligned.alayout.blayout.shape{.rnd}.f64.f64.f64.f64 d, a, b, c;
.alayout = {.row, .col};
.blayout = {.row, .col};
.shape   = {.m8n8k4 };
.rnd = { .rn, .rz, .rm, .rp };
```

Sub-byte (`.u4`/`.s4` multiplicands) `wmma.mma`:

```
wmma.mma.sync.aligned.row.col.shape.s32.atype.btype.s32{.satfinite} d, a, b, c;
.shape  = {.m8n8k32};
.atype  = {.s4, .u4};
.btype  = {.s4, .u4};
```

Single-bit (`.b1` multiplicands) `wmma.mma`:

```
wmma.mma.op.popc.sync.aligned.row.col.shape.s32.atype.btype.s32 d, a, b, c;
.shape  = {.m8n8k128};
.atype  = {.b1};
.btype  = {.b1};
.op     = {.xor, .and}
```

Description

Perform a warp-level matrix multiply-and-accumulate computation `D = A * B + C` using matrices A, B and C loaded in registers `a`, `b` and `c` respectively, and store the result matrix in register `d`. The register arguments `a`, `b`, `c` and `d` hold unspecified fragments of the corresponding matrices as described in *Matrix Fragments for WMMA*

The qualifiers `.dtype`, `.atype`, `.btype` and `.ctype` indicate the data-type of the elements in the matrices D, A, B and C respectively.

For `wmma.mma` without explicit `.atype` and `.btype`: `.atype` and `.btype` are implicitly set to `.f16`.

For integer `wmma`, `.ctype` and `.dtype` must be specified as `.s32`. Also, the values for `.atype` and `.btype` must be the same, i.e., either both are `.s8` or both are `.u8`.

For sub-byte single-bit `wmma`, `.ctype` and `.dtype` must be specified as `.s32`. Also, the values for `.atype` and `.btype` must be the same; i.e., either both are `.s4`, both are `.u4`, or both are `.b1`.

For single-bit `wmma`, multiplication is replaced by a sequence of logical operations; specifically, `wmma.xor.popc` and `wmma.and.popc` computes the XOR, AND respectively of a 128-bit row of A with a 128-bit column of B, then counts the number of set bits in the result (`popc`). This result is added to the corresponding element of C and written into D.

The qualifiers `.alayout` and `.blayout` must match the layout specified on the `wmma.load` instructions that produce the contents of operands `a` and `b` respectively. Similarly, the qualifiers `.atype`, `.btype` and `.ctype` must match the corresponding qualifiers on the `wmma.load` instructions that produce the contents of operands `a`, `b` and `c` respectively.

The `.shape` qualifier must match the `.shape` qualifier used on the `wmma.load` instructions that produce the contents of all three input operands `a`, `b` and `c` respectively.

The destination operand `d` is a brace-enclosed vector expression that matches the `.shape` of the fragment computed by the `wmma.mma` instruction.

Saturation at the output:
The optional qualifier `.satfinite` indicates that the final values in the destination register are saturated as follows:

- The output is clamped to the minimum or maximum 32-bit signed integer value. Otherwise, if the accumulation would overflow, the value wraps.

Precision and rounding for `.f16` floating point operations:
Element-wise multiplication of matrix A and B is performed with at least single precision. When `.ctype` or `.dtype` is `.f32`, accumulation of the intermediate values is performed with at least single precision. When both `.ctype` and `.dtype` are specified as `.f16`, the accumulation is performed with at least half precision.

The accumulation order, rounding and handling of subnormal inputs is unspecified.

Precision and rounding for `.bf16`, `.tf32` floating point operations:
Element-wise multiplication of matrix A and B is performed with specified precision. Accumulation of the intermediate values is performed with at least single precision.

The accumulation order, rounding and handling of subnormal inputs is unspecified.

Rounding modifiers on double precision `wmma.mma` (default is `.rn`):

`.rn` mantissa LSB rounds to nearest even

`.rz` mantissa LSB rounds towards zero

`.rm` mantissa LSB rounds towards negative infinity

.rp mantissa LSB rounds towards positive infinity

The mandatory .sync qualifier indicates that wmma.mma causes the executing thread to wait until all threads in the warp execute the same wmma.mma instruction before resuming execution.

The mandatory .aligned qualifier indicates that all threads in the warp must execute the same wmma.mma instruction. In conditionally executed code, a wmma.mma instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of wmma.mma is undefined if all threads in the same warp do not use the same qualifiers, or if any thread in the warp has exited.

PTX ISA Notes

Introduced in PTX ISA version 6.0.

.m8n32k16 and .m32n8k16 introduced in PTX ISA version 6.1.

Integer, sub-byte integer and single-bit wmma introduced in PTX ISA version 6.3.

Double precision and alternate floating point precision wmma introduced in PTX ISA version 7.0.

Support for .and operation in single-bit wmma introduced in PTX ISA version 7.1.

Modifier .aligned is required from PTX ISA version 6.3 onwards, and considered implicit in PTX ISA versions less than 6.3.

Support for .satfinite on floating point wmma.mma is deprecated in PTX ISA version 6.4 and is removed from PTX ISA version 6.5.

Preview Feature:

Sub-byte wmma and single-bit wmma are preview features in PTX ISA. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

Floating point wmma requires sm_70 or higher.

Integer wmma requires sm_72 or higher.

Sub-byte and single-bit wmma requires sm_75 or higher.

Double precision, alternate floating point precision wmma require sm_80 or higher.

.and operation in single-bit wmma requires sm_80 or higher.

Examples

```
.global .align 32 .f16 A[256], B[256];
.global .align 32 .f32 C[256], D[256];
.reg .b32 a<8> b<8> c<8> d<8>;

wmma.load.a.sync.aligned.m16n16k16.global.row.f16
        {a0, a1, a2, a3, a4, a5, a6, a7}, [A];
wmma.load.b.sync.aligned.m16n16k16.global.col.f16
        {b0, b1, b2, b3, b4, b5, b6, b7}, [B];
```

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```
wmma.load.c.sync.aligned.m16n16k16.global.row.f32
        {c0, c1, c2, c3, c4, c5, c6, c7}, [C];

wmma.mma.sync.aligned.m16n16k16.row.col.f32.f32
        {d0, d1, d2, d3, d4, d5, d6, d7},
        {a0, a1, a2, a3, a4, a5, a6, a7},
        {b0, b1, b2, b3, b4, b5, b6, b7},
        {c0, c1, c2, c3, c4, c5, c6, c7};

wmma.store.d.sync.aligned.m16n16k16.global.col.f32
        [D], {d0, d1, d2, d3, d4, d5, d6, d7};

// Compute an integer WMMA:
.reg .b32  a, b<4>;
.reg .b32 c<8>, d<8>;
wmma.mma.sync.aligned.m8n32k16.row.col.s32.s8.s8.s32
        {d0, d1, d2, d3, d4, d5, d6, d7},
        {a}, {b0, b1, b2,  b3},
        {c0, c1, c2, c3, c4, c5, c6, c7};

// Compute sub-byte WMMA:
.reg .b32 a, b, c<2> d<2>
wmma.mma.sync.aligned.m8n8k32.row.col.s32.s4.s4.s32
        {d0, d1}, {a}, {b}, {c0, c1};

// Compute single-bit type WMMA:
.reg .b32 a, b, c<2> d<2>
wmma.mma.xor.popc.sync.aligned.m8n8k128.row.col.s32.b1.b1.s32
        {d0, d1}, {a}, {b}, {c0, c1};

// Compute double precision wmma
.reg .f64 a, b, c<2>, d<2>;
wmma.mma.sync.aligned.m8n8k4.row.col.f64.f64.f64.f64
        {d0, d1}, {a}, {b}, {c0, c1};

// Compute alternate floating point precision wmma
.reg .b32 a<2>, b<2>, c<8>, d<8>;
wmma.mma.sync.aligned.m16n16k8.row.col.f32.tf32.tf32.f32
        {d0, d1, d2, d3, d4, d5, d6, d7},
        {a0, a1, a2, a3}, {b0, b1, b2, b3},
        {c0, c1, c2, c3, c4, c5, c6, c7};
```

9.7.14.5 Matrix multiply-accumulate operation using `mma` instruction

This section describes warp-level `mma`, `ldmatrix`, `stmatrix`, and `movmatrix` instructions and the organization of various matrices involved in these instructions.

9.7.14.5.1 Matrix Fragments for `mma.m8n8k4` with `.f16` floating point type

A warp executing `mma.m8n8k4` with `.f16` floating point type will compute 4 MMA operations of shape `.m8n8k4`.

Elements of 4 matrices need to be distributed across the threads in a warp. The following table shows distribution of matrices for MMA operations.

MMA Computation	Threads participating in MMA computation
MMA computation 1	Threads with `%laneid` 0-3 (low group) and 16-19 (high group)
MMA computation 2	Threads with `%laneid` 4-7 (low group) and 20-23 (high group)
MMA computation 3	Threads with `%laneid` 8-11 (low group) and 24-27 (high group)
MMA computation 4	Threads with `%laneid` 12-15 (low group) and 28-31 (high group)

For each of the individual MMA computation shown above, each of the required thread holds a fragment of the matrix for performing mma operation as follows:

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.f16`	A vector expression containing two `.f16x2` registers, with each register containing two `.f16` elements from the matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown below:

- Fragment layout for Row Major matrix A is shown in Figure 46.

  The row and column of a matrix fragment can be computed as:

```
row =              %laneid % 4          if %laneid < 16
                  (%laneid % 4) + 4     otherwise

col =              i                    for ai where i = {0,..,3}
```

- Fragment layout for Column Major matrix A is shown in Figure 47.

  The layout of the fragments held by different threads is shown below:

  The row and column of a matrix fragment can be computed as:

```
row =         i % 4             for ai  where i = {0,..,3}   if %laneid < 16
             (i % 4) + 4        for ai  where i = {0,..,3}   otherwise

col =         %laneid % 4
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
`.f16`	A vector expression containing two `.f16x2` registers, with each register containing two `.f16` elements from the matrix B.	b0, b1, b2, b3

MMA computation 1

Row\Col	0	1	2	3
0	T0 : { a0, a1, a2, a3 }			
..	↓			
3	T3: { a0, a1, a2, a3 }			
4	T16: { a0, a1, a2, a3 }			
..	↓			
7	T19: { a0, a1, a2, a3 }			

MMA computation 3

Row\Col	0	1	2	3
0	T8 : { a0, a1, a2, a3}			
..	↓			
3	T11: { a0, a1, a2, a3 }			
4	T24: { a0, a1, a2, a3 }			
..	↓			
7	T27: { a0, a1, a2, a3 }			

MMA computation 2

Row\Col	0	1	2	3
0	T4 : { a0, a1, a2, a3}			
..	↓			
3	T7: { a0, a1, a2, a3 }			
4	T20: { a0, a1, a2, a3 }			
..	↓			
7	T23: { a0, a1, a2, a3 }			

MMA computation 4

Row\Col	0	1	2	3
0	T12 : { a0, a1, a2, a3}			
..	↓			
3	T15: { a0, a1, a2, a3 }			
4	T28: { a0, a1, a2, a3 }			
..	↓			
7	T31: { a0, a1, a2, a3 }			

%laneid:{fragments}

Figure 46: MMA .m8n8k4 fragment layout for row-major matrix A with `.f16` type

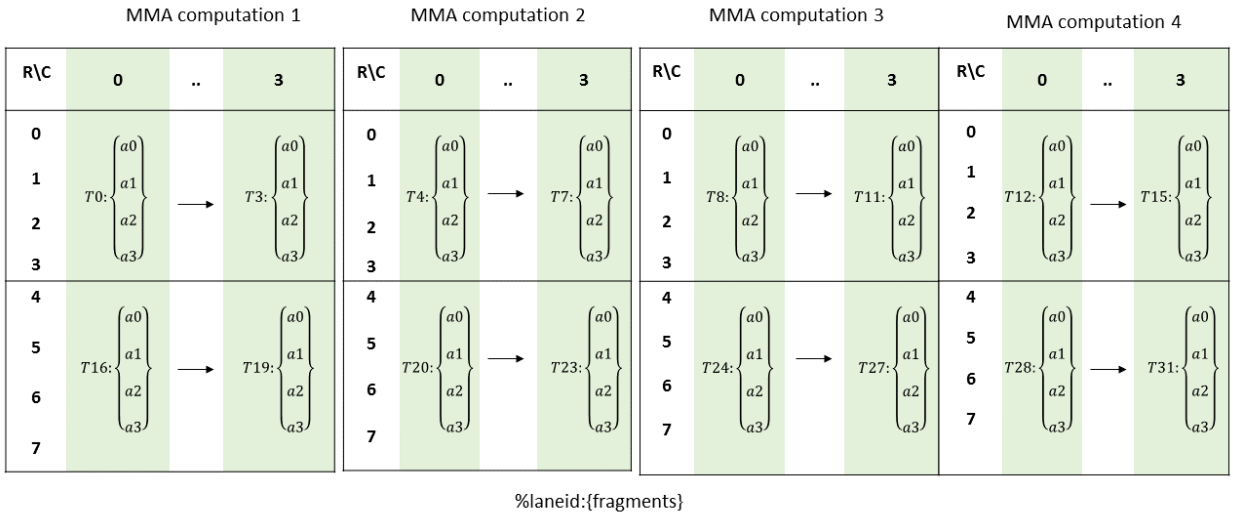

Figure 47: MMA .m8n8k4 fragment layout for column-major matrix A with `.f16` type

The layout of the fragments held by different threads is shown below:

- Fragment layout for Row Major matrix B is shown in Figure 48.

MMA computation 1

Row\Col	0	1	2	3	4	5	6	7
0	T0 : { b0, b1, b2, b3 }				T16 : { b0, b1, b2, b3 }			
..	↓				↓			
3	T3: { b0, b1, b2, b3 }				T19 : { b0, b1, b2, b3 }			

MMA computation 3

Row\Col	0	1	2	3	4	5	6	7
0	T8 : { b0, b1, b2, b3 }				T24 : { b0, b1, b2, b3 }			
..	↓				↓			
3	T11: { b0, b1, b2, b3 }				T27 : { b0, b1, b2, b3 }			

MMA computation 2

Row\Col	0	1	2	3	4	5	6	7
0	T4 : { b0, b1, b2, b3 }				T20: { b0, b1, b2, b3 }			
..	↓				↓			
3	T7: { b0, b1, b2, b3 }				T23: { b0, b1, b2, b3 }			

MMA computation 4

Row\Col	0	1	2	3	4	5	6	7
0	T12 : { b0, b1, b2, b3 }				T28 : { b0, b1, b2, b3 }			
..	↓				↓			
3	T15: { b0, b1, b2, b3 }				T31 : { b0, b1, b2, b3 }			

Figure 48: MMA .m8n8k4 fragment layout for row-major matrix B with `.f16` type

The row and column of a matrix fragment can be computed as:

```
row =         %laneid % 4

col =          i       for bi   where i = {0,..,3}   if %laneid < 16
              i+4      for bi   where i = {0,..,3}   otherwise
```

- Fragment layout for Column Major matrix B is shown in Figure 49.

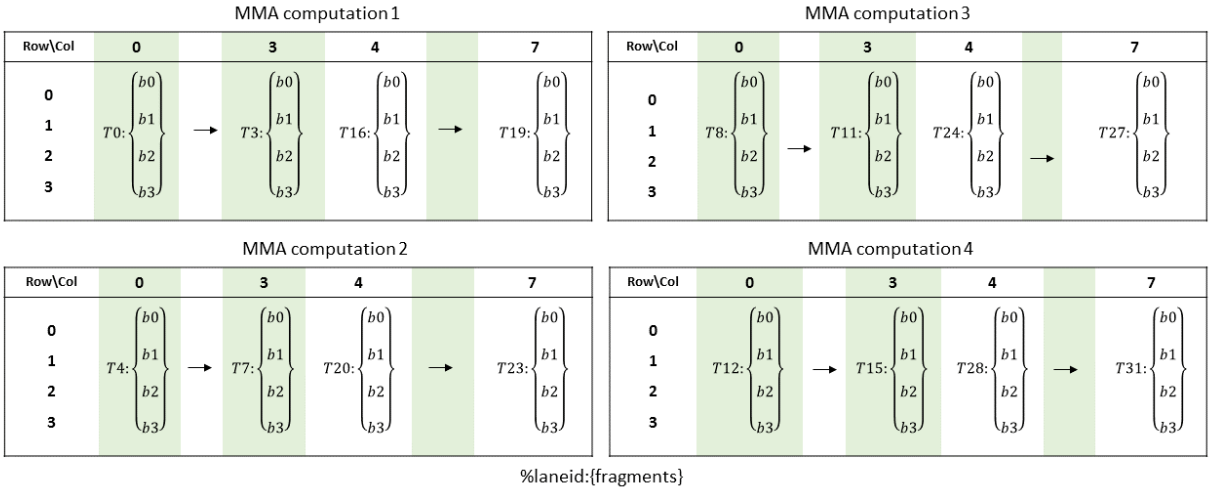

Figure 49: MMA .m8n8k4 fragment layout for column-major matrix B with `.f16` type

The row and column of a matrix fragment can be computed as:

```
row =          i                  for bi   where i = {0,..,3}

col =       %laneid % 4           if %laneid < 16
           (%laneid % 4) + 4      otherwise
```

- Accumulators C (or D):

.ctype / .dtype	Fragment	Elements (low to high)
.f16	A vector expression containing four .f16x2 registers, with each register containing two .f16 elements from the matrix C (or D).	c0, c1, c2, c3, c4, c5, c6, c7
.f32	A vector expression of eight .f32 registers.	

The layout of the fragments held by different threads is shown below:

- Fragment layout for accumulator matrix when .ctype is .f16 is shown in Figure 50.

MMA computation 1

Row\ Col	0	1	2	3	4	5	6	7
0	T0 : { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
3	T3: { c0, c1, c2, c3, c4, c5, c6, c7 }							
4	T16: { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
7	T19: { c0, c1, c2, c3, c4, c5, c6, c7 }							

MMA computation 3

Row\Col	0	1	2	3	4	5	6	7
0	T8 : { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
3	T11: { c0, c1, c2, c3, c4, c5, c6, c7 }							
4	T24: { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
7	T27: { c0, c1, c2, c3, c4, c5, c6, c7 }							

MMA computation 2

Row\Col	0	1	2	3	4	5	6	7
0	T4 : { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
3	T7: { c0, c1, c2, c3, c4, c5, c6, c7 }							
4	T20: { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
7	T23: { c0, c1, c2, c3, c4, c5, c6, c7 }							

MMA computation 4

Row\Col	0	1	2	3	4	5	6	7
0	T12 : { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
3	T15: { c0, c1, c2, c3, c4, c5, c6, c7 }							
4	T28: { c0, c1, c2, c3, c4, c5, c6, c7 }							
..								
7	T31: { c0, c1, c2, c3, c4, c5, c6, c7 }							

Figure 50: MMA .m8n8k4 fragment layout for matrix C/D with .ctype = .f16

The row and column of a matrix fragment can be computed as:

```
row =       %laneid % 4          if %laneid < 16
          (%laneid % 4) + 4      otherwise

col =          i                 for ci   where i = {0,..,7}
```

- Fragment layout for accumulator matrix when .ctype is .f32 is shown in Figure 51 and Figure 52.

The row and column of a matrix fragment can be computed as:

```
row =     X            if %laneid < 16
        X + 4          otherwise

          where X = (%laneid & 0b1) + (i & 0b10)  for ci where i = {0,..,7}
```

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MMA computation 1

R\C	0	1	2	3	4	5	6	7
0	T0 : { c0, c1 }		T2 : { c0, c1 }		T0 : { c4, c5 }		T2 : { c4, c5 }	
1	T1 : { c0, c1 }		T3 : { c0 , c1 }		T1 : { c4, c5 }		T3 : { c4 , c5 }	
2	T0 : { c2, c3 }		T2 : { c2, c3 }		T0 : { c6, c7 }		T2 : { c6, c7 }	
3	T1 : { c2, c3 }		T3 : { c2 , c3 }		T1 : { c6, c7 }		T3 : { c6 , c7 }	
4	T16 : { c0, c1 }		T18 : { c0, c1 }		T16 : { c4, c5 }		T18 : { c4, c5 }	
5	T17 : { c0, c1 }		T19 : { c0 , c1 }		T17 : { c4, c5 }		T19 : { c4 , c5 }	
6	T16 : { c2, c3 }		T18 : { c2, c3 }		T16 : { c6, c7 }		T18 : { c6, c7 }	
7	T17 : { c2, c3 }		T19 : { c2 , c3 }		T17 : { c6, c7 }		T19 : { c6 , c7 }	

MMA computation 2

R\C	0	1	2	3	4	5	6	7
0	T4 : { c0, c1 }		T6 : { c0, c1 }		T4 : { c4, c5 }		T6 : { c4, c5 }	
1	T5 : { c0, c1 }		T7 : { c0 , c1 }		T5 : { c4, c5 }		T7 : { c4 , c5 }	
2	T4 : { c2, c3 }		T6 : { c2, c3 }		T4 : { c6, c7 }		T6 : { c6, c7 }	
3	T5 : { c2, c3 }		T7 : { c2 , c3 }		T5 : { c6, c7 }		T7 : { c6 , c7 }	
4	T20 : { c0, c1 }		T22 : { c0, c1 }		T20 : { c4, c5 }		T22 : { c4, c5 }	
5	T21 : { c0, c1 }		T23 : { c0 , c1 }		T21 : { c4, c5 }		T23 : { c4 , c5 }	
6	T20 : { c2, c3 }		T22 : { c2, c3 }		T20 : { c6, c7 }		T22 : { c6, c7 }	
7	T21 : { c2, c3 }		T23: { c2 , c3 }		T21 : { c6, c7 }		T23: { c6 , c7 }	

Figure 51: MMA .m8n8k4 computation 1 and 2 fragment layout for matrix C/D with `.ctype` = `.f32`

MMA computation 3

R\C	0	1	2	3	4	5	6	7
0	T8 : { c0, c1 }		T10 : { c0, c1 }		T8 : { c4, c5 }		T10 : { c4, c5 }	
1	T9 : { c0, c1 }		T11 : { c0 , c1 }		T9 : { c4, c5 }		T11 : { c4 , c5 }	
2	T8 : { c2, c3 }		T10 : { c2, c3 }		T8 : { c6, c7 }		T10 : { c6, c7 }	
3	T9 : { c2, c3 }		T11 : { c2 , c3 }		T9 : { c6, c7 }		T11 : { c6 , c7 }	
4	T24 : { c0, c1 }		T26: { c0, c1 }		T24 : { c4, c5 }		T26 : { c4, c5 }	
5	T25 : { c0, c1 }		T27 : { c0 , c1 }		T25 : { c4, c5 }		T27 : { c4 , c5 }	
6	T24 : { c2, c3 }		T26 : { c2, c3 }		T24 : { c6, c7 }		T26 : { c6, c7 }	
7	T25 : { c2, c3 }		T27 : { c2 , c3 }		T25 : { c6, c7 }		T27 : { c6 , c7 }	

MMA computation 4

R\C	0	1	2	3	4	5	6	7
0	T12 : { c0, c1 }		T14 : { c0, c1 }		T12 : { c4, c5 }		T14 : { c4, c5 }	
1	T13 : { c0, c1 }		T15 : { c0 , c1 }		T13 : { c4, c5 }		T15 : { c4 , c5 }	
2	T12 : { c2, c3 }		T14 : { c2, c3 }		T12 : { c6, c7 }		T14 : { c6, c7 }	
3	T13 : { c2, c3 }		T15 : { c2 , c3 }		T13 : { c6, c7 }		T15 : { c6 , c7 }	
4	T28 : { c0, c1 }		T30 : { c0, c1 }		T28 : { c4, c5 }		T30 : { c4, c5 }	
5	T29 : { c0, c1 }		T31 : { c0 , c1 }		T29 : { c4, c5 }		T31 : { c4 , c5 }	
6	T28 : { c2, c3 }		T30 : { c2, c3 }		T28 : { c6, c7 }		T30 : { c6, c7 }	
7	T29 : { c2, c3 }		T31: { c2 , c3 }		T29 : { c6, c7 }		T31: { c6 , c7 }	

Figure 52: MMA .m8n8k4 computation 3 and 4 fragment layout for matrix C/D with `.ctype` = `.f32`

(continued from previous page)

```
col = (i & 0b100) + (%laneid & 0b10) + (i & 0b1)  for ci where i = {0,..,7}
```

9.7.14.5.2 Matrix Fragments for `mma.m8n8k4` with `.f64` floating point type

A warp executing `mma.m8n8k4` with `.f64` floating point type will compute an MMA operation of shape `.m8n8k4`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.f64`	A vector expression containing a single `.f64` register, containing single `.f64` element from the matrix A.	a0

The layout of the fragments held by different threads is shown in Figure 53.

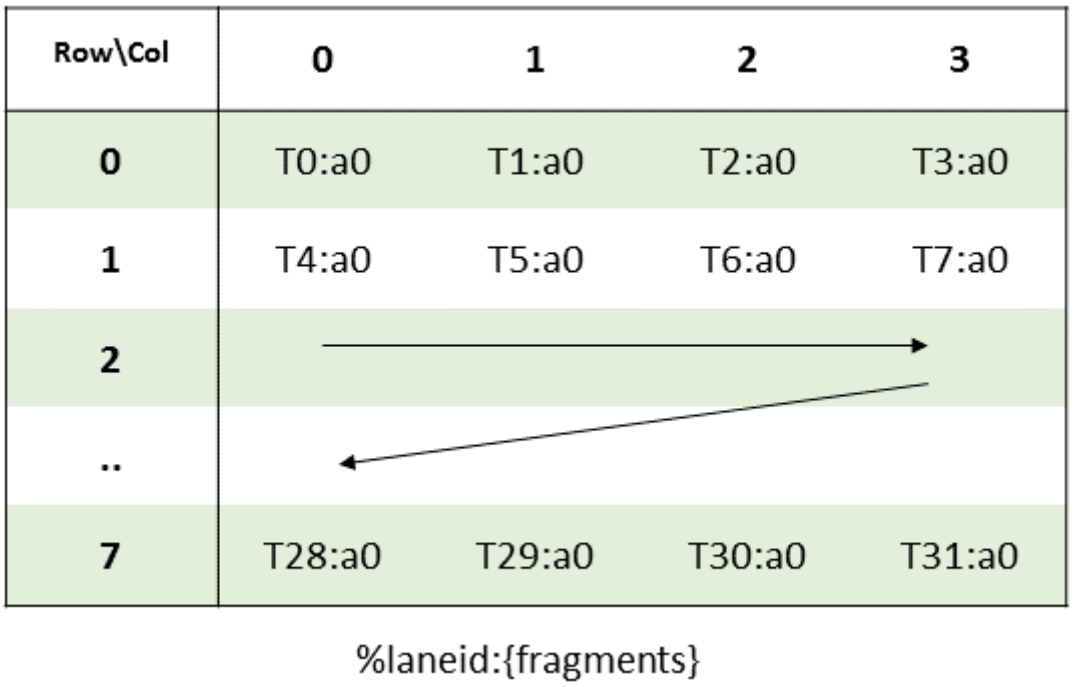

Figure 53: MMA .m8n8k4 fragment layout for matrix A with `.f64` type

The row and column of a matrix fragment can be computed as:

```
row =        %laneid >> 2

col =        %laneid % 4
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
.f64	A vector expression containing a single .f64 register, containing a single .f64 element from the matrix B.	b0

The layout of the fragments held by different threads is shown in Figure 54.

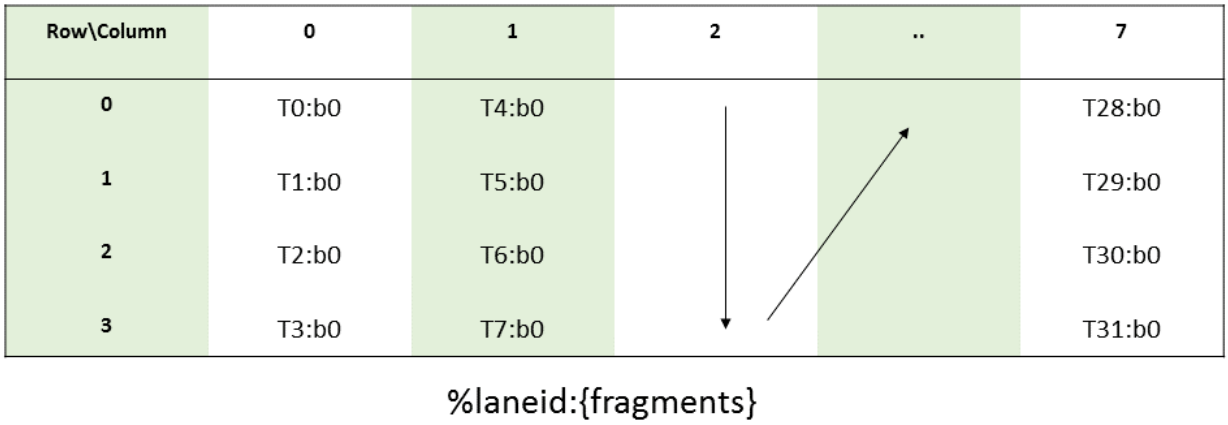

Figure 54: MMA .m8n8k4 fragment layout for matrix B with .f64 type

The row and column of a matrix fragment can be computed as:

```
row =        %laneid % 4

col =        %laneid >> 2
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.f64	A vector expression containing of two .f64 registers containing two .f64 elements from the matrix C.	c0, c1

The layout of the fragments held by different threads is shown in Figure 55.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID

col =      (threadID_in_group * 2) + (i & 0x1)       for ci   where i = {0, 1}
```

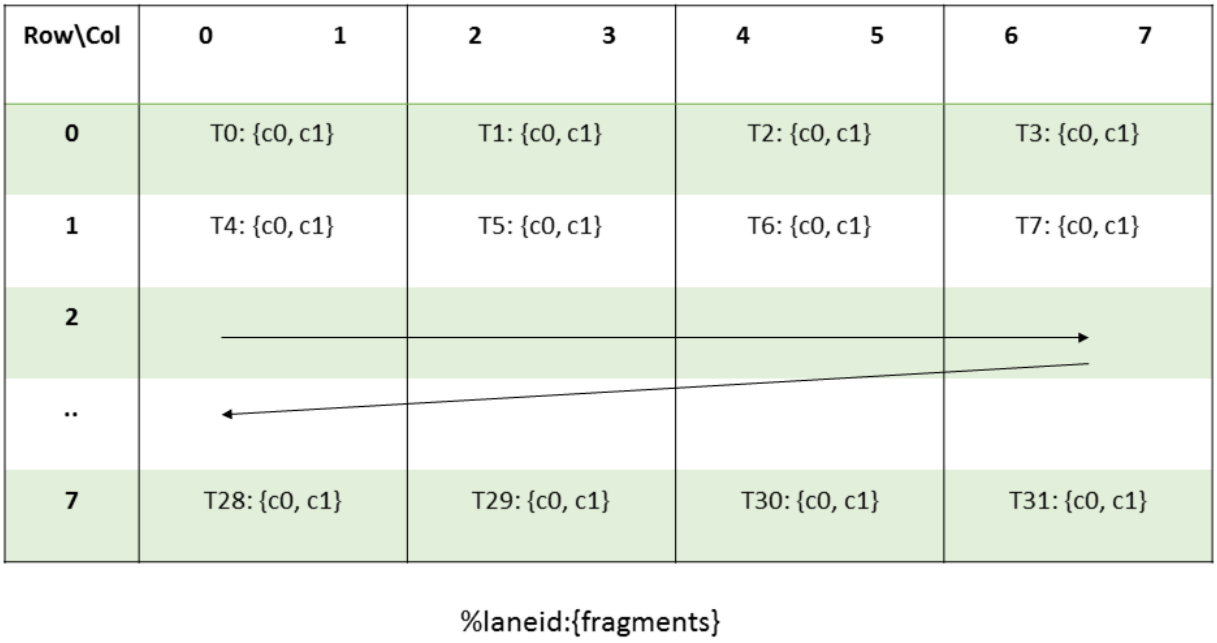

Figure 55: MMA .m8n8k4 fragment layout for accumulator matrix C/D with `.f64` type

9.7.14.5.3 Matrix Fragments for `mma.m8n8k16`

A warp executing `mma.m8n8k16` will compute an MMA operation of shape `.m8n8k16`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.s8` / `.u8`	A vector expression containing a single `.b32` register, containing four `.s8` or `.u8` elements from the matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown in Figure 56.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row = groupID

col =  (threadID_in_group * 4) + i       for ai    where i = {0,..,3}
```

- Multiplicand B:

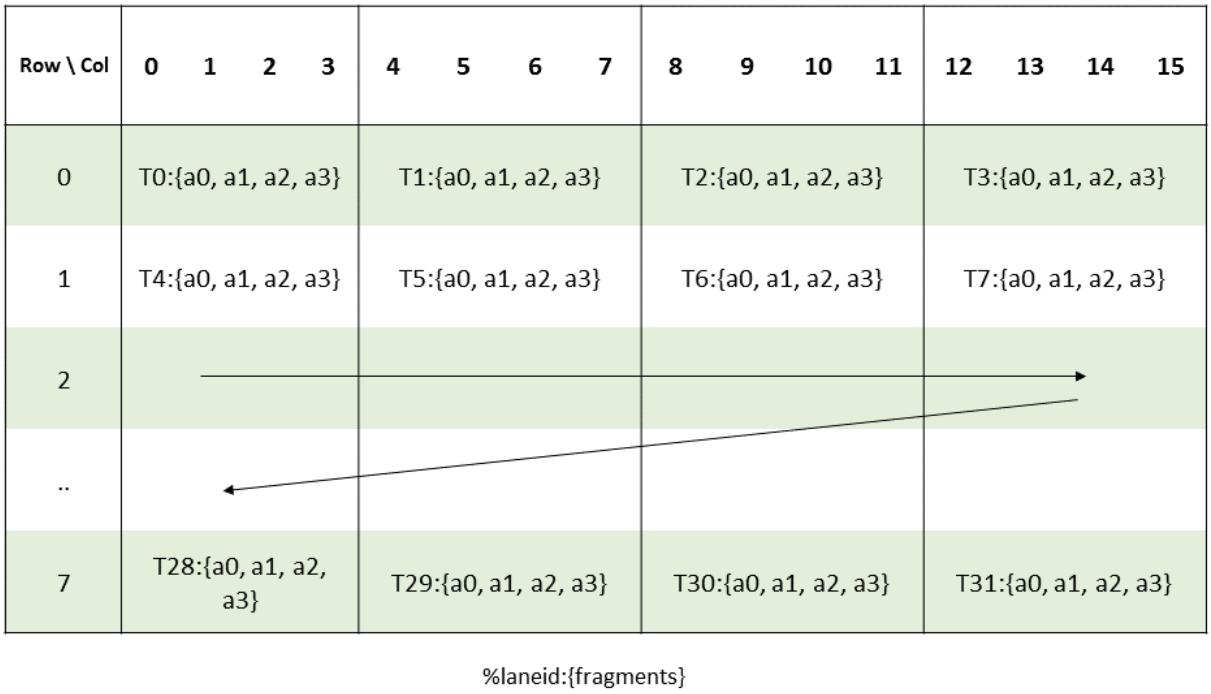

Figure 56: MMA .m8n8k16 fragment layout for matrix A with `.u8`/`.s8` type

.btype	Fragment	Elements (low to high)
`.s8` / `.u8`	A vector expression containing a single `.b32` register, containing four `.s8` or `.u8` elements from the matrix B.	b0, b1, b2, b3

The layout of the fragments held by different threads is shown in Figure 57.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  (threadID_in_group * 4) + i         for bi    where i = {0,..,3}

col =    groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
`.s32`	A vector expression containing of two `.s32` registers.	c0, c1

The layout of the fragments held by different threads is shown in Figure 58.

The row and column of a matrix fragment can be computed as:

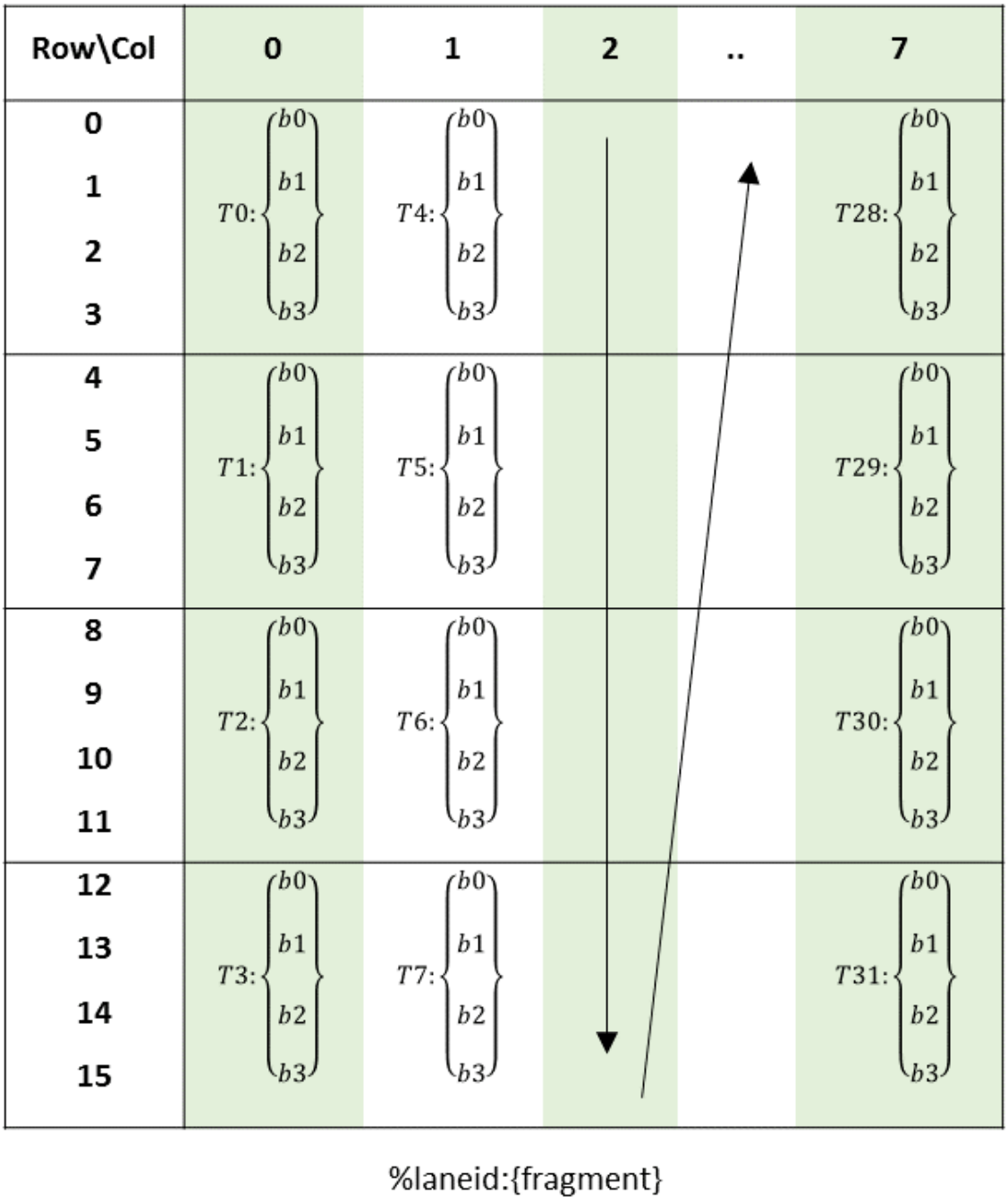

Figure 57: MMA .m8n8k16 fragment layout for matrix B with `.u8/.s8` type

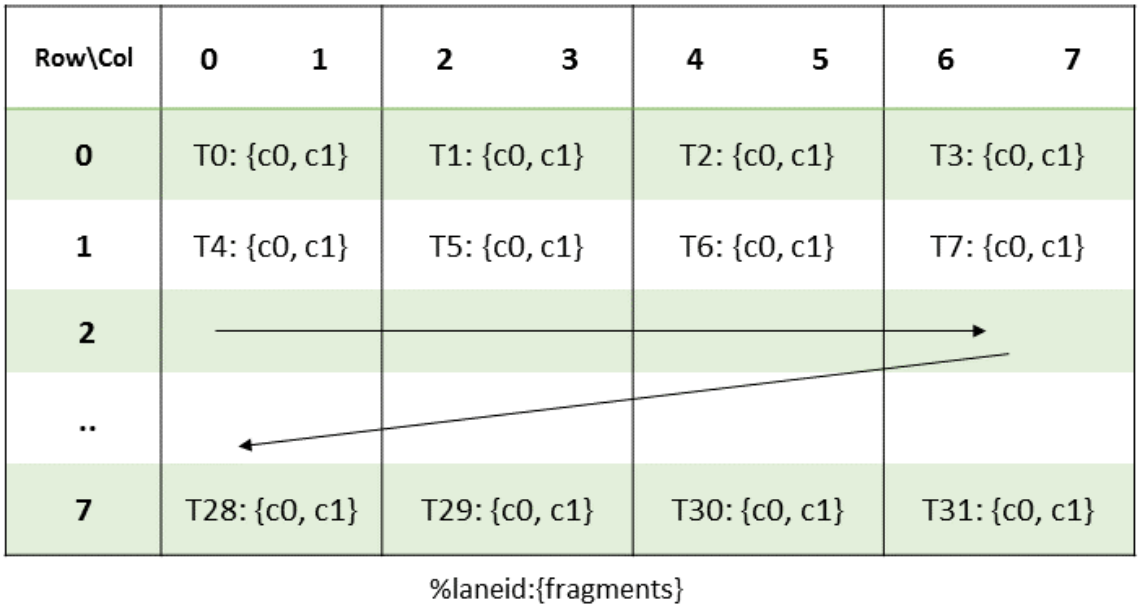

Figure 58: MMA .m8n8k16 fragment layout for accumulator matrix C/D with `.s32` type

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row = groupID

col = (threadID_in_group * 2) + i         for ci    where i = {0, 1}
```

9.7.14.5.4 Matrix Fragments for `mma.m8n8k32`

A warp executing `mma.m8n8k32` will compute an MMA operation of shape `.m8n8k32`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing a single `.b32` register, containing eight `.s4` or `.u4` elements from the matrix A.	a0, a1, a2, a3, a4, a5, a6, a7

The layout of the fragments held by different threads is shown in Figure 59.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID
```

(continues on next page)

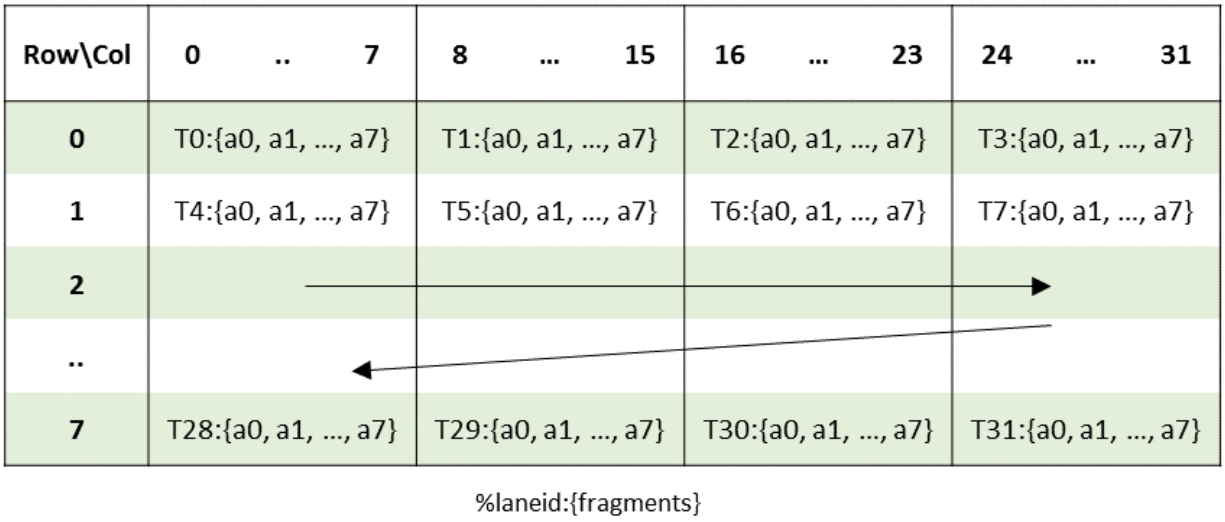

Figure 59: MMA .m8n8k32 fragment layout for matrix A with `.u4/.s4` type

(continued from previous page)

```
col = (threadID_in_group * 8) + i          for ai    where i = {0,..,7}
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing a single `.b32` register, containing eight `.s4` or `.u4` elements from the matrix B.	b0, b1, b2, b3, b4, b5, b6, b7

The layout of the fragments held by different threads is shown in Figure 60.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row = (threadID_in_group * 8) + i          for bi    where i = {0,..,7}

col = groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
`.s32`	A vector expression of two `.s32` registers.	c0, c1

The layout of the fragments held by different threads is shown in Figure 61:

The row and column of a matrix fragment can be computed as:

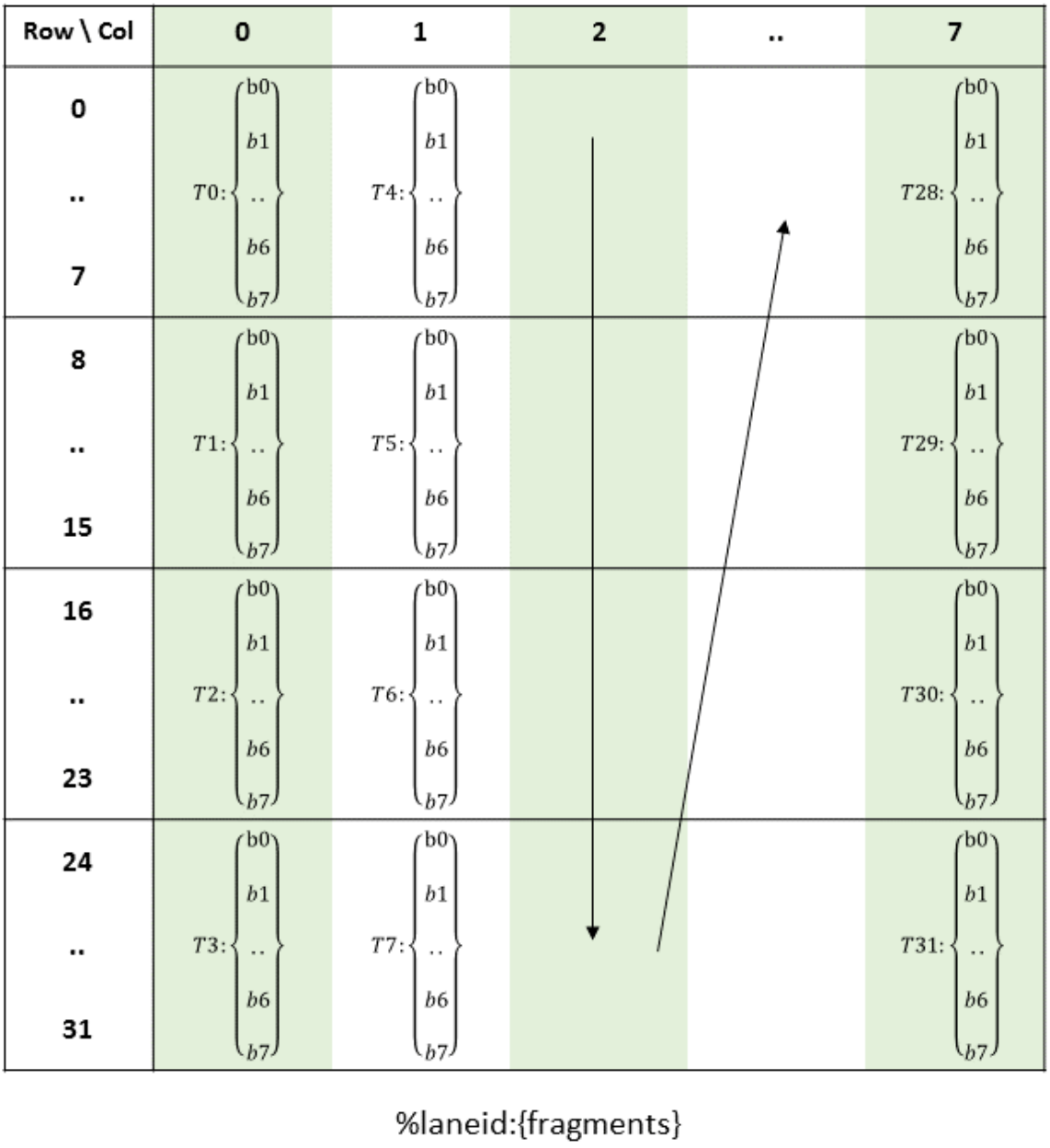

Figure 60: MMA .m8n8k32 fragment layout for matrix B with `.u4/.s4` type

Row\Col	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
..				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}

%laneid:{fragments}

Figure 61: MMA .m8n8k32 fragment layout for accumulator matrix C/D with .s32 type

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =   groupID
col = (threadID_in_group * 2) + i         for ci   where i = {0, 1}
```

9.7.14.5.5 Matrix Fragments for mma.m8n8k128

A warp executing mma.m8n8k128 will compute an MMA operation of shape .m8n8k128.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
.b1	A vector expression containing a single .b32 register, containing thirty two .b1 elements from the matrix A.	a0, a1, ... a30, a31

The layout of the fragments held by different threads is shown in Figure 62.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  groupID

col =  (threadID_in_group * 32) + i       for ai where i = {0,..,31}
```

- Multiplicand B:

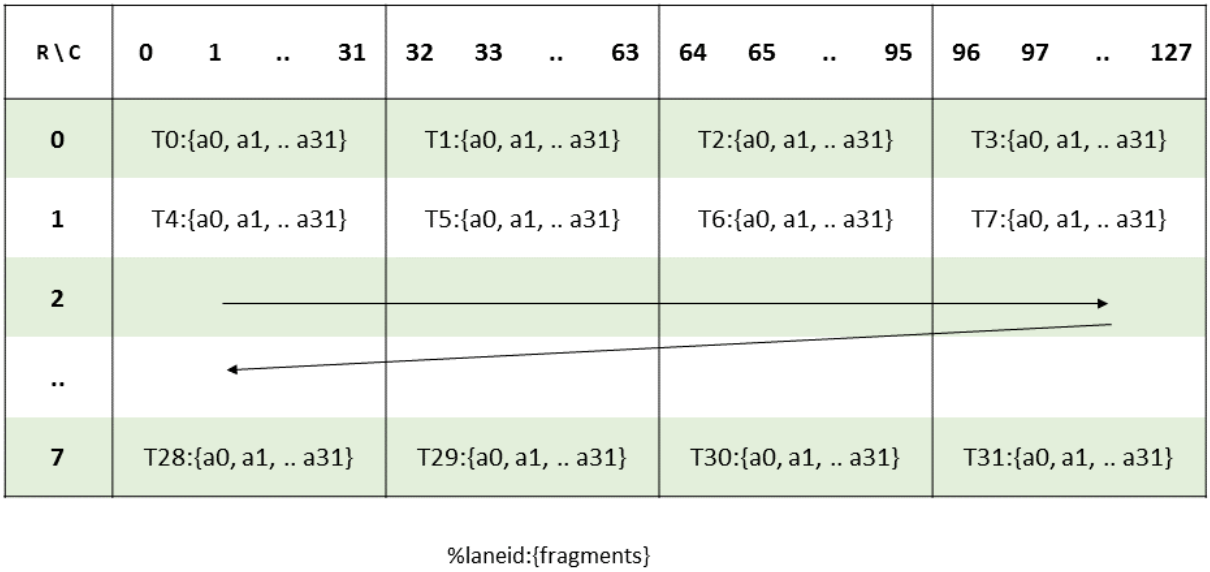

Figure 62: MMA .m8n8k128 fragment layout for matrix A with `.b1` type.

.btype	Fragment	Elements (low to high)
`.b1`	A vector expression containing a single `.b32` register, containing thirty two `.b1` elements from the matrix B.	b0, b1, ..., b30, b31

The layout of the fragments held by different threads is shown in Figure 63.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row = (threadID_in_group * 32) + i         for bi where i = {0,..,31}

col = groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
`.s32`	A vector expression containing two `.s32` registers, containing two `.s32` elements from the matrix C (or D).	c0, c1

The layout of the fragments held by different threads is shown in Figure 64.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4
```

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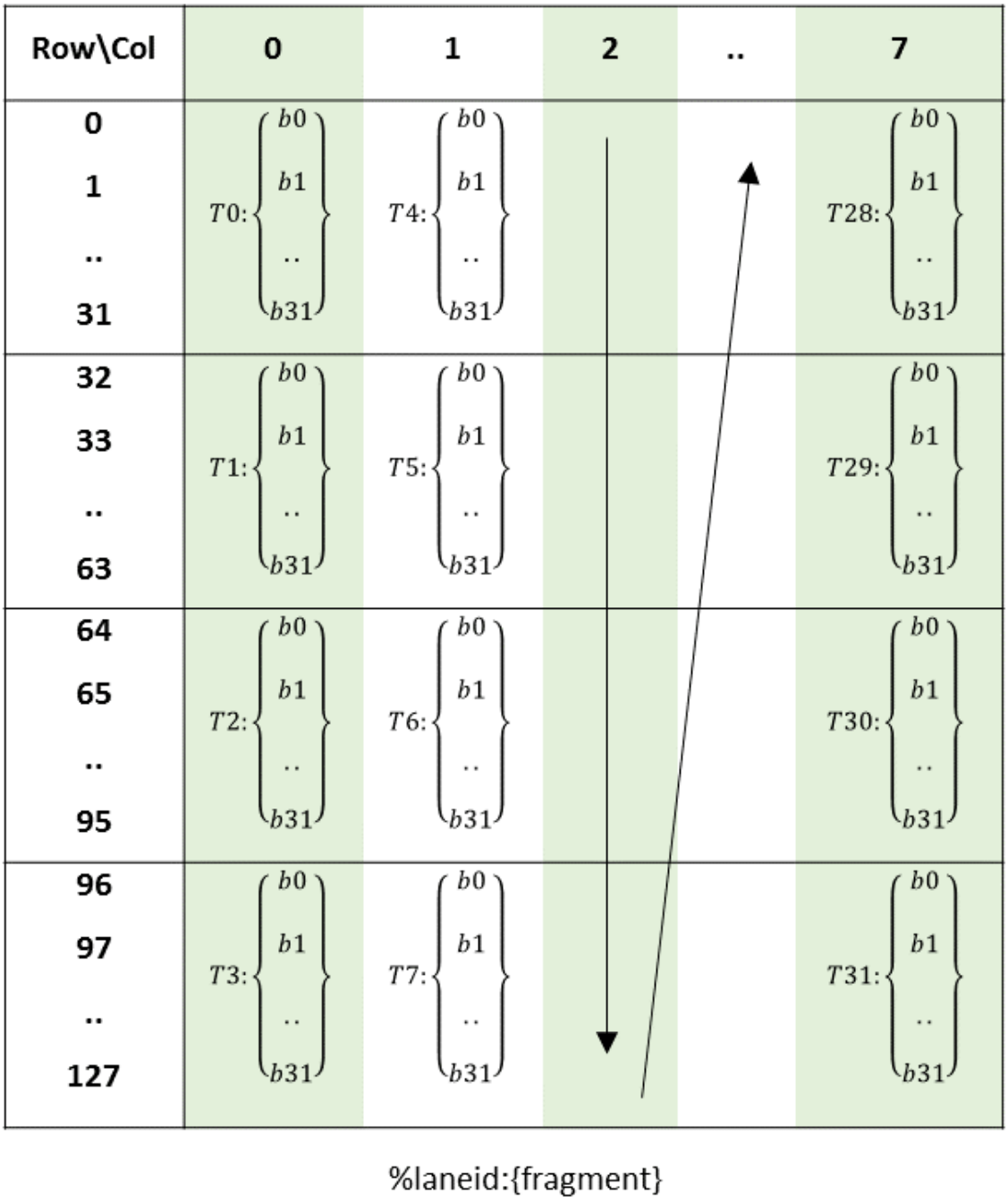

Figure 63: MMA .m8n8k128 fragment layout for matrix B with `.b1` type.

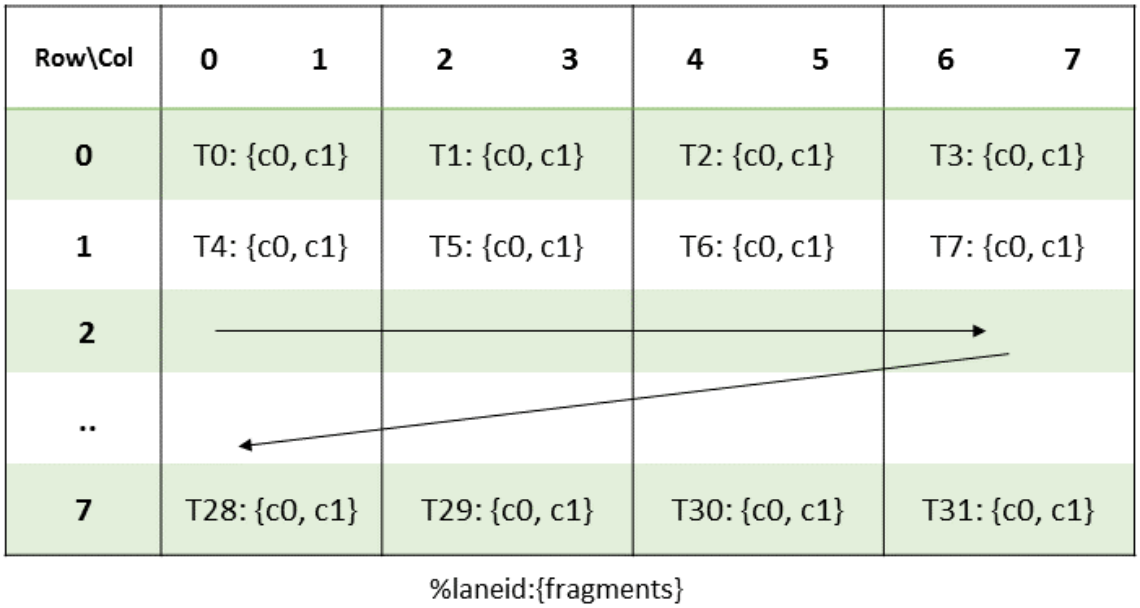

Figure 64: MMA .m8n8k128 fragment layout for accumulator matrix C/D with .s32 type

(continued from previous page)

```
row =      groupID

col =  (threadID_in_group * 2) + i    for ci where i = {0, 1}
```

9.7.14.5.6 Matrix Fragments for mma.m16n8k4

A warp executing mma.m16n8k4 will compute an MMA operation of shape .m16n8k4.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:
  - .tf32:

.atype	Fragment	Elements (low to high)
.tf32	A vector expression containing two .b32 registers, containing two .tf32 elements from the matrix A.	a0, a1

The layout of the fragments held by different threads is shown in Figure 65.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4
```

(continues on next page)

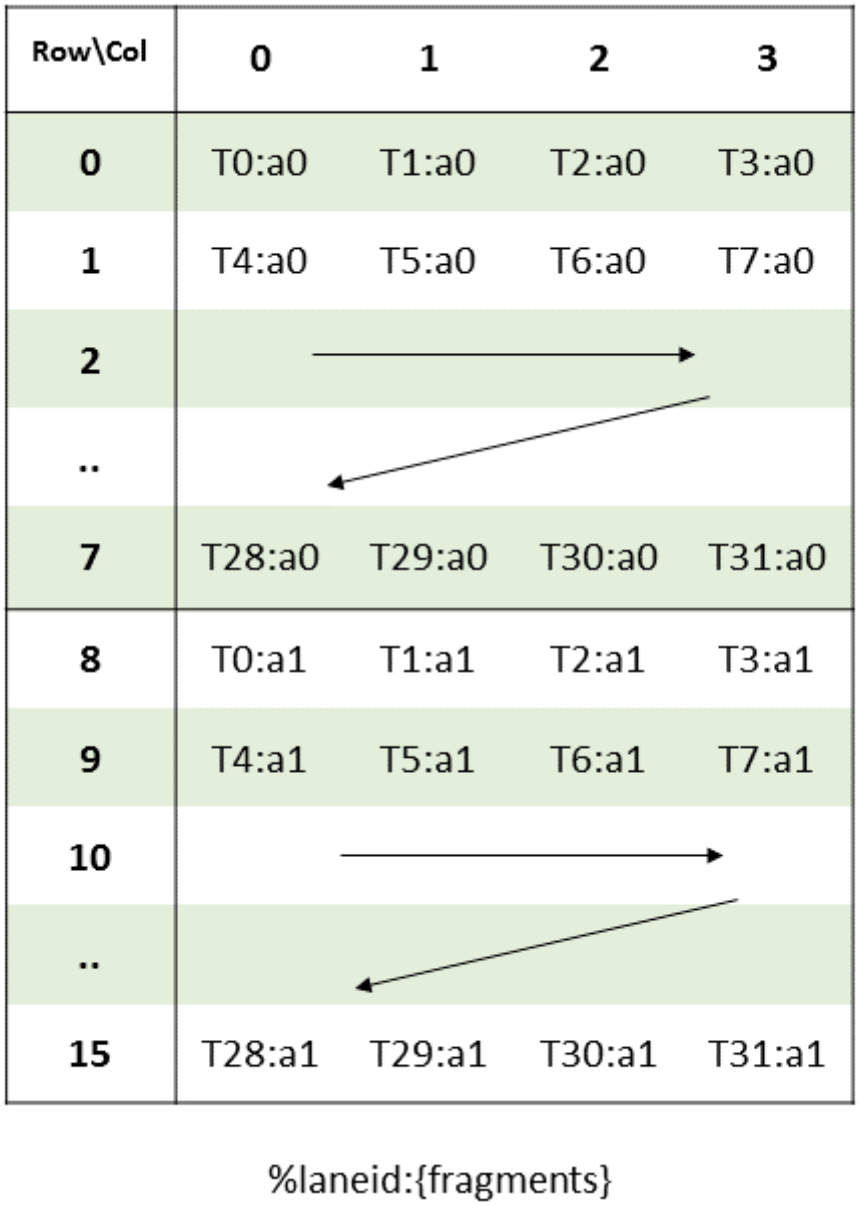

Figure 65: MMA .m16n8k4 fragment layout for matrix A with `.tf32` type.

(continued from previous page)

```
row =      groupID            for a0
           groupID + 8        for a1

col =  threadID_in_group
```

- `.f64`:

.atype	Fragment	Elements (low to high)
`.f64`	A vector expression containing two `.f64` registers, containing two `.f64` elements from the matrix A.	a0, a1

The layout of the fragments held by different threads is shown in Figure 66.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID            for a0
           groupID + 8        for a1

col =  threadID_in_group
```

- Multiplicand B:
  - `.tf32`:

.btype	Fragment	Elements (low to high)
`.tf32`	A vector expression of a single `.b32` register, containing a single `.tf32` element from the matrix B.	b0

The layout of the fragments held by different threads is shown in Figure 67.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  threadID_in_group

col =  groupID
```

  - `.f64`:

.btype	Fragment	Elements (low to high)
`.f64`	A vector expression of a single `.f64` register, containing a single `.f64` element from the matrix B.	b0

The layout of the fragments held by different threads is shown in Figure 68.

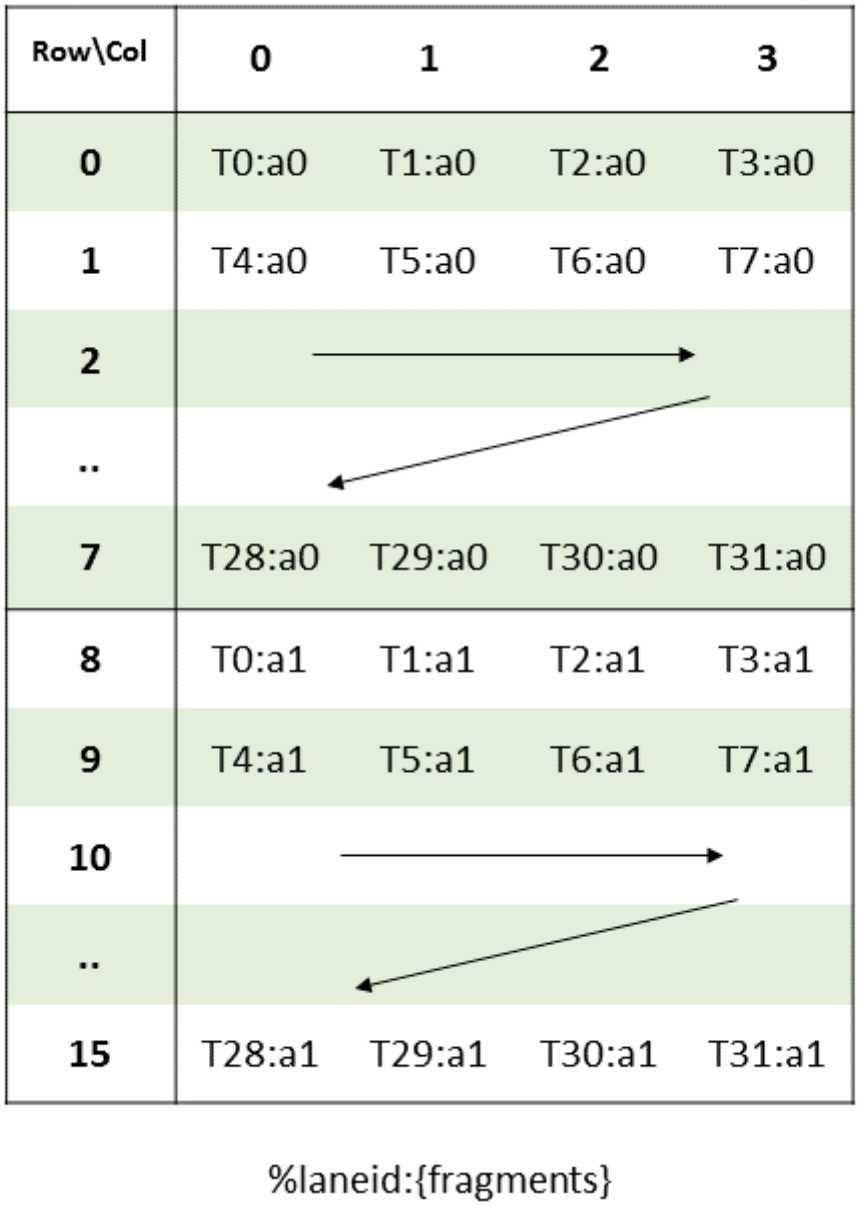

Figure 66: MMA .m16n8k4 fragment layout for matrix A with `.f64` type.

Row\Column	0	1	2	..	7
0	T0:b0	T4:b0			T28:b0
1	T1:b0	T5:b0			T29:b0
2	T2:b0	T6:b0			T30:b0
3	T3:b0	T7:b0			T31:b0

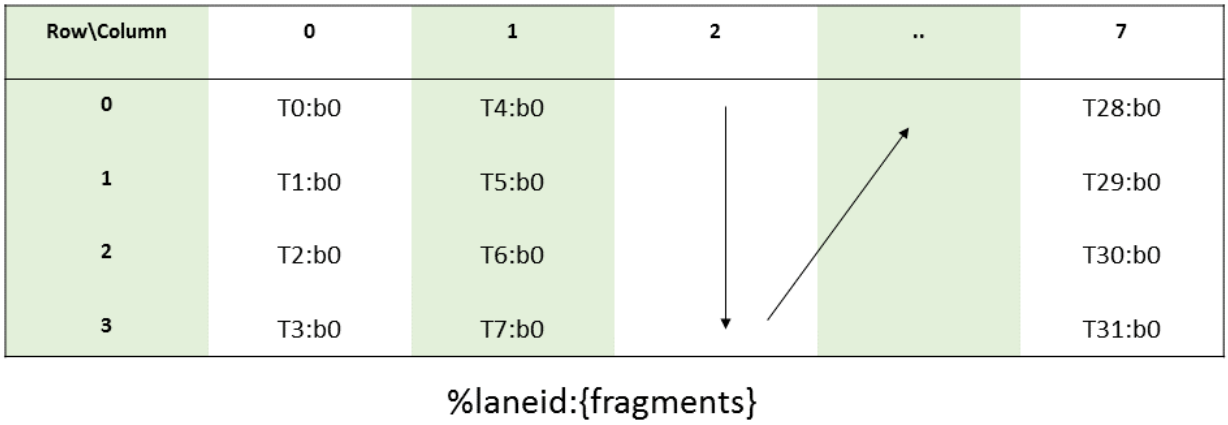

Figure 67: MMA .m16n8k4 fragment layout for matrix B with `.tf32` type.

Row\Column	0	1	2	..	7
0	T0:b0	T4:b0			T28:b0
1	T1:b0	T5:b0			T29:b0
2	T2:b0	T6:b0			T30:b0
3	T3:b0	T7:b0			T31:b0

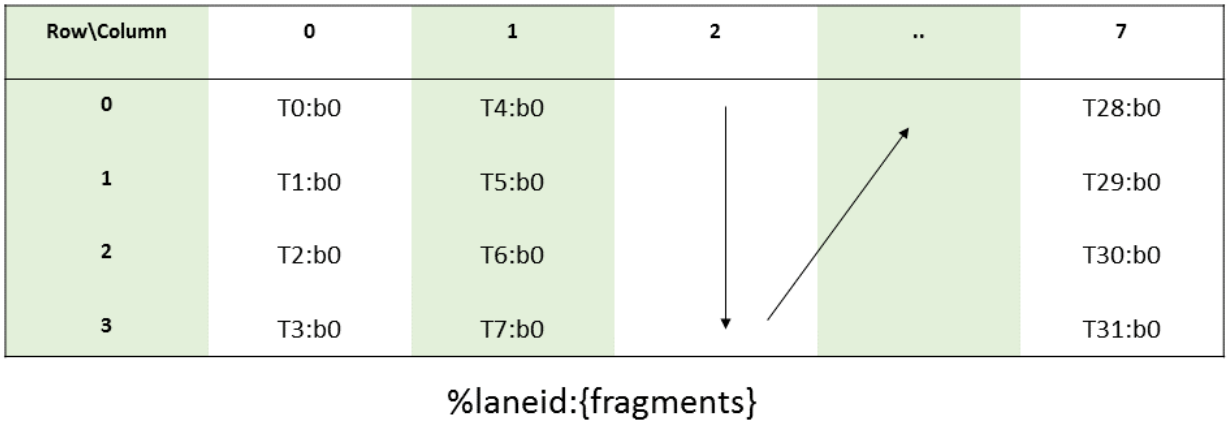

Figure 68: MMA .m16n8k4 fragment layout for matrix B with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  threadID_in_group

col =  groupID
```

- Accumulators (C or D):
  - `.tf32`:

.ctype / .dtype	Fragment	Elements (low to high)
`.f32`	A vector expression containing four `.f32` registers, containing four `.f32` elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 69.

Row\Col	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
..				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0:{c2, c3}	T1:{c2, c3}	T2:{c2, c3}	T3:{c2, c3}
9	T4:{c2, c3}	T5:{c2, c3}	T6:{c2, c3}	T7:{c2, c3}
10				
..				
15	T28:{c2, c3}	T29:{c2, c3}	T30:{c2, c3}	T31:{c2, c3}

%laneid:{fragments}

Figure 69: MMA .m16n8k4 fragment layout for accumulator matrix C/D with `.f32` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                              for c0 and c1
         groupID + 8                            for c2 and c3

col =  (threadID_in_group * 2) + (i & 0x1)      for ci   where i = {0,..,
↪3}
```

- `.f64`:

.ctype / .dtype	Fragment	Elements (low to high)
`.f64`	A vector expression containing four `.f64` registers, containing four `.f64` elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 70.

Row\Col	0	1	2	3	4	5	6	7
0	T0: {c0, c1}		T1: {c0, c1}		T2: {c0, c1}		T3: {c0, c1}	
1	T4: {c0, c1}		T5: {c0, c1}		T6: {c0, c1}		T7: {c0, c1}	
2								
..								
7	T28: {c0, c1}		T29: {c0, c1}		T30: {c0, c1}		T31: {c0, c1}	
8	T0:{c2, c3}		T1:{c2, c3}		T2:{c2, c3}		T3:{c2, c3}	
9	T4:{c2, c3}		T5:{c2, c3}		T6:{c2, c3}		T7:{c2, c3}	
10								
..								
15	T28:{c2, c3}		T29:{c2, c3}		T30:{c2, c3}		T31:{c2, c3}	

%laneid:{fragments}

Figure 70: MMA .m16n8k4 fragment layout for accumulator matrix C/D with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                              for c0 and c1
         groupID + 8                            for c2 and c3

col =  (threadID_in_group * 2) + (i & 0x1)     for ci   where i = {0,..,
↪3}
```

9.7.14.5.7 Matrix Fragments for `mma.m16n8k8`

A warp executing `mma.m16n8k8` will compute an MMA operation of shape `.m16n8k8`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:
  - `.f16` and `.bf16` :

.atype	Fragment	Elements (low to high)
`.f16` / `.bf16`	A vector expression containing two `.f16x2` registers, with each register containing two `.f16` / `.bf16` elements from the matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown in Figure 71.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for a0 and a1
           groupID + 8         for a2 and a3

col =  threadID_in_group * 2 + (i & 0x1)    for ai     where i = {0,..,
↪3}
```

  - `.tf32` :

.atype	Fragment	Elements (low to high)
`.tf32`	A vector expression containing four `.b32` registers, containing four `.tf32` elements from the matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown in Figure 72.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4
```

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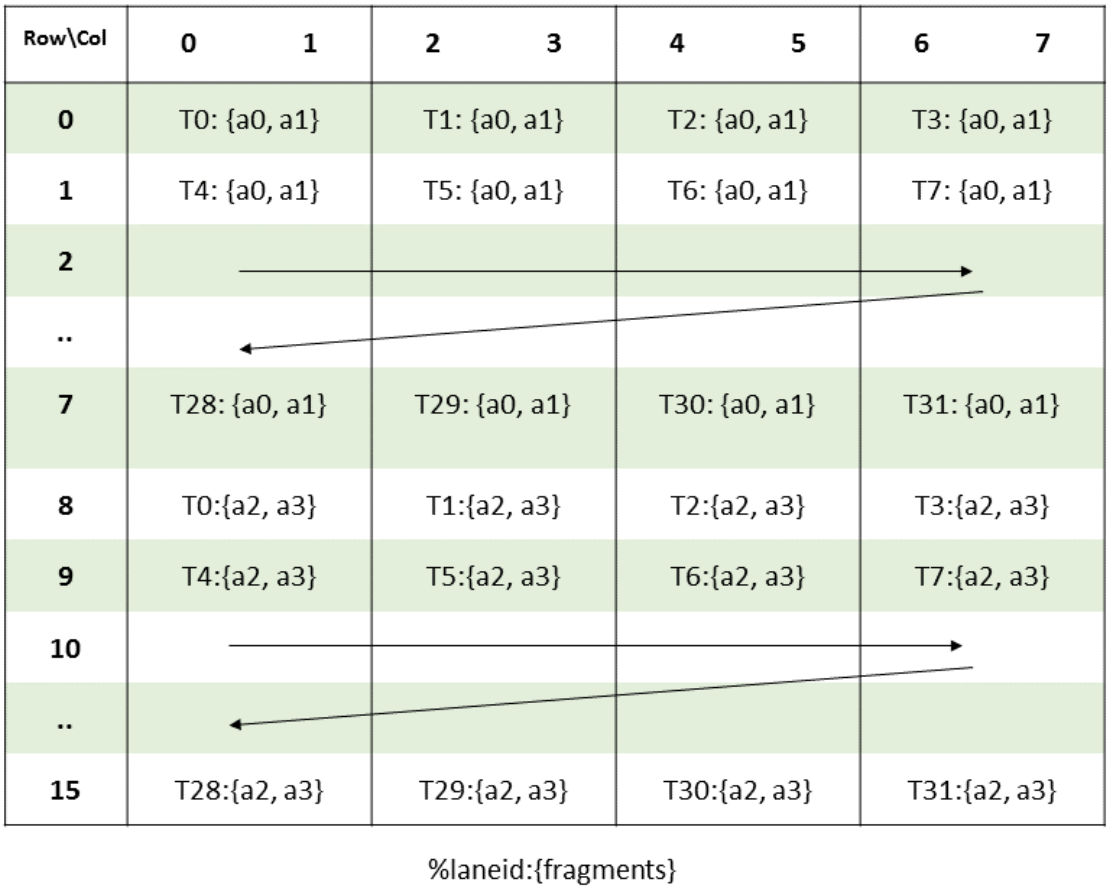

Figure 71: MMA .m16n8k8 fragment layout for matrix A with `.f16` / `.bf16` type.

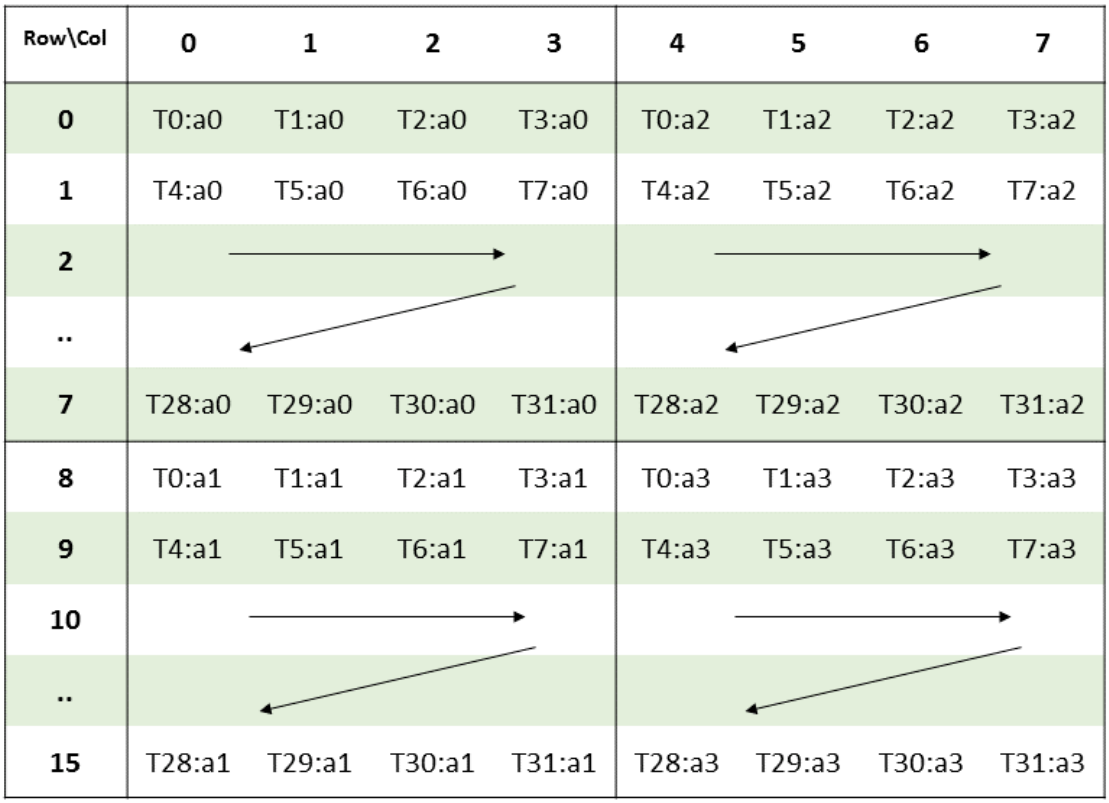

Figure 72: MMA .m16n8k8 fragment layout for matrix A with `.tf32` type.

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```
row =      groupID             for a0 and a2
           groupID + 8         for a1 and a3

col =  threadID_in_group        for a0 and a1
       threadID_in_group + 4    for a2 and a3
```

- `.f64` :

.atype	Fragment	Elements (low to high)
`.f64`	A vector expression containing four `.f64` registers, containing four `.f64` elements from the matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown in Figure 73.

Row\Col	0	1	2	3	4	5	6	7
0	T0:a0	T1:a0	T2:a0	T3:a0	T0:a2	T1:a2	T2:a2	T3:a2
1	T4:a0	T5:a0	T6:a0	T7:a0	T4:a2	T5:a2	T6:a2	T7:a2
2								
..								
7	T28:a0	T29:a0	T30:a0	T31:a0	T28:a2	T29:a2	T30:a2	T31:a2
8	T0:a1	T1:a1	T2:a1	T3:a1	T0:a3	T1:a3	T2:a3	T3:a3
9	T4:a1	T5:a1	T6:a1	T7:a1	T4:a3	T5:a3	T6:a3	T7:a3
10								
..								
15	T28:a1	T29:a1	T30:a1	T31:a1	T28:a3	T29:a3	T30:a3	T31:a3

%laneid:{fragments}

Figure 73: MMA .m16n8k8 fragment layout for matrix A with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4
```

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```
row =      groupID            for a0 and a2
           groupID + 8        for a1 and a3

col =  threadID_in_group       for a0 and a1
       threadID_in_group + 4   for a2 and a3
```

- Multiplicand B:
  - `.f16` and `.bf16` :

.btype	Fragment	Elements (low to high)
`.f16` / `.bf16`	A vector expression containing a single `.f16x2` register, containing two `.f16` / `.bf16` elements from the matrix B.	b0, b1

The layout of the fragments held by different threads is shown in Figure 74.

Row\Column	0	1	2	..	7
0 1	$T0:\begin{Bmatrix}b0\\b1\end{Bmatrix}$	$T4:\begin{Bmatrix}b0\\b1\end{Bmatrix}$			$T28:\begin{Bmatrix}b0\\b1\end{Bmatrix}$
2 3	$T1:\begin{Bmatrix}b0\\b1\end{Bmatrix}$	$T5:\begin{Bmatrix}b0\\b1\end{Bmatrix}$			$T29:\begin{Bmatrix}b0\\b1\end{Bmatrix}$
4 5	$T2:\begin{Bmatrix}b0\\b1\end{Bmatrix}$	$T6:\begin{Bmatrix}b0\\b1\end{Bmatrix}$			$T30:\begin{Bmatrix}b0\\b1\end{Bmatrix}$
6 7	$T3:\begin{Bmatrix}b0\\b1\end{Bmatrix}$	$T7:\begin{Bmatrix}b0\\b1\end{Bmatrix}$			$T31:\begin{Bmatrix}b0\\b1\end{Bmatrix}$

%laneid:{fragments}

Figure 74: MMA .m16n8k8 fragment layout for matrix B with `.f16` / `.bf16` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4
```

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```
row = (threadID_in_group * 2) + i       for bi    where i = {0, 1}

col =  groupID
```

- `.tf32` :

.btype	Fragment	Elements (low to high)
`.tf32`	A vector expression containing two `.b32` registers, containing two `.tf32` elements from the matrix B.	b0, b1

The layout of the fragments held by different threads is shown in Figure 75.

Row\Column	0	1	2	..	7
0	T0:b0	T4:b0			T28:b0
1	T1:b0	T5:b0			T29:b0
2	T2:b0	T6:b0			T30:b0
3	T3:b0	T7:b0			T31:b0
4	T0:b1	T4:b1			T28:b1
5	T1:b1	T5:b1			T29:b1
6	T2:b1	T6:b1			T30:b1
7	T3:b1	T7:b1			T31:b1

%laneid:{fragments}

Figure 75: MMA .m16n8k8 fragment layout for matrix B with `.tf32` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =    threadID_in_group         for b0
       threadID_in_group + 4       for b1

col =  groupID
```

- `.f64` :

.btype	Fragment	Elements (low to high)
`.f64`	A vector expression containing two `.f64` registers, containing two `.f64` elements from the matrix B.	b0, b1

The layout of the fragments held by different threads is shown in Figure 76.

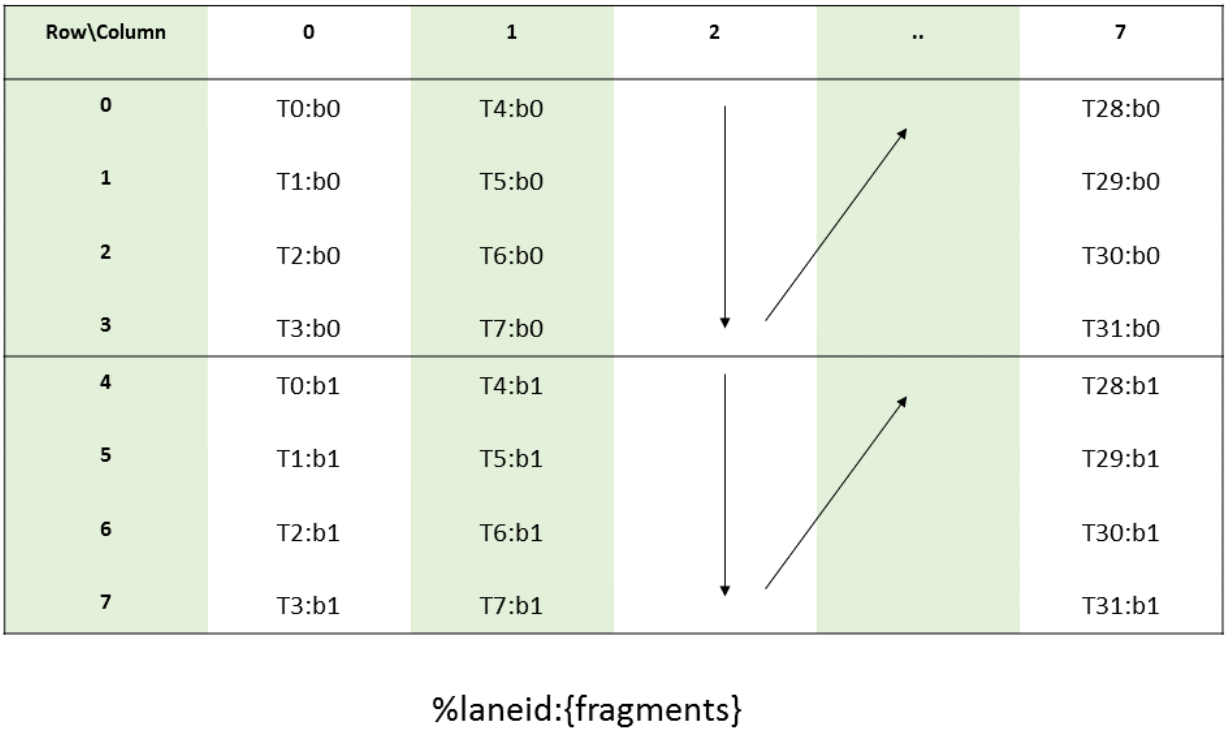

Figure 76: MMA .m16n8k8 fragment layout for matrix B with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =    threadID_in_group         for b0
       threadID_in_group + 4       for b1

col =  groupID
```

- Accumulators (C or D):
  - `.f16`, `.bf16` and `.tf32`:

.ctype / .dtype	Fragment	Elements (low to high)
.f16	A vector expression containing two .f16x2 registers, with each register containing two .f16 elements from the matrix C (or D).	c0, c1, c2, c3
.f32	A vector expression of four .f32 registers.	

The layout of the fragments held by different threads is shown in Figure 77.

Row\Col	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
..				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0:{c2, c3}	T1:{c2, c3}	T2:{c2, c3}	T3:{c2, c3}
9	T4:{c2, c3}	T5:{c2, c3}	T6:{c2, c3}	T7:{c2, c3}
10				
..				
15	T28:{c2, c3}	T29:{c2, c3}	T30:{c2, c3}	T31:{c2, c3}

%laneid:{fragments}

Figure 77: MMA .m16n8k8 fragment layout for accumulator matrix C/D with .f16x2/.f32 type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                            for c0 and c1
         groupID + 8                          for c2 and c3

col =  (threadID_in_group * 2) + (i & 0x1)    for ci   where i = {0,..,
↪3}
```

- .f64 :

.ctype / .dtype	Fragment	Elements (low to high)
.f64	A vector expression of four .f64 registers containing four .f64 elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 78.

Row\Col	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
..				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0:{c2, c3}	T1:{c2, c3}	T2:{c2, c3}	T3:{c2, c3}
9	T4:{c2, c3}	T5:{c2, c3}	T6:{c2, c3}	T7:{c2, c3}
10				
..				
15	T28:{c2, c3}	T29:{c2, c3}	T30:{c2, c3}	T31:{c2, c3}

%laneid:{fragments}

Figure 78: MMA .m16n8k8 fragment layout for accumulator matrix C/D with .f64 type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                            for c0 and c1
         groupID + 8                          for c2 and c3

col =  (threadID_in_group * 2) + (i & 0x1)    for ci   where i = {0,..,
↪3}
```

9.7.14.5.8 Matrix Fragments for `mma.m16n8k16` with floating point type

A warp executing `mma.m16n8k16` floating point types will compute an MMA operation of shape `.m16n8k16`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:
  - `.f16` and `.bf16` :

.atype	Fragment	Elements (low to high)
`.f16` / `.bf16`	A vector expression containing four `.f16x2` registers, with each register containing two `.f16` / `.bf16` elements from the matrix A.	a0, a1, a2, a3, a4, a5, a6, a7

The layout of the fragments held by different threads is shown in Figure 79.

R\C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	T0:{a0,a1}		T1:{a0,a1}		T2:{a0,a1}		T3:{a0,a1}		T0:{a4,a5}		T1:{a4,a5}		T2:{a4,a5}		T3:{a4,a5}	
1	T4:{a0,a1}		T5:{a0,a1}		T6:{a0,a1}		T7:{a0,a1}		T4:{a4,a5}		T5:{a4,a5}		T6:{a4,a5}		T7:{a4,a5}	
2																
..																
7	T28:{a0,a1}		T29:{a0,a1}		T30:{a0,a1}		T31:{a0,a1}		T28:{a4,a5}		T29:{a4,a5}		T30:{a4,a5}		T31:{a4,a5}	
8	T0:{a2,a3}		T1:{a2,a3}		T2:{a2,a3}		T3:{a2,a3}		T0:{a6,a7}		T1:{a6,a7}		T2:{a6,a7}		T3:{a6,a7}	
9	T4:{a2,a3}		T5:{a2,a3}		T6:{a2,a3}		T7:{a2,a3}		T4:{a6,a7}		T5:{a6,a7}		T6:{a6,a7}		T7:{a6,a7}	
10																
..																
15	T28:{a2,a3}		T29:{a2,a3}		T30:{a2,a3}		T31:{a2,a3}		T28:{a6,a7}		T29:{a6,a7}		T30:{a6,a7}		T31:{a6,a7}	

%laneid:{fragments}

Figure 79: MMA .m16n8k16 fragment layout for matrix A with `.f16` / `.bf16` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID            for ai where  0 <= i < 2 || 4 <= i < 6
         groupID + 8          Otherwise

col =  (threadID_in_group * 2) + (i & 0x1)          for ai where i <  4
(threadID_in_group * 2) + (i & 0x1) + 8      for ai where i >= 4
```

- `.f64` :

.atype	Fragment	Elements (low to high)
`.f64`	A vector expression containing eight `.f64` registers, with each register containing one `.f64` element from the matrix A.	a0, a1, a2, a3, a4, a5, a6, a7

The layout of the fragments held by different threads is shown in Figure 80.

R\C	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	T0:a0	T1:a0	T2:a0	T3:a0	T0:a2	T1:a2	T2:a2	T3:a2	T0:a4	T1:a4	T2:a4	T3:a4	T0:a6	T1:a6	T2:a6	T3:a6
1	T4:a0	T5:a0	T6:a0	T7:a0	T4:a2	T5:a2	T6:a2	T7:a2	T4:a4	T5:a4	T6:a4	T7:a4	T4:a6	T5:a6	T6:a6	T7:a6
2	→				→				→				→			
..	↙				↙				↙				↙			
7	T28:a0	T29:a0	T30:a0	T31:a0	T28:a2	T29:a2	T30:a2	T31:a2	T28:a4	T29:a4	T30:a4	T31:a4	T28:a6	T29:a6	T30:a6	T31:a6
8	T0:a1	T1:a1	T2:a1	T3:a1	T0:a3	T1:a3	T2:a3	T3:a3	T0:a5	T1:a5	T2:a5	T3:a5	T0:a7	T1:a7	T2:a7	T3:a7
9	T4:a1	T5:a1	T6:a1	T7:a1	T4:a3	T5:a3	T6:a3	T7:a3	T4:a5	T5:a5	T6:a5	T7:a5	T4:a7	T5:a7	T6:a7	T7:a7
10	→				→				→				→			
..	↙				↙				↙				↙			
15	T28:a1	T29:a1	T30:a1	T31:a1	T28:a3	T29:a3	T30:a3	T31:a3	T28:a5	T29:a5	T30:a5	T31:a5	T28:a7	T29:a7	T30:a7	T31:a7

laneid:{fragments}

Figure 80: MMA .m16n8k16 fragment layout for matrix A with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  groupID                              for ai where  i % 2 = 0
       groupID + 8                          Otherwise
```

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```
col =  (i * 2) + threadID_in_group          for ai where i % 2 = 0
       (i * 2) - 2 + (threadID_in_group     Otherwise
```

- Multiplicand B:
  - `.f16` and `.bf16` :

.btype	Fragment	Elements (low to high)
`.f16` / `.bf16`	A vector expression containing two `.f16x2` registers, with each register containing two `.f16` / `.bf16` elements from the matrix B.	b0, b1, b2, b3

The layout of the fragments held by different threads is shown in Figure 81.

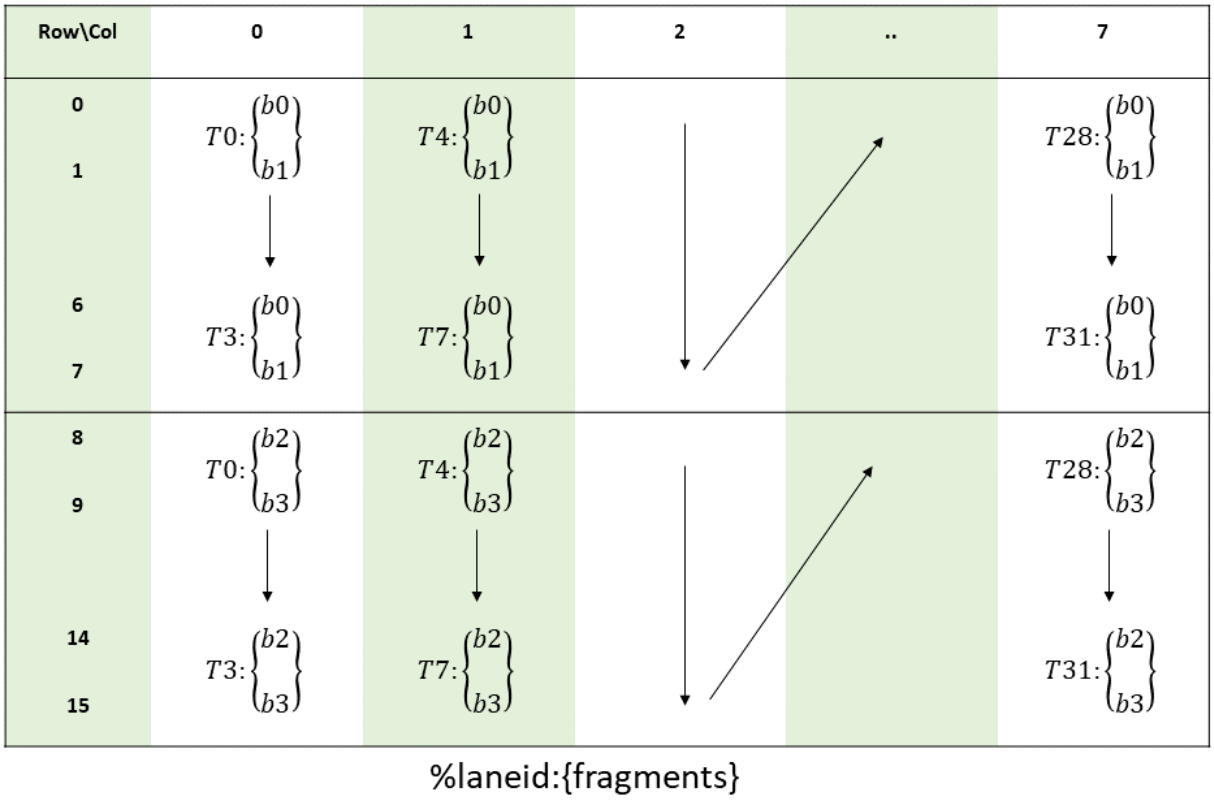

Figure 81: MMA .m16n8k16 fragment layout for matrix B with `.f16` / `.bf16` type.

where the row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  (threadID_in_group * 2) + (i & 0x1)          for bi where i <
↪2
       (threadID_in_group * 2) + (i & 0x1) + 8      for bi where i >=
↪2
```

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```
col = groupID
```

- `.f64` :

.atype	Fragment	Elements (low to high)
`.f64`	A vector expression containing four `.f64` registers, with each register containing one `.f64` element from the matrix B.	b0, b1, b2, b3

The layout of the fragments held by different threads is shown in Figure 82.

Row\Column	0	1	2	...	7
0	T0:B0	T4:B0			T28:B0
1	T1:B0	T5:B0			T29:B0
2	T2:B0	T6:B0			T30:B0
3	T3:B0	T7:B0			T31:B0
4	T0:B1	T4:B1			T28:B1
5	T1:B1	T5:B1			T29:B1
6	T2:B1	T6:B1			T30:B1
7	T3:B1	T7:B1			T31:B1
8	T0:B2	T4:B2			T28:B2
9	T1:B2	T5:B2			T29:B2
10	T2:B2	T6:B2			T30:B2
11	T3:B2	T7:B2			T31:B2
12	T0:B3	T4:B3			T28:B3
13	T1:B3	T5:B3			T29:B3
14	T2:B3	T6:B3			T30:B3
15	T3:B3	T7:B3			T31:B3

%laneid:{fragments}

Figure 82: MMA .m16n8k16 fragment layout for matrix B with `.f64` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  threadID_in_group + (i * 4)          for bi where  i < 4

col =  groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.f64	A vector expression containing four .f64 registers containing .f64 elements from the matrix C (or D).	c0, c1, c2, c3
.f32	A vector expression containing four .f32 registers containing four .f32 elements from the matrix C (or D).	
.f16	A vector expression containing two .f16x2 registers, with each register containing two .f16 elements from the matrix C (or D).	

The layout of the fragments held by different threads is shown in Figure 83.

Row\Col	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
..				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0:{c2, c3}	T1:{c2, c3}	T2:{c2, c3}	T3:{c2, c3}
9	T4:{c2, c3}	T5:{c2, c3}	T6:{c2, c3}	T7:{c2, c3}
10				
..				
15	T28:{c2, c3}	T29:{c2, c3}	T30:{c2, c3}	T31:{c2, c3}

%laneid:{fragments}

Figure 83: MMA .m16n8k16 fragment layout for accumulator matrix matrix C/D.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                              for ci where i <  2
         groupID + 8                            for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)       for ci where i = {0,..,3}
```

9.7.14.5.9 Matrix Fragments for `mma.m16n8k16` with integer type

A warp executing `mma.m16n8k16` will compute an MMA operation of shape `.m16n8k16`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.u8` / `.s8`	A vector expression containing two `.b32` registers, with each register containing four `.u8` / `.s8` elements from the matrix A.	a0, a1, a2, a3, a4, a5, a6, a7
`.e4m3` / `.e5m2`	A vector expression containing two `.b32` registers, with each register containing four `.e4m3` / `.e5m2` elements from the matrix A.	a0, a1, a2, a3, a4, a5, a6, a7

The layout of the fragments held by different threads is shown in Figure 84.

R\C	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15
0	T0:{a0, a1, a2, a3}	T1:{a0, a1, a2, a3}	T2:{a0, a1, a2, a3}	T3:{a0, a1, a2, a3}
1	T4:{a0, a1, a2, a3}	T5:{a0, a1, a2, a3}	T6:{a0, a1, a2, a3}	T7:{a0, a1, a2, a3}
2				
..				
7	T28:{a0, a1, a2, a3}	T29:{a0, a1, a2, a3}	T30:{a0, a1, a2, a3}	T31:{a0, a1, a2, a3}
8	T0:{a4, a5, a6, a7}	T1:{a4, a5, a6, a7}	T2:{a4, a5, a6, a7}	T3:{a4, a5, a6, a7}
9	T4:{a4, a5, a6, a7}	T5:{a4, a5, a6, a7}	T6:{a4, a5, a6, a7}	T7:{a4, a5, a6, a7}
10				
..				
15	T28:{a4, a5, a6, a7}	T29:{a4, a5, a6, a7}	T30:{a4, a5, a6, a7}	T31:{a4, a5, a6, a7}

%laneid:{fragments}

Figure 84: MMA .m16n8k16 fragment layout for matrix A with `.u8` / `.s8` type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                          for ai where i < 4
         groupID + 8                        for ai where i >= 4
```

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```
col =  (threadID_in_group * 4) + (i & 0x3)    for ai where i = {0,..,7}
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
.u8 / .s8	A vector expression containing a single .b32 register, containing four .u8 / .s8 elements from the matrix B.	b0, b1, b2, b3
.e4m3 / .e5m2	A vector expression containing a single .b32 register, containing four .e4m3 / .e5m2 elements from the matrix B.	b0, b1. b2. b3

The layout of the fragments held by different threads is shown in Figure 85.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  (threadID_in_group * 4) + i         for bi where i = {0,..,3}

col = groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.s32	A vector expression containing four .s32 registers, containing four .s32 elements from the matrix C (or D).	c0, c1, c2, c3
.f32	A vector expression containing four .f32 registers, containing four .f32 elements from the matrix C (or D).	c0, c1, c2, c3
.f16	A vector expression containing two .f16x2 registers, with each register containing two .f16 elements from the matrix C (or D).	c0, c1, c1, c2

The layout of the fragments held by different threads is shown in Figure 86.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                          for ci where i <  2
         groupID + 8                        for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)    for ci where i = {0,..,3}
```

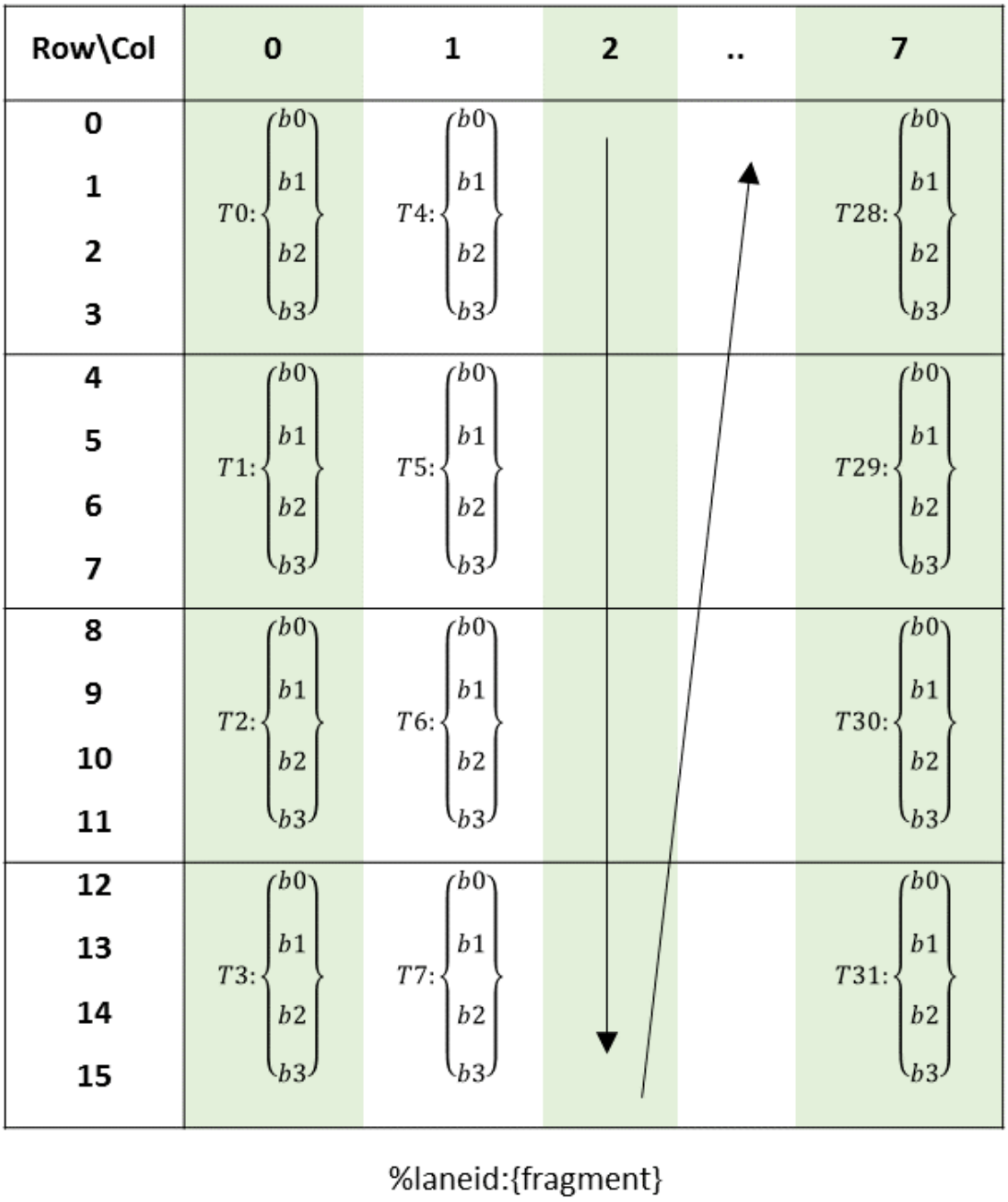

Figure 85: MMA .m16n8k16 fragment layout for matrix B with `.u8` / `.s8` type.

R\C	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0: {c2, c3}	T1: {c2, c3}	T2: {c2, c3}	T3: {c2, c3}
9	T4: {c2, c3}	T5: {c2, c3}	T6: {c2, c3}	T7: {c2, c3}
10				
..				
15	T28: {c2, c3}	T29: {c2, c3}	T30: {c2, c3}	T31: {c2, c3}

Figure 86: MMA .m16n8k16 fragment layout for accumulator matrix C/D with `.s32` type.

9.7.14.5.10 Matrix Fragments for `mma.m16n8k32`

A warp executing `mma.m16n8k32` will compute an MMA operation of shape `.m16n8k32`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:
  - `.s4` or `.u4` :

.atype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing two `.b32` registers, with each register containing eight `.u4` / `.s4` elements from the matrix A.	a0, a1, ..., a14, a15

The layout of the fragments held by different threads is shown in Figure 87.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                            for ai where i < 8
         groupID + 8                          for ai where i >= 8

col =  (threadID_in_group * 8) + (i & 0x7)    for ai where i = {0,..,
↪15}
```

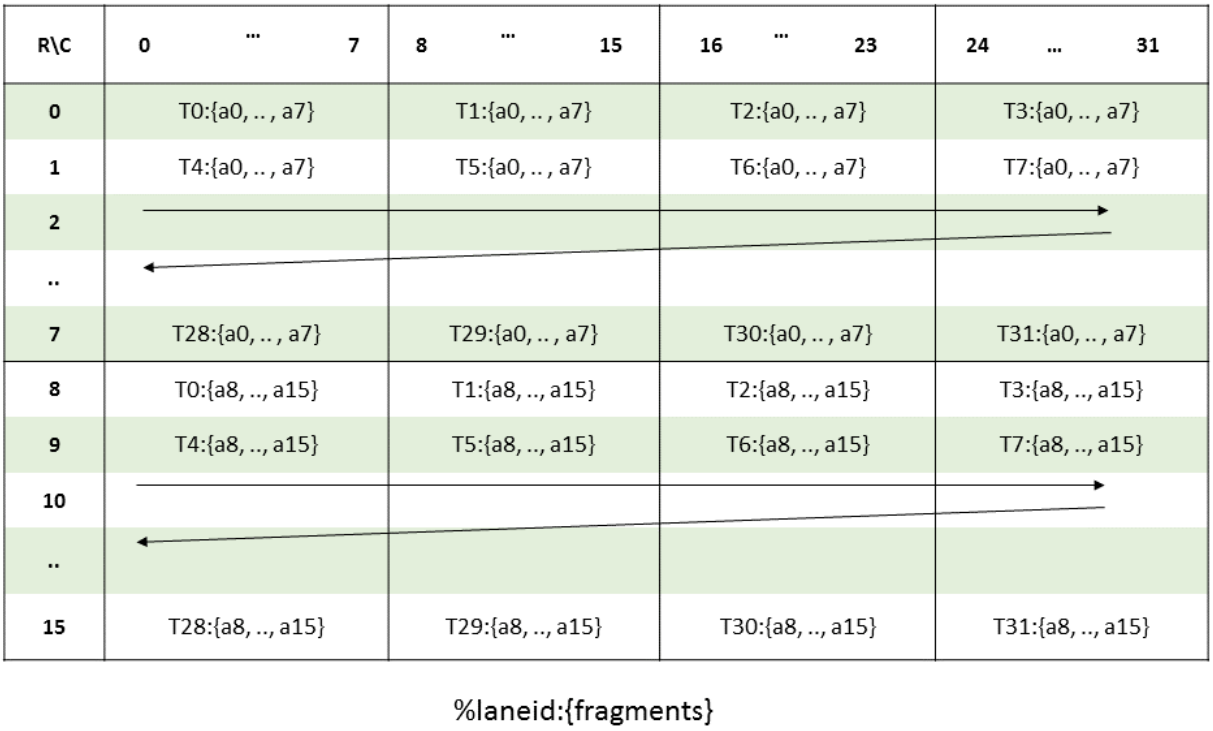

Figure 87: MMA .m16n8k32 fragment layout for matrix A with `.u4` / `.s4` type.

- `.s8` or `.u8` or `.e4m3` or `.e5m2` or `.e3m2` or `.e2m3` or `.e2m1`:

.atype	Fragment	Elements (low to high)
`.s8` / `.u8`	A vector expression containing four `.b32` registers, with each register containing four `.s8` / `.u8` elements from the matrix A.	a0, a1, .., a14, a15
`.e4m3` / `.e5m2` / `.e3m2` / `.e2m3` / `.e2m1`	A vector expression containing four `.b32` registers, with each register containing four `.e4m3` / `.e5m2` / `.e3m2` / `.e2m3` / `.e2m1` elements from the matrix A.	a0, a1, ..., a14, a15

The layout of the fragments held by different threads is shown in Figure 88.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =   groupID                                          for ai where 0
↪<= i < 4 || 8 <= i < 12
       groupID + 8                                       otherwise

col =    (threadID_in_group * 4) + (i & 0x3)             for ai where i
↪< 8
```

(continues on next page)

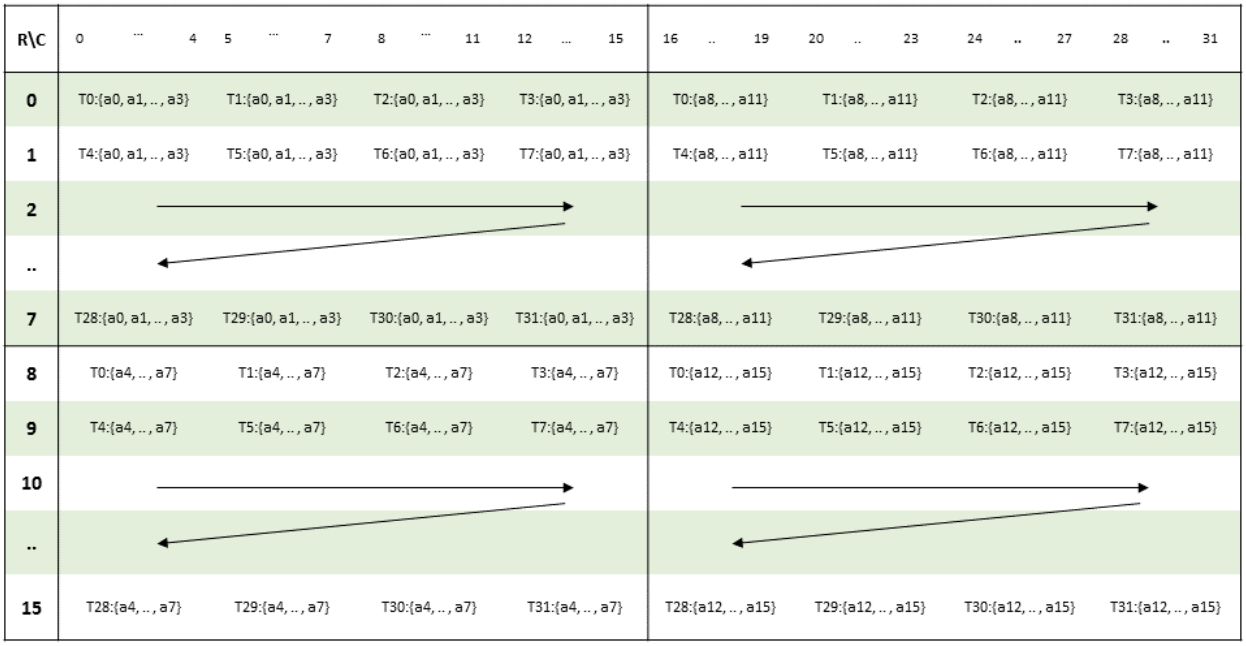

Figure 88: MMA .m16n8k32 fragment layout for matrix A with `.u8` / `.s8` / `.e4m3` / `.e5m2` / `.e3m2` / `.e2m3` / `.e2m1` type.

(continued from previous page)

```
        (threadID_in_group * 4) + (i & 0x3) + 16      for ai where i >
↪= 8
```

- Multiplicand B:
  - `.s4` or `.u4` :

.btype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing a single `.b32` register, containing eight `.s4` / `.u4` elements from the matrix B.	b0, b1, b2, b3, b4, b5, b6, b7

The layout of the fragments held by different threads is shown in Figure 89.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =    (threadID_in_group * 8) + (i & 0x7)      for bi where i = {0,..,7}
col =     groupID
```

  - `.s8` or `.u8` or `.e4m3` or `.e5m2` or `.e3m2` or `.e2m3` or `.e2m1`:

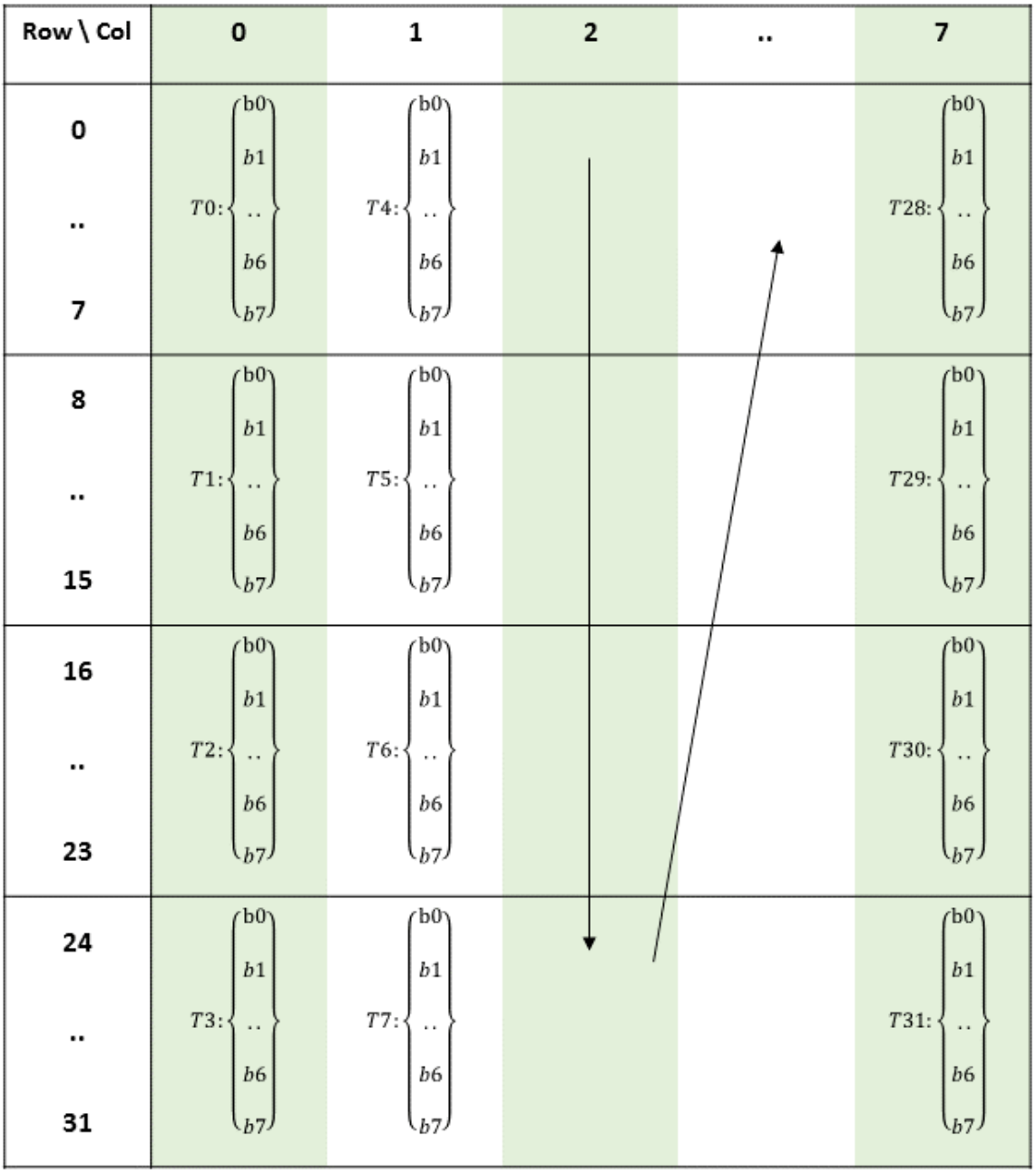

Figure 89: MMA .m16n8k32 fragment layout for matrix B with `.u4` / `.s4` type.

.btype	Fragment	Elements (low to high)
.s8 / .u8	A vector expression containing two .b32 registers, with each register containing four .s8 / .u8 elements from the matrix B.	b0, b1, b2, b3, b4, b5, b6, b7
.e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1	A vector expression containing two .b32 registers, with each register containing four .e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1 elements from the matrix B.	b0, b1, b2, b3, b4, b5, b6, b7

The layout of the fragments held by different threads is shown in Figure 90 and Figure 91.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      (threadID_in_group * 4) + (i & 0x3)           for bi where
↪i < 4
           (threadID_in_group * 4) + (i & 0x3) + 16      for bi where
↪i >= 4

col =   groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.s32	A vector expression containing four .s32 registers, containing four .s32 elements from the matrix C (or D).	c0, c1, c2, c3
.f32	A vector expression containing four .f32 registers, containing four .f32 elements from the matrix C (or D).	c0, c1, c2, c3
.f16	A vector expression containing two .f16x2 registers, with each register containing two .f16 elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 92.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                          for ci where i <  2
         groupID + 8                        for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)    for ci where i = {0,..,3}
```

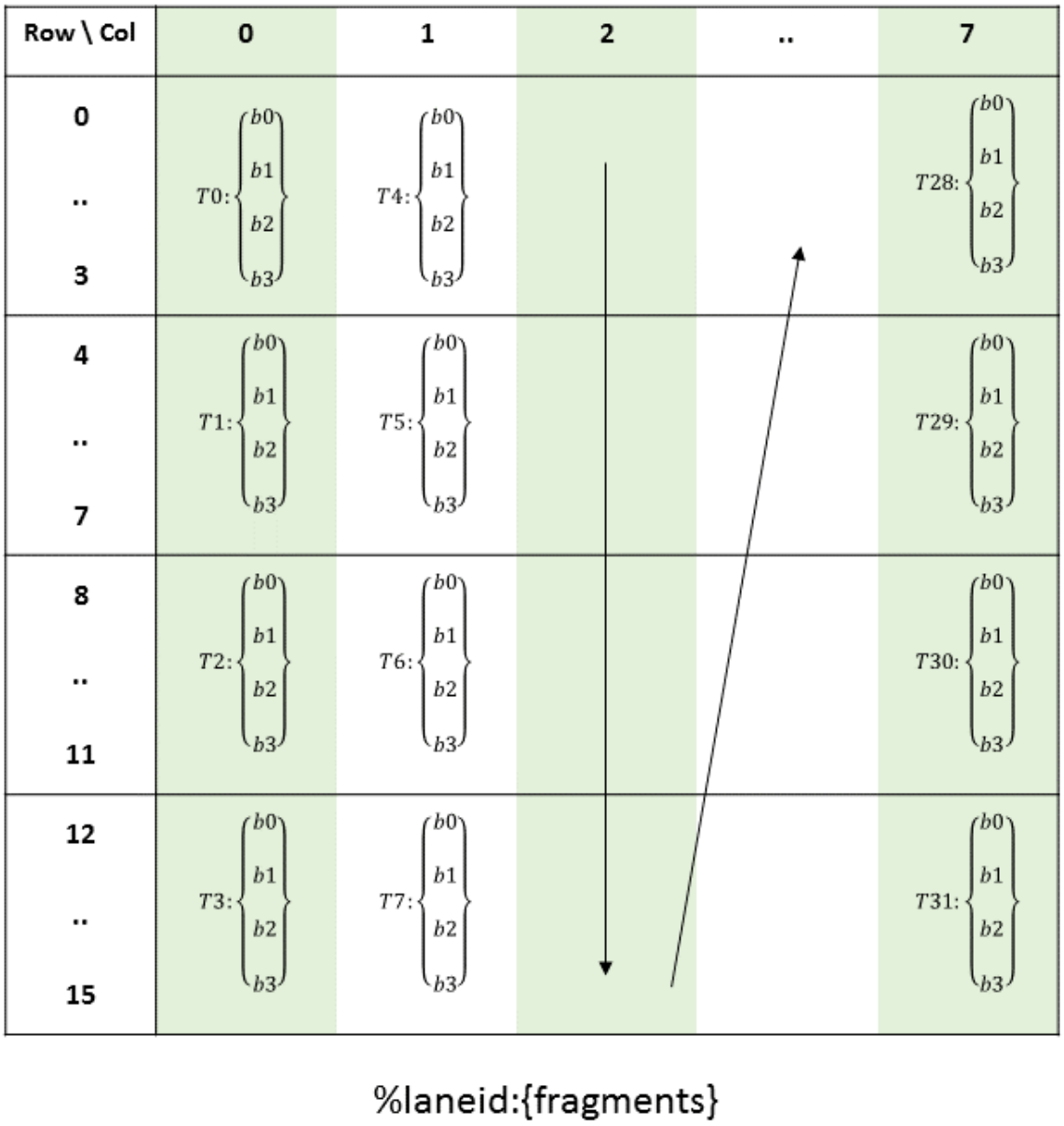

Figure 90: MMA .m16n8k32 fragment layout for rows 0–15 of matrix B with `.u8` / `.s8` / `.e4m3` / `.e5m2` / `.e3m2` / `.e2m3` / `.e2m1` type.

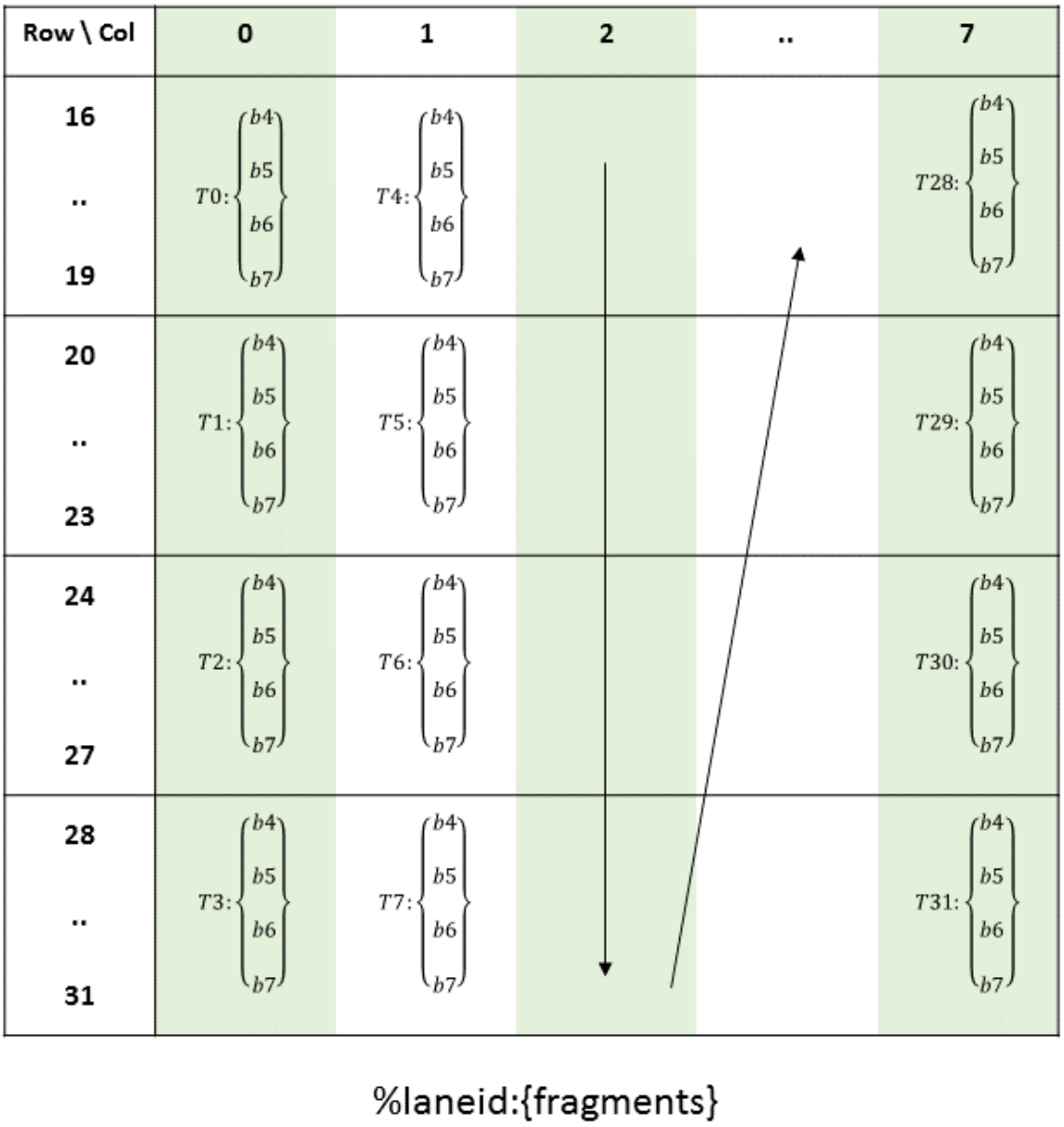

Figure 91: MMA .m16n8k32 fragment layout for rows 16–31 of matrix B with `.u8` / `.s8` / `.e4m3` / `.e5m2` / `.e3m2` / `.e2m3` / `.e2m1` type.

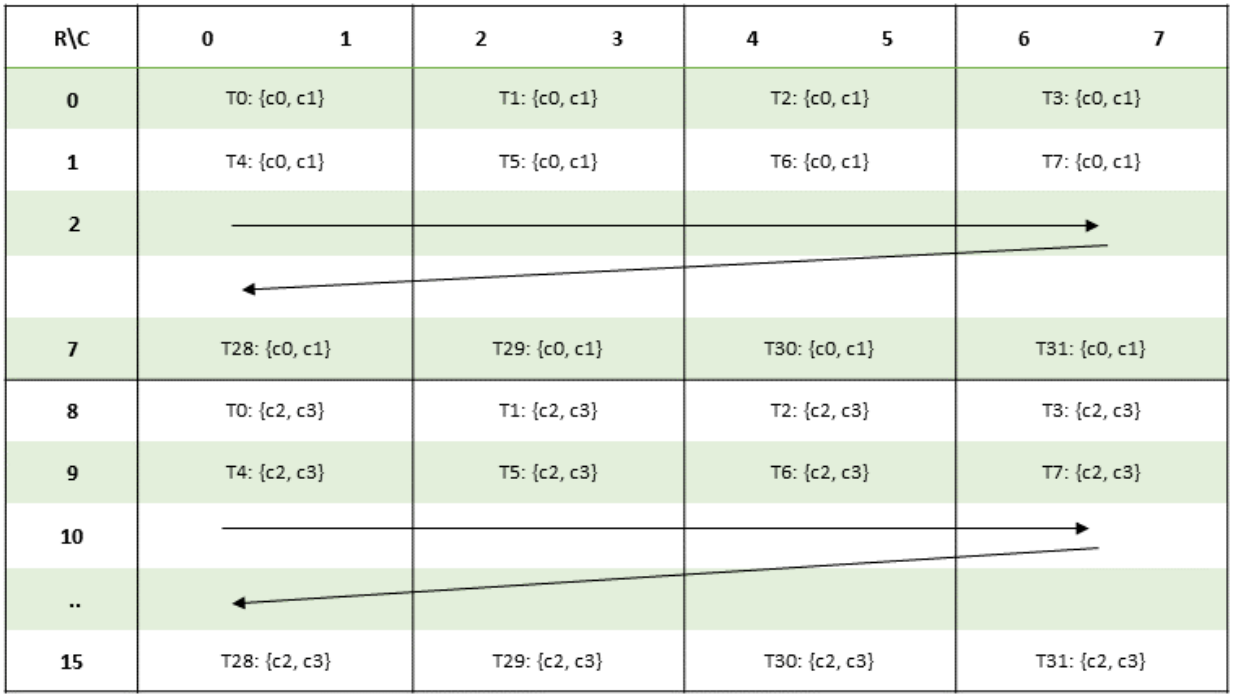

Figure 92: MMA .m16n8k32 fragment layout for accumulator matrix C/D with `.s32` / `.f32` / `.f16` type.

9.7.14.5.11 Matrix Fragments for `mma.m16n8k64`

A warp executing `mma.m16n8k64` will compute an MMA operation of shape `.m16n8k64`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing four `.b32` registers, with each register containing eight `.s4` / `.u4` elements from the matrix A.	a0, a1, ..., a30, a31
`.e2m1`	A vector expression containing four `.b32` registers, with each register containing eight `.e2m1` elements from the matrix A.	a0, a1, ..., a30, a31

The layout of the fragments held by different threads is shown in Figure 93.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =     groupID                                   for ai where 0 <= i < 8 ||
↪16 <= i < 24
        groupID + 8                                 otherwise
```

(continues on next page)

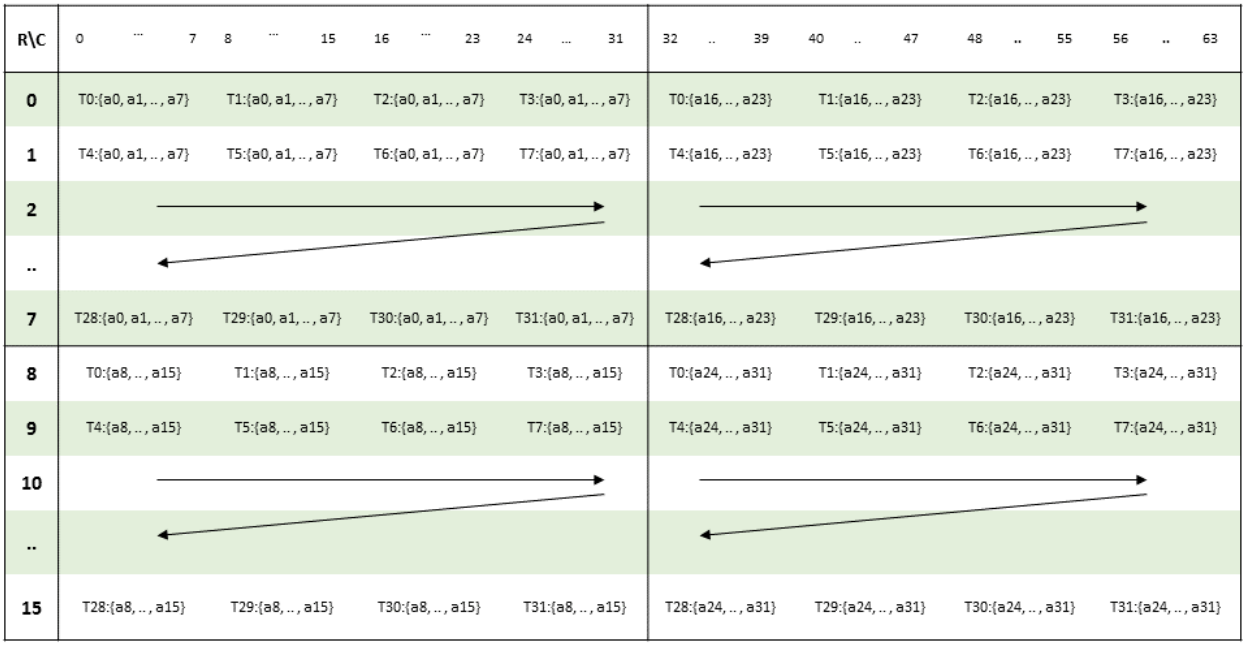

Figure 93: MMA .m16n8k64 fragment layout for matrix A with `.u4` / `.s4` / `.e2m1` type.

(continued from previous page)

```
col =      (threadID_in_group * 8) + (i & 0x7)        for ai where i < 16
           (threadID_in_group * 8) + (i & 0x7) + 32   for ai where i >= 16
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
`.s4` / `.u4`	A vector expression containing two `.b32` registers, with each register containing eight `.s4` / `.u4` elements from the matrix B.	b0, b1, ..., b14, b15
`.e2m1`	A vector expression containing two `.b32` registers, with each register containing eight `.e2m1` elements from the matrix B.	b0, b1, ..., b14, b15

The layout of the fragments held by different threads is shown in Figure 94 and Figure 95.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      (threadID_in_group * 8) + (i & 0x7)          for bi where i < 8
           (threadID_in_group * 8) + (i & 0x7) + 32     for bi where i >= 8

col =   groupID
```

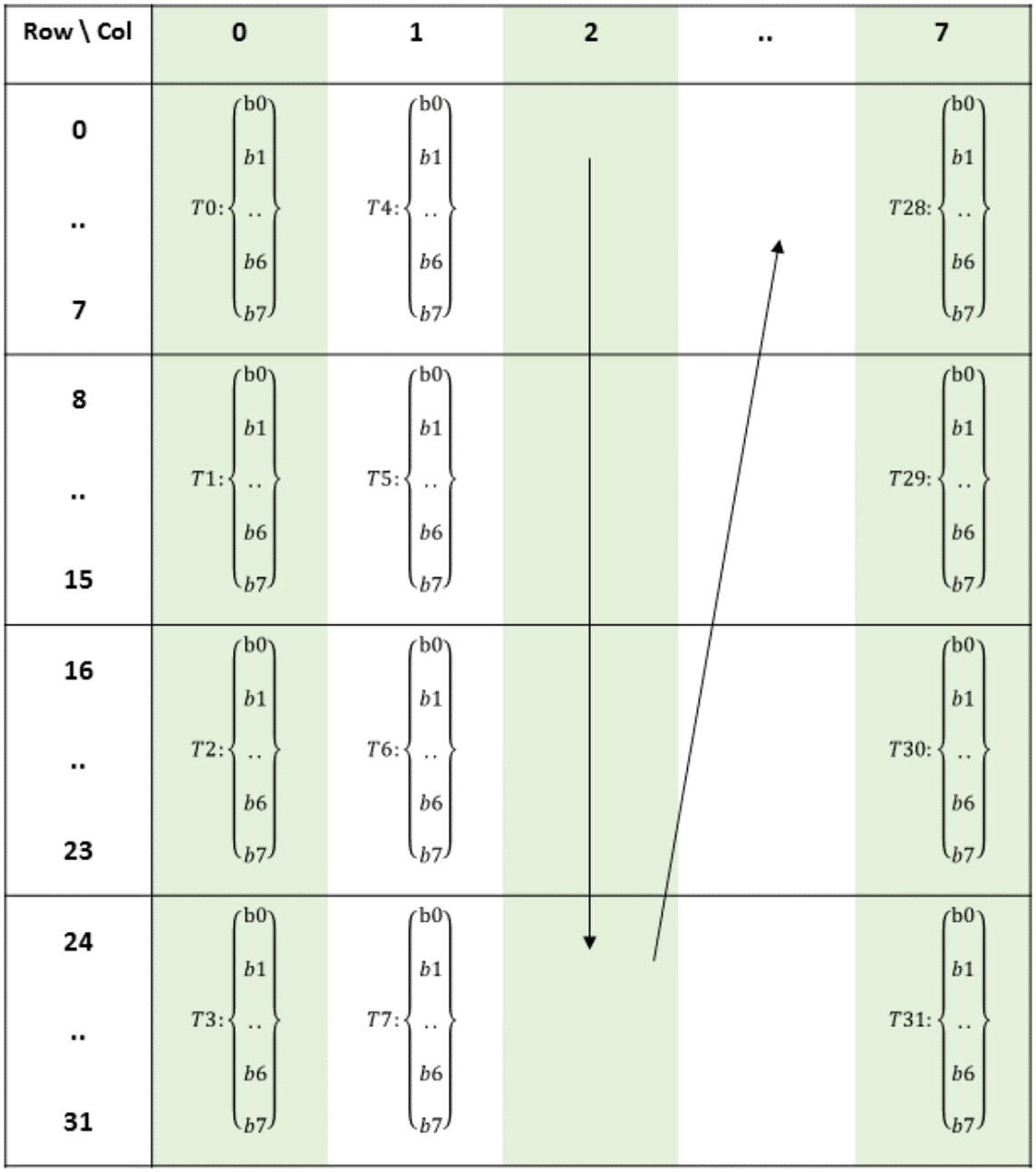

Figure 94: MMA .m16n8k64 fragment layout for rows 0–31 of matrix B with `.u4` / `.s4` / `.e2m1` type.

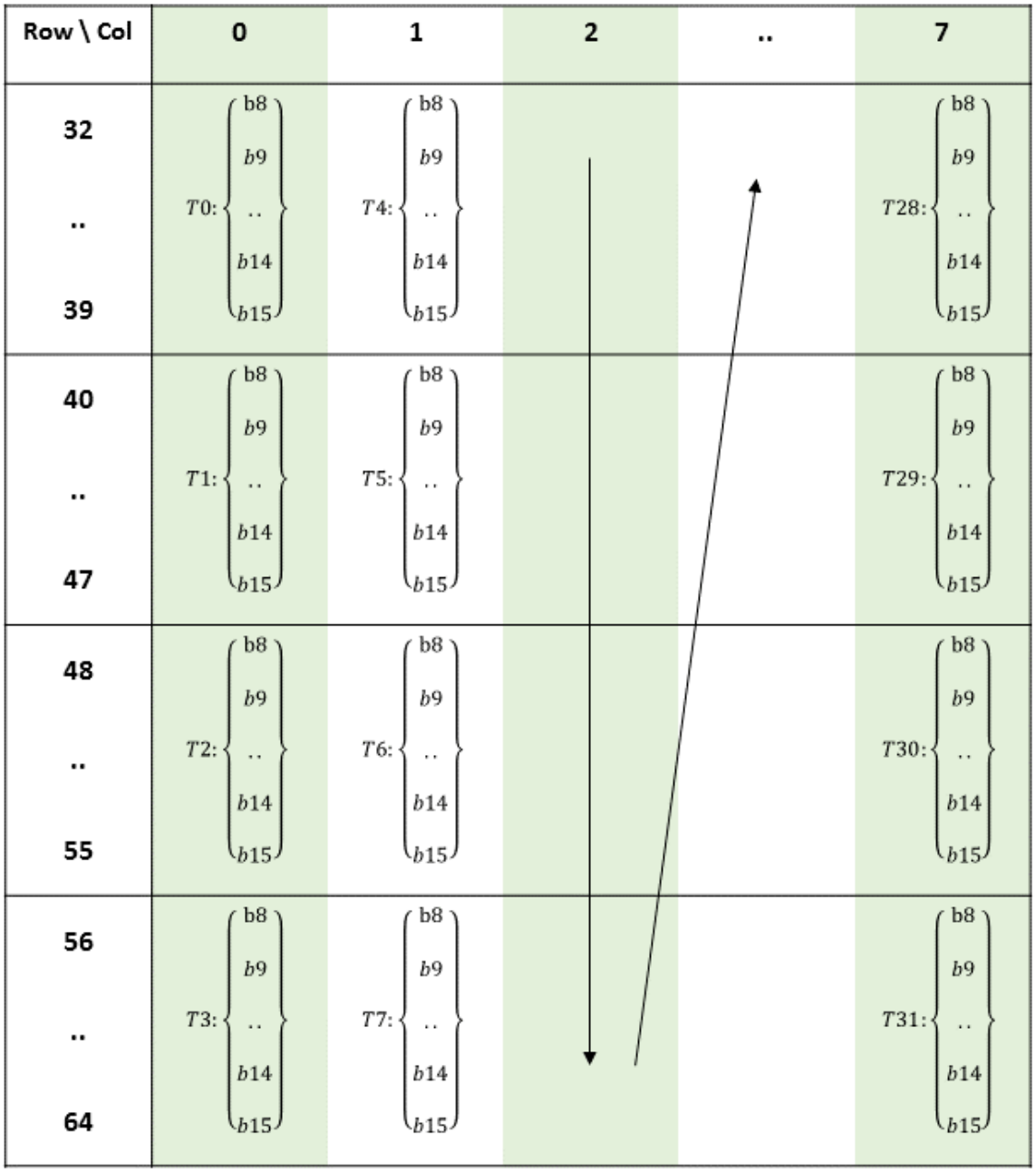

Figure 95: MMA .m16n8k64 fragment layout for rows 32–63 of matrix B with `.u4` / `.s4` / `.e2m1` type.

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.s32	A vector expression containing four .s32 registers, containing four .s32 elements from the matrix C (or D).	c0, c1, c2, c3
.f32	A vector expression containing four .f32 registers, containing four .f32 elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 96.

R\C	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0: {c2, c3}	T1: {c2, c3}	T2: {c2, c3}	T3: {c2, c3}
9	T4: {c2, c3}	T5: {c2, c3}	T6: {c2, c3}	T7: {c2, c3}
10				
..				
15	T28: {c2, c3}	T29: {c2, c3}	T30: {c2, c3}	T31: {c2, c3}

Figure 96: MMA .m16n8k64 fragment layout for accumulator matrix C/D with .s32 / .f32 type.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                            for ci where i <  2
           groupID + 8                        for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)     for ci  where i = {0,..,3}
```

9.7.14.5.12 Matrix Fragments for mma.m16n8k128

A warp executing mma.m16n8k128 will compute an MMA operation of shape .m16n8k128.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
.b1	A vector expression containing two .b32 registers, with each register containing thirty two .b1 elements from the matrix A.	a0, a1, ..., a62, a63

The layout of the fragments held by different threads is shown in Figure 97.

R\C	0 1 .. 31	32 33 .. 63	64 65 .. 95	96 97 .. 127
0	T0:{a0, a1, .., a31}	T1:{a0, a1, .., a31}	T2:{a0, a1, .., a31}	T3:{a0, a1, .., a31}
1	T4:{a0, a1, .., a31}	T5:{a0, a1, .., a31}	T6:{a0, a1, .., a31}	T7:{a0, a1, .., a31}
2				
..				
7	T28:{a0, a1, .., a31}	T29:{a0, a1, .., a31}	T30:{a0, a1, .., a31}	T31:{a0, a1, .., a31}
8	T0:{a32, a33, .., a63}	T1:{a32, a33, .., a63}	T2:{a32, a33, .., a63}	T3:{a32, a33, .., a63}
9	T4:{a32, a33, .., a63}	T5:{a32, a33, .., a63}	T6:{a32, a33, .., a63}	T7:{a32, a33, .., a63}
10				
..				
15	T28:{a32, a33, .., a63}	T29:{a32, a33, .., a63}	T30:{a32, a33, .., a63}	T31:{a32, a33, .., a63}

%laneid:{fragments}

Figure 97: MMA .m16n8k128 fragment layout for matrix A with .b1 type.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                              for ai where i < 32
          groupID + 8                           for ai where i >= 32

col =  (threadID_in_group * 32) + (i & 0x1F)     for ai where i = {0, ...,63}
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
.b1	A vector expression containing a single .b32 register containing thirty two .b1 elements from the matrix B.	b0, b1, … , b30, b31

The layout of the fragments held by different threads is shown in Figure 98.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =  (threadID_in_group * 32) + i         for bi where i = {0,...,31}
col = groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.s32	A vector expression containing four .s32 registers, containing four .s32 elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 99.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID                          for ci where i <  2
          groupID + 8                       for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)    for ci where i = {0, 1, 2, 3}
```

9.7.14.5.13 Matrix Fragments for mma.m16n8k256

A warp executing mma.m16n8k256 will compute an MMA operation of shape .m16n8k256.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements (low to high)
.b1	A vector expression containing four .b32 registers, with each register containing thirty two .b1 elements from the matrix A.	a0, a1, …, a126, a127

The layout of the fragments held by different threads is shown in Figure 100.

The row and column of a matrix fragment can be computed as:

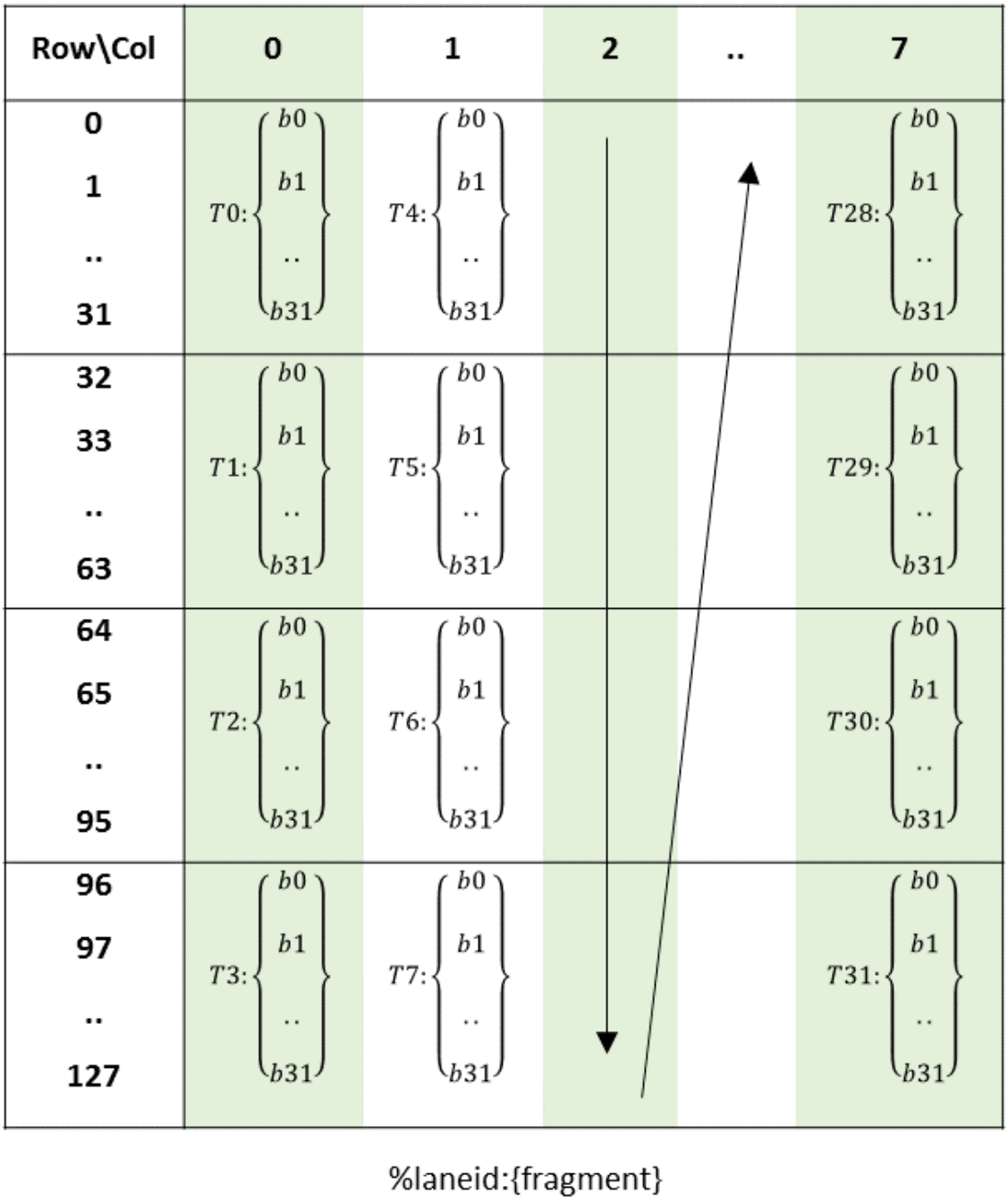

Figure 98: MMA .m16n8k128 fragment layout for matrix B with .b1 type.

R\C	0 1	2 3	4 5	6 7
0	T0: {c0, c1}	T1: {c0, c1}	T2: {c0, c1}	T3: {c0, c1}
1	T4: {c0, c1}	T5: {c0, c1}	T6: {c0, c1}	T7: {c0, c1}
2				
7	T28: {c0, c1}	T29: {c0, c1}	T30: {c0, c1}	T31: {c0, c1}
8	T0: {c2, c3}	T1: {c2, c3}	T2: {c2, c3}	T3: {c2, c3}
9	T4: {c2, c3}	T5: {c2, c3}	T6: {c2, c3}	T7: {c2, c3}
10				
..				
15	T28: {c2, c3}	T29: {c2, c3}	T30: {c2, c3}	T31: {c2, c3}

Figure 99: MMA .m16n8k128 fragment layout for accumulator matrix C/D with `.s32` type.

R\C	0 ... 31	32 ... 63	64 ... 95	96 ... 127	128 .. 159	160 .. 191	192 .. 223	224 .. 255
0	T0:{a0, a1, .. , a31}	T1:{a0, a1, .. , a31}	T2:{a0, a1, .. , a31}	T3:{a0, a1, .. , a31}	T0:{a64, .. , a95}	T1:{a64, .. , a95}	T2:{a64, .. , a95}	T3:{a64, .. , a95}
1	T4:{a0, a1, .. , a31}	T5:{a0, a1, .. , a31}	T6:{a0, a1, .. , a31}	T7:{a0, a1, .. , a31}	T4:{a64, .. , a95}	T5:{a64, .. , a95}	T6:{a64, .. , a95}	T7:{a64, .. , a95}
2								
..								
7	T28:{a0, a1, .. , a31}	T29:{a0, a1, .. , a31}	T30:{a0, a1, .. , a31}	T31:{a0, a1, .. , a31}	T28:{a64, .. , a95}	T29:{a64, .. , a95}	T30:{a64, .. , a95}	T31:{a64, .. , a95}
8	T0:{a32, .. , a63}	T1:{a32, .. , a63}	T2:{a32, .. , a63}	T3:{a32, .. , a63}	T0:{a96, .. , a127}	T1:{a96, .. , a127}	T2:{a96, .. , a127}	T3:{a96, .. , a127}
9	T4:{a32, .. , a63}	T5:{a32, .. , a63}	T6:{a32, .. , a63}	T7:{a32, .. , a63}	T4:{a96, .. , a127}	T5:{a96, .. , a127}	T6:{a96, .. , a127}	T7:{a96, .. , a127}
10								
..								
15	T28:{a32, .. , a63}	T29:{a32, .. , a63}	T30:{a32, .. , a63}	T31:{a32, .. , a63}	T28:{a96, .. , a127}	T29:{a96, .. , a127}	T30:{a96, .. , a127}	T31:{a96, .. , a127}

%laneid:{fragments}

Figure 100: MMA .m16n8k256 fragment layout for matrix A with `.b1` type.

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =   groupID                                                 for ai where 0 <= i <
↪32 || 64 <= i < 96
        groupID + 8                                             otherwise

col =      (threadID_in_group * 32) + i                         for ai where i < 64
           (threadID_in_group * 32) + (i & 0x1F) + 128          for ai where i >= 64
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
.b1	A vector expression containing two .b32 registers, with each register containing thirty two .b1 elements from the matrix B.	b0, b1, ..., b62, b63

The layout of the fragments held by different threads is shown in Figure 101 and Figure 102.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =      (threadID_in_group * 32) + (i & 0x1F)              for bi where i < 32
           (threadID_in_group * 32) + (i & 0x1F) + 128        for bi where i >= 32

col =      groupID
```

- Accumulators (C or D):

.ctype / .dtype	Fragment	Elements (low to high)
.s32	A vector expression containing four .s32 registers, containing four .s32 elements from the matrix C (or D).	c0, c1, c2, c3

The layout of the fragments held by different threads is shown in Figure 103.

The row and column of a matrix fragment can be computed as:

```
groupID           = %laneid >> 2
threadID_in_group = %laneid % 4

row =        groupID                          for ci where i < 2
           groupID + 8                        for ci where i >= 2

col =  (threadID_in_group * 2) + (i & 0x1)     for ci where i = {0, 1, 2, 3}
```

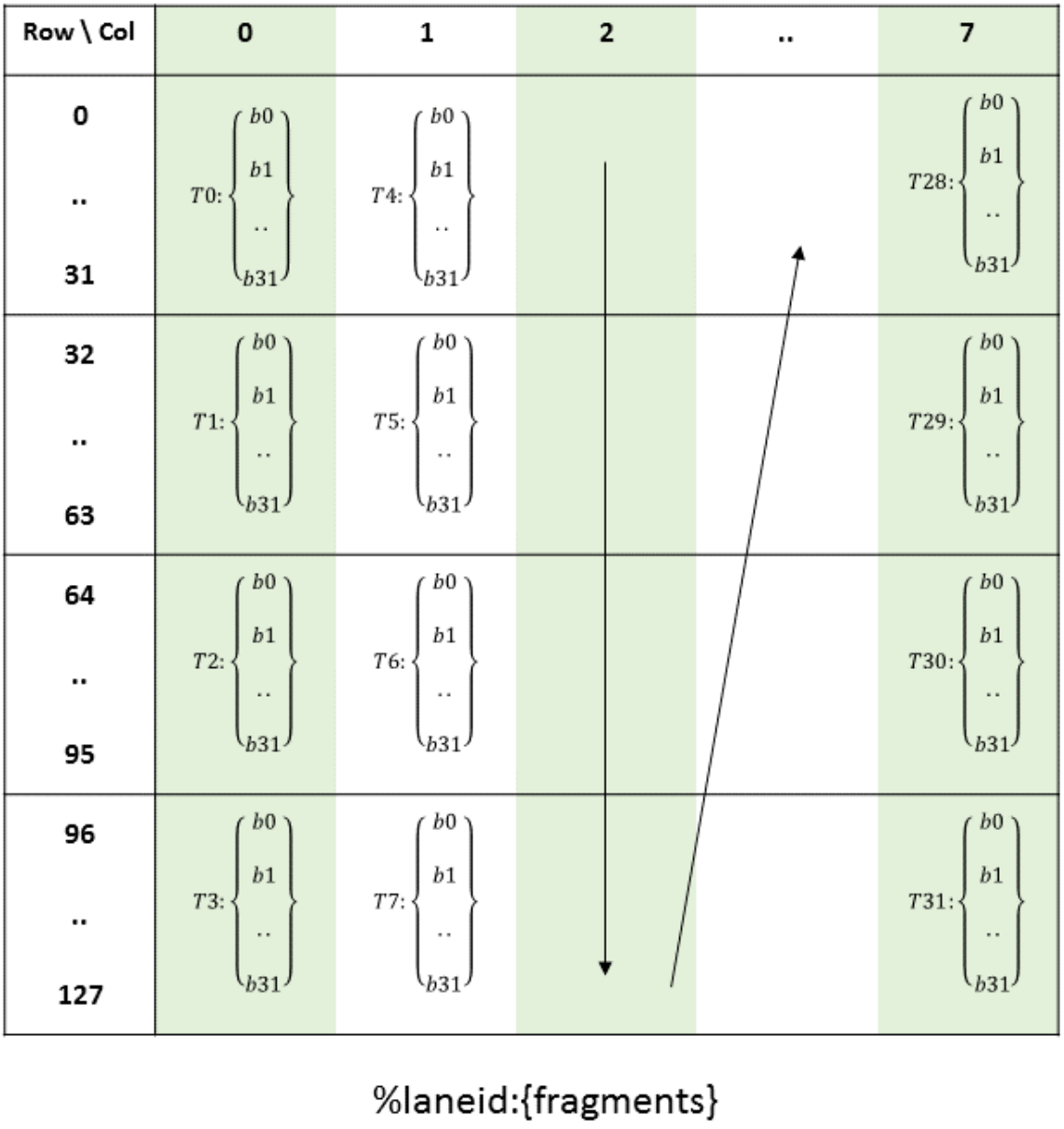

Figure 101: MMA .m16n8k256 fragment layout for rows 0–127 of matrix B with `.b1` type.

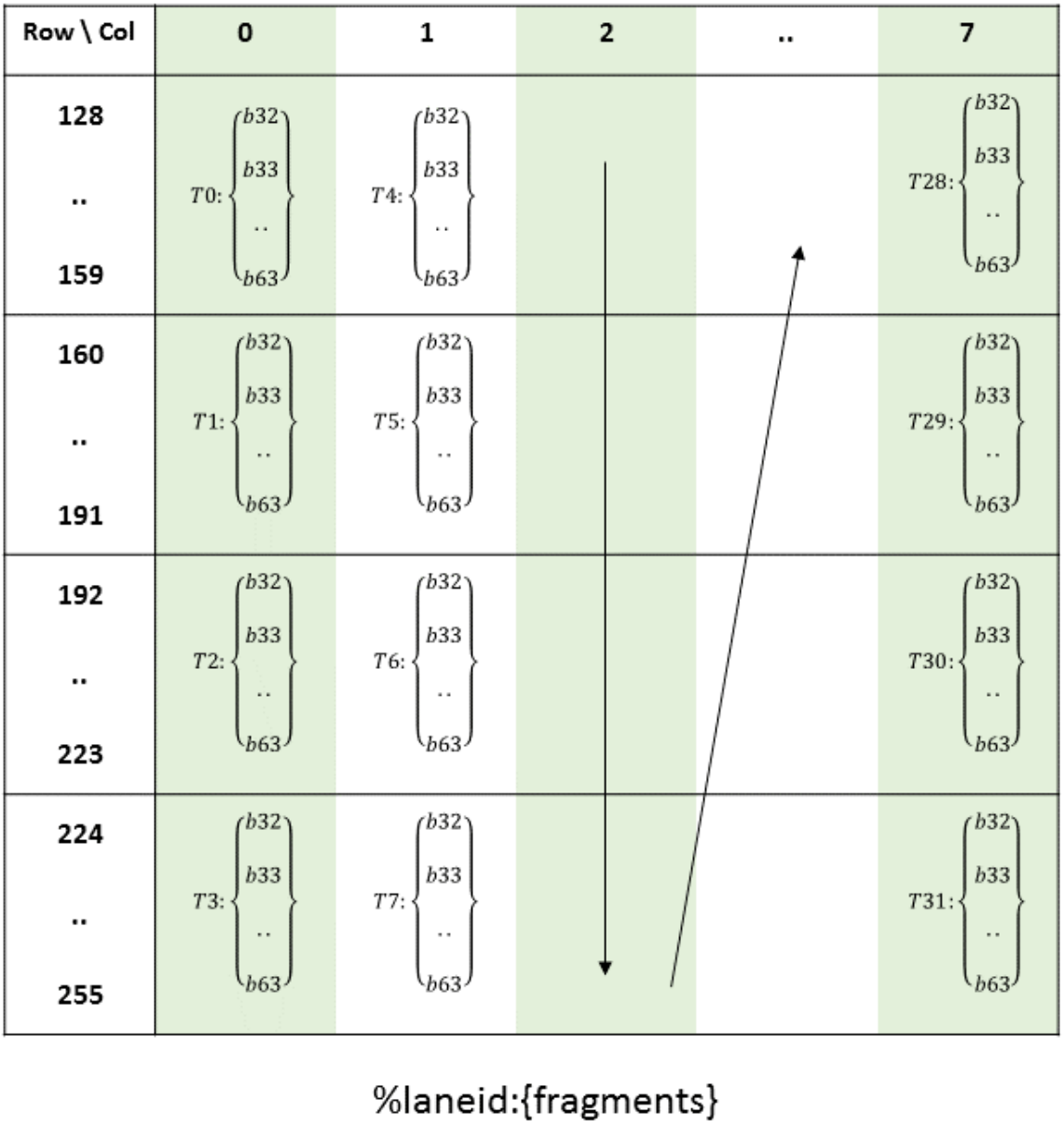

Figure 102: MMA .m16n8k256 fragment layout for rows 128–255 of matrix B with `.b1` type.

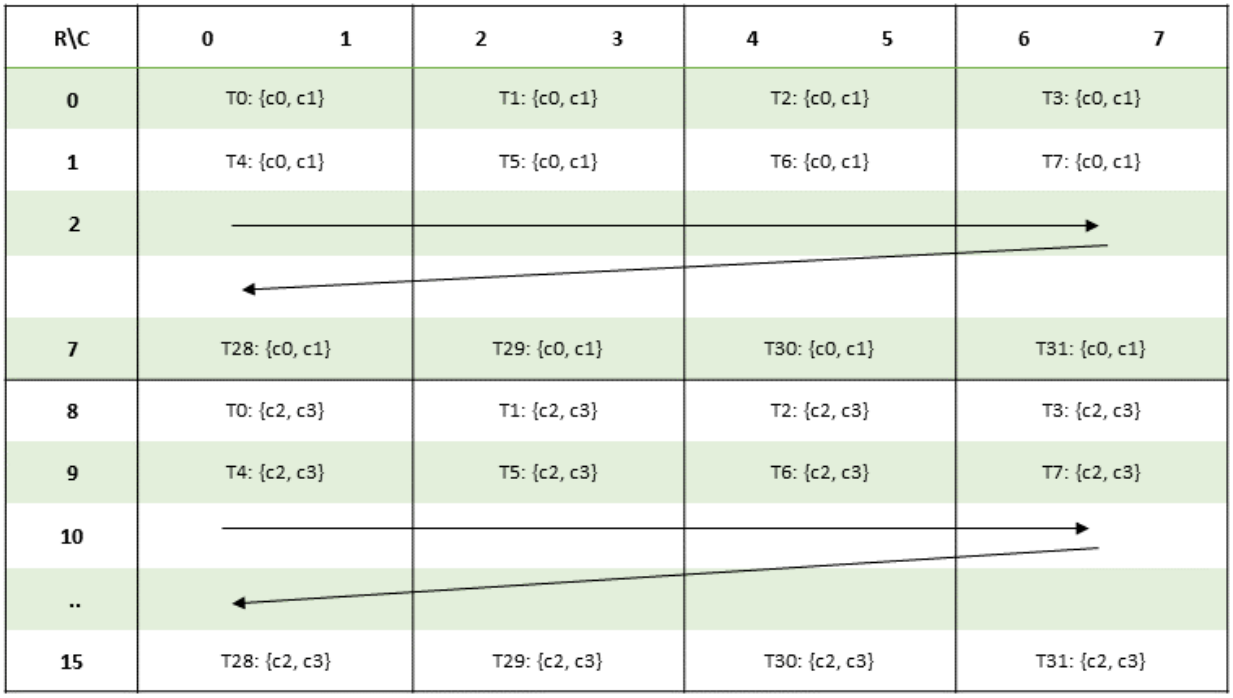

Figure 103: MMA .m16n8k256 fragment layout for accumulator matrix C/D with `.s32` type.

9.7.14.5.14 Multiply-and-Accumulate Instruction: `mma`

`mma`

Perform matrix multiply-and-accumulate operation

Syntax

Half precision floating point type:

```
mma.sync.aligned.m8n8k4.alayout.blayout.dtype.f16.f16.ctype  d, a, b, c;
mma.sync.aligned.m16n8k8.row.col.dtype.f16.f16.ctype  d, a, b, c;
mma.sync.aligned.m16n8k16.row.col.dtype.f16.f16.ctype d, a, b, c;

.alayout = {.row, .col};
.blayout = {.row, .col};
.ctype   = {.f16, .f32};
.dtype   = {.f16, .f32};
```

Alternate floating point type:

```
mma.sync.aligned.m16n8k4.row.col.f32.tf32.tf32.f32        d, a, b, c;
mma.sync.aligned.m16n8k8.row.col.f32.atype.btype.f32      d, a, b, c;
mma.sync.aligned.m16n8k16.row.col.f32.bf16.bf16.f32       d, a, b, c;
mma.sync.aligned.shape.row.col.dtype.f8type.f8type.ctype  d, a, b, c;
mma.sync.aligned.m16n8k32.row.col.kind.dtype.f8f6f4type.f8f6f4type.ctype d, a, b, c;

.atype      = {.bf16, .tf32};
```

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```
.btype      = {.bf16, .tf32};
.f8type     = {.e4m3, .e5m2};
.f8f6f4type = {.e4m3, .e5m2, .e3m2, .e2m3, .e2m1};
.ctype      = {.f16, .f32};
.dtype      = {.f16, .f32};
.shape      = {.m16n8k16, .m16n8k32};
.kind       = {.kind::f8f6f4};
```

Alternate floating point type with block scaling:

```
mma.sync.aligned.m16n8k64.row.col.kind.block_scale{.scale_vec_size}.f32.e2m1.e2m1.f32.
↪stype d, a, b, c, scale-a-data, {byte-id-a, thread-id-a}, scale-b-data, {byte-id-b,
↪thread-id-b};

.kind           = {.kind::mxf4};
.scale_vec_size = {.scale_vec::2X};
.stype          = {.ue8m0};

mma.sync.aligned.m16n8k64.row.col.kind.block_scale.scale_vec_size.f32.e2m1.e2m1.f32.
↪stype d, a, b, c, scale-a-data, {byte-id-a, thread-id-a}, scale-b-data, {byte-id-b,
↪thread-id-b};

.kind           = {.kind::mxf4nvf4};
.scale_vec_size = {.scale_vec::2X, .scale_vec::4X};
.stype          = {.ue8m0, .ue4m3};

mma.sync.aligned.m16n8k32.row.col.kind.block_scale{.scale_vec_size}.f32.f8f6f4type.
↪f8f6f4type.f32.stype d, a, b, c, scale-a-data, {byte-id-a, thread-id-a}, scale-b-
↪data, {byte-id-b, thread-id-b};

.kind           = {.kind::mxf8f6f4};
.scale_vec_size = {.scale_vec::1X};
.f8f6f4type     = {.e4m3, .e5m2, .e3m2, .e2m3, .e2m1};
.stype          = {.ue8m0};
```

Double precision floating point type:

```
mma.sync.aligned.shape.row.col.f64.f64.f64.f64 d, a, b, c;

.shape   = {.m8n84, .m16n8k4, .m16n8k8, .m16n8k16};
```

Integer type:

```
mma.sync.aligned.shape.row.col{.satfinite}.s32.atype.btype.s32 d, a, b, c;

.shape   = {.m8n8k16, .m16n8k16, .m16n8k32}
.atype   = {.u8, .s8};
.btype   = {.u8, .s8};

mma.sync.aligned.shape.row.col{.satfinite}.s32.atype.btype.s32 d, a, b, c;

.shape   = {.m8n8k32, .m16n8k32, .m16n8k64}
.atype   = {.u4, .s4};
.btype   = {.u4, .s4};
```

Single bit:

```
mma.sync.aligned.shape.row.col.s32.b1.b1.s32.bitOp.popc d, a, b, c;

.bitOp = {.xor, .and}
.shape = {.m8n8k128, .m16n8k128, .m16n8k256}
```

Description

Perform a MxNxK matrix multiply and accumulate operation, `D = A*B+C`, where the A matrix is `MxK`, the B matrix is `KxN`, and the C and D matrices are `MxN`.

Qualifier `.block_scale` specifies that the matrices A and B are scaled with `scale_A` and `scale_B` matrices respectively before performing the matrix multiply and accumulate operation as specified in the section *Block Scaling*. The data type corresponding to each of the element within `scale_A` and `Scale_B` matrices is specified by `.stype`. Qualifier `.scale_vec_size` specifies the number of columns of `scale_A` matrix and number of rows in the matrix `scale_B`.

The valid combinations of `.kind`, `.stype` and `.scale_vec_size` are described in Table 38. For `mma` with `.kind::mxf4` when the qualifier `.scale_vec_size` is not specified, then it defaults to 2X. In contrast, when `.kind` is specified as `.kind::mxf8f6f4` then the qualifier `.scale_vec_size` defaults to 1X. However, for `.kind::mxf4nvf4`, it is mandatory to provide valid `.scale_vec_size`.

A warp executing `mma.sync.m8n8k4` instruction computes 4 matrix multiply and accumulate operations. Rest of the `mma.sync` operations compute a single matrix mutliply and accumulate operation per warp.

For single-bit `mma.sync`, multiplication is replaced by a sequence of logical operations; specifically, `mma.xor.popc` and `mma.and.popc` computes the XOR, AND respectively of a k-bit row of A with a k-bit column of B, then counts the number of set bits in the result (`popc`). This result is added to the corresponding element of C and written into D.

Operands `a` and `b` represent two multiplicand matrices A and B, while `c` and `d` represent the accumulator and destination matrices, distributed across the threads in warp. When `.block_scale` qualifier is specified, operand `scale-a-data`, `scale-b-data` represents the scale matrix metadata corresponding to `scale_A` and `scale_B` matrices respectively. The tuple `{byte-id-a, thread-id-a}` and `{byte-id-b, thread-id-b}` represent selectors for matrices `scale_A` and `scale_B` respectively from their corresponding metadata arguments `scale-a-data`, `scale-b-data`. The operands `scale-a-data`, `scale-b-data` are of type `.b32`. The operands `byte-id-a`, `thread-id-a`, `byte-id-b`, `thread-id-b` are unsigned 16-bit integer values. For more details on selector arguments refer *Block Scaling* section.

The registers in each thread hold a fragment of matrix as described in *Matrix multiply-accumulate operation using mma instruction*.

The qualifiers `.dtype`, `.atype`, `.btype` and `.ctype` indicate the data-type of the elements in the matrices D, A, B and C respectively. The qualifier `.stype` indicate the data-type of the elements in the matrices `scale_A` and `scale_B`. Specific shapes have type restrictions :

- `.m8n8k4` : When `.ctype` is `.f32`, `.dtype` must also be `.f32`.
- `.m16n8k8` :
  - `.dtype` must be the same as `.ctype`.
  - `.atype` must be the same as `.btype`.

The qualifiers `.alayout` and `.blayout` indicate the row-major or column-major layouts of matrices A and B respectively.

When `.kind` is either of `.kind::mxf8f6f4` or `.kind::f8f6f4`, the individual 4-bit and the 6-bit floating point type elements must be packed in an 8-bit container. The matrix element of type `.e2m1` resides in central 4 bits of the 8-bit container with padding in the upper 2 bits and lower 2 bits of the container. When the matrix element is of type `.e3m2` or `.e2m3`, the matrix element resides in the lower 6 bits of the 8-bit container with padding in the upper 2 bits of the container. In contrast, note that when using `mma` with `.kind::mxf4` or `.kind::mxf4nvf4`, no explicit padding is necessary even though matrix elements are of type `.e2m1`.

Precision and rounding :

- `.f16` floating point operations:

  Element-wise multiplication of matrix A and B is performed with at least single precision. When `.ctype` or `.dtype` is `.f32`, accumulation of the intermediate values is performed with at least single precision. When both `.ctype` and `.dtype` are specified as `.f16`, the accumulation is performed with at least half precision.

  The accumulation order, rounding and handling of subnormal inputs are unspecified.

- `.e4m3`, `.e5m2`, `.e3m2`, `.e2m3`, `.e2m1` floating point operations :

  Element-wise multiplication of matrix A and B is performed with specified precision. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- `.bf16` and `.tf32` floating point operations :

  Element-wise multiplication of matrix A and B is performed with specified precision. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- `.f64` floating point operations :

  Precision of the element-wise multiplication and addition operation is identical to that of `.f64` precision fused multiply-add. Supported rounding modifiers are :

  - `.rn` : mantissa LSB rounds to nearest even. This is the default.
  - `.rz` : mantissa LSB rounds towards zero.
  - `.rm` : mantissa LSB rounds towards negative infinity.
  - `.rp` : mantissa LSB rounds towards positive infinity.

- Integer operations :

  The integer `mma` operation is performed with `.s32` accumulators. The `.satfinite` qualifier indicates that on overflow, the accumulated value is limited to the range *MIN_INT32*.. *MAX_INT32* (where the bounds are defined as the minimum negative signed 32-bit integer and the maximum positive signed 32-bit integer respectively).

  If `.satfinite` is not specified, the accumulated value is wrapped instead.

The mandatory `.sync` qualifier indicates that `mma` instruction causes the executing thread to wait until all threads in the warp execute the same `mma` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `mma` instruction. In conditionally executed code, a `mma` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of `mma` instruction is undefined if all threads in the same warp do not use the same qualifiers, or if any thread in the warp has exited.

Notes

Programs using double precision floating point `mma` instruction with shapes `.m16n8k4`, `.m16n8k8`, and `.m16n8k16` require at least 64 registers for compilation.

PTX ISA Notes

Introduced in PTX ISA version 6.4.

`.f16` floating point type `mma` operation with `.m8n8k4` shape introduced in PTX ISA version 6.4.

`.f16` floating point type `mma` operation with `.m16n8k8` shape introduced in PTX ISA version 6.5.

`.u8/.s8` integer type `mma` operation with `.m8n8k16` shape introduced in PTX ISA version 6.5.

`.u4/.s4` integer type `mma` operation with `.m8n8k32` shape introduced in PTX ISA version 6.5.

`.f64` floating point type `mma` operation with `.m8n8k4` shape introduced in PTX ISA version 7.0.

`.f16` floating point type `mma` operation with `.m16n8k16` shape introduced in PTX ISA version 7.0.

`.bf16` alternate floating point type `mma` operation with `.m16n8k8` and `.m16n8k16` shapes introduced in PTX ISA version 7.0.

`.tf32` alternate floating point type `mma` operation with `.m16n8k4` and `.m16n8k8` shapes introduced in PTX ISA version 7.0.

`.u8/.s8` integer type `mma` operation with `.m16n8k16` and `.m16n8k32` shapes introduced in PTX ISA version 7.0.

`.u4/.s4` integer type `mma` operation with `.m16n8k32` and `.m16n8k64` shapes introduced in PTX ISA version 7.0.

`.b1` single-bit integer type `mma` operation with `.m8n8k128`, `.m16n8k128` and `.m16n8k256` shapes introduced in PTX ISA version 7.0.

Support for `.and` operation in single-bit `mma` introduced in PTX ISA version 7.1.

`.f64` floating point type `mma` operation with `.m16n8k4`, `.m16n8k8`, and `.m16n8k16` shapes introduced in PTX ISA version 7.8.

Support for `.e4m3` and `.e5m2` alternate floating point type `mma` operation introduced in PTX ISA version 8.4.

Support for shape `.m16n8k16` and `.f16` `dtype/ctype` with `.e4m3/.e5m2` alternate floating point type mma operation introduced in PTX ISA version 8.7.

Support for `.e3m2`, `.e2m3`, `.e2m1` alternate floating point type `mma` operation introduced in PTX ISA version 8.7.

Support for `.kind`, `.block_scale`, `.scale_vec_size` qualifier introduced in PTX ISA version 8.7.

Target ISA Notes

Requires sm_70 or higher.

.f16 floating point type mma operation with .m8n8k4 shape requires sm_70 or higher.

Note: mma.sync.m8n8k4 is optimized for target architecture sm_70 and may have substantially reduced performance on other target architectures.

.f16 floating point type mma operation with .m16n8k8 shape requires sm_75 or higher.

.u8/.s8 integer type mma operation with .m8n8k16 shape requires sm_75 or higher.

.u4/.s4 integer type mma operation with .m8n8k32 shape sm_75 or higher.

.b1 single-bit integer type mma operation with .m8n8k128 shape sm_75 or higher.

.f64 floating point type mma operation with .m8n8k4 shape requires sm_80 or higher.

.f16 floating point type mma operation with .m16n8k16 shape requires sm_80 or higher.

.bf16 alternate floating point type mma operation with .m16n8k8 and .m16n8k16 shapes requires sm_80 or higher.

.tf32 alternate floating point type mma operation with .m16n8k4 and .m16n8k8 shapes requires sm_80 or higher.

.u8/.s8 integer type mma operation with .m16n8k16 and .m16n8k32 shapes requires sm_80 or higher.

.u4/.s4 integer type mma operation with .m16n8k32 and .m16n8k64 shapes requires sm_80 or higher.

.b1 single-bit integer type mma operation with .m16n8k128 and .m16n8k256 shapes requires sm_80 or higher.

.and operation in single-bit mma requires sm_80 or higher.

.f64 floating point type mma operation with .m16n8k4, .m16n8k8, and .m16n8k16 shapes require sm_90 or higher.

.e4m3 and .e5m2 alternate floating point type mma operation requires sm_89 or higher.

.e3m2, .e2m3 and .e2m1 alternate floating point type mma operation requires sm_120a and is supported on sm_120f from PTX ISA version 8.8.

Support for .kind, .block_scale, .scale_vec_size qualifier requires sm_120a and are supported on sm_120f or higher in the same family from PTX ISA version 8.8.

Examples of half precision floating point type

```
// f16 elements in C and D matrix
.reg .f16x2 %Ra<2> %Rb<2> %Rc<4> %Rd<4>
mma.sync.aligned.m8n8k4.row.col.f16.f16.f16.f16
{%Rd0, %Rd1, %Rd2, %Rd3},
{%Ra0, %Ra1},
{%Rb0, %Rb1},
{%Rc0, %Rc1, %Rc2, %Rc3};


// f16 elements in C and f32 elements in D
.reg .f16x2 %Ra<2> %Rb<2> %Rc<4>
```

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```
.reg .f32 %Rd<8>
mma.sync.aligned.m8n8k4.row.col.f32.f16.f16.f16
{%Rd0, %Rd1, %Rd2, %Rd3, %Rd4, %Rd5, %Rd6, %Rd7},
{%Ra0, %Ra1},
{%Rb0, %Rb1},
{%Rc0, %Rc1, %Rc2, %Rc3};

 // f32 elements in C and D
.reg .f16x2 %Ra<2>, %Rb<1>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k8.row.col.f32.f16.f16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .f16x2 %Ra<4>, %Rb<2>, %Rc<2>, %Rd<2>;
mma.sync.aligned.m16n8k16.row.col.f16.f16.f16.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1};

.reg .f16 %Ra<4>, %Rb<2>;
.reg .f32 %Rc<2>, %Rd<2>;
mma.sync.aligned.m16n8k16.row.col.f32.f16.f16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};
```

Examples of alternate floating point type

```
.reg .b32 %Ra<2>, %Rb<1>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k4.row.col.f32.tf32.tf32.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .f16x2 %Ra<2>, %Rb<1>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k8.row.col.f32.bf16.bf16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<2>, %Rb<1>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k8.row.col.f32.tf32.tf32.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Rb2, %Rb3},
```

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```
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .f16x2 %Ra<2>, %Rb<1>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k16.row.col.f32.bf16.bf16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.f32.e4m3.e5m2.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k16.row.col.f32.e5m2.e4m3.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .b32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.f16.e4m3.e5m2.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .b32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k16.row.col.f16.e5m2.e5m2.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.kind::f8f6f4.f32.e3m2.e2m3.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .b32 %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.kind::f8f6f4.f16.e2m3.e2m1.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1, %Ra2, %Ra3},
```

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```
  {%Rb0, %Rb1},
  {%Rc0, %Rc1};
```

Examples of integer type

```
.reg .b32 %Ra, %Rb, %Rc<2>, %Rd<2>;

// s8 elements in A and u8 elements in B
mma.sync.aligned.m8n8k16.row.col.satfinite.s32.s8.u8.s32
  {%Rd0, %Rd1},
  {%Ra},
  {%Rb},
  {%Rc0, %Rc1};

// u4 elements in A and B matrix
mma.sync.aligned.m8n8k32.row.col.satfinite.s32.u4.u4.s32
  {%Rd0, %Rd1},
  {%Ra},
  {%Rb},
  {%Rc0, %Rc1};

// s8 elements in A and u8 elements in B
.reg .b32 %Ra<2>, %Rb, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k16.row.col.satfinite.s32.s8.u8.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb},
  {%Rc0, %Rc1, %Rc2, %Rc3};

// u4 elements in A and s4 elements in B
.reg .b32 %Ra<2>, %Rb, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.satfinite.s32.u4.s4.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb},
  {%Rc0, %Rc1, %Rc2, %Rc3};

// s8 elements in A and s8 elements in B
.reg .b32 %Ra<4>, %Rb<2>, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k32.row.col.satfinite.s32.s8.s8.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

// u8 elements in A and u8 elements in B
.reg .b32 %Ra<4>, %Rb<2>, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k64.row.col.satfinite.s32.u4.u4.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1 },
  {%Rc0, %Rc1, %Rc2, %Rc3};
```

Examples of single bit type

```
// b1 elements in A and B
.reg .b32 %Ra, %Rb, %Rc<2>, %Rd<2>;
mma.sync.aligned.m8n8k128.row.col.s32.b1.b1.s32.and.popc
  {%Rd0, %Rd1},
  {%Ra},
  {%Rb},
  {%Rc0, %Rc1};

// b1 elements in A and B
.reg .b32 %Ra, %Rb, %Rc<2>, %Rd<2>;
mma.sync.aligned.m8n8k128.row.col.s32.b1.b1.s32.xor.popc
  {%Rd0, %Rd1},
  {%Ra},
  {%Rb},
  {%Rc0, %Rc1};

.reg .b32 %Ra<2>, %Rb, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k128.row.col.s32.b1.b1.s32.xor.popc
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<2>, %Rb, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k128.row.col.s32.b1.b1.s32.and.popc
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<2>, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k256.row.col.s32.b1.b1.s32.xor.popc
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

.reg .b32 %Ra<4>, %Rb<2>, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k256.row.col.s32.b1.b1.s32.and.popc
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};
```

Examples of .f64 floating point type

```
.reg .f64 %Ra, %Rb, %Rc<2>, %Rd<2>;
mma.sync.aligned.m8n8k4.row.col.f64.f64.f64.f64
  {%Rd0, %Rd1},
  {%Ra},
  {%Rb},
  {%Rc0, %Rc1};
```

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```
.reg .f64 %Ra<8>, %Rb<4>, %Rc<4>, %Rd<4>;
mma.sync.aligned.m16n8k4.row.col.f64.f64.f64.f64.rn
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0},
  {%Rc0, %Rc1, %Rc2, %Rc3};

mma.sync.aligned.m16n8k8.row.col.f64.f64.f64.f64.rn
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3};

mma.sync.aligned.m16n8k16.row.col.f64.f64.f64.f64.rn
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3, %Ra4, %Ra5, %Ra6, %Ra7},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3};
```

Examples of `mma` with block scale

```
.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
mma.sync.aligned.m16n8k64.row.col.kind::mxf4.block_scale.f32.e2m1.e2m1.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  scaleAData, {2, 1}, scaleBData, {2, 3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
.reg .u16 bidA, bidB, tidA, tidB;
mma.sync.aligned.m16n8k64.row.col.kind::mxf4nvf4.block_scale.scale_vec::4X.f32.e2m1.
↪e2m1.f32.ue4m3
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  scaleAData, {bidA, tidA}, scaleBData, {bidB, tidB};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
mma.sync.aligned.m16n8k32.row.col.kind::mxf8f6f4.block_scale.scale_vec::1X.f32.e3m2.
↪e2m1.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  scaleAData, {0, 1}, scaleBData, {0, 1};
```

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```
.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
mma.sync.aligned.m16n8k32.row.col.kind::mxf8f6f4.block_scale.scale_vec::1X.f32.e4m3.
↪e5m2.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2,  %Ra3},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  scaleAData, {0, 1}, scaleBData, {0, 0};
```

9.7.14.5.15 Warp-level matrix load instruction: `ldmatrix`

`ldmatrix`

Collectively load one or more matrices from shared memory for `mma` instruction

Syntax

```
ldmatrix.sync.aligned.shape.num{.trans}{.ss}.type r, [p];

ldmatrix.sync.aligned.m8n16.num{.ss}.dst_fmt.src_fmt        r, [p];
ldmatrix.sync.aligned.m16n16.num.trans{.ss}.dst_fmt.src_fmt r, [p];

.shape   = {.m8n8, .m16n16};
.num     = {.x1, .x2, .x4};
.ss      = {.shared{::cta}};
.type    = {.b16, .b8};
.dst_fmt = { .b8x16 };
.src_fmt = { .b6x16_p32, .b4x16_p64 };
```

Description

Collectively load one or more matrices across all threads in a warp from the location indicated by the address operand `p`, from `.shared` state space into destination register `r`. If no state space is provided, generic addressing is used, such that the address in `p` points into `.shared` space. If the generic address doesn't fall in `.shared` state space, then the behavior is undefined.

The `.shape` qualifier indicates the dimensions of the matrices being loaded. Each matrix element holds 16-bit or 8-bit or 6-bit or 4-bit data.

Following table shows the matrix load case for each `.shape`.

.shape	Matrix shape	Element size
.m8n8	8x8	16-bit
.m16n16	16x16	8-bit or 6-bit or 4-bit
.m8n16	8x16	6-bit or 4-bit

Following table shows the valid use of 6-bit or 4-bit data load.

.src_fmt	.shape	Source data	Padding	.dst_fmt
.b6x16_p32	.m8n16	16 6-bit elements	32 bits	.b8x16 (16 8-bit elements)
	.m16n16			
.b4x16_p64	.m8n16	16 4-bit elements	64 bits	
	.m16n16			

For .b6x16_p32 format source data is 16 unsigned 6-bit elements with 32 bits padding. For .b4x16_p64 format source data is 16 unsigned 4-bit elements with 64 bits padding.

The values .x1, .x2 and .x4 for .num indicate one, two or four matrices respectively. When .shape is .m16n16, only .x1 and .x2 are valid values for .num.

The mandatory .sync qualifier indicates that ldmatrix causes the executing thread to wait until all threads in the warp execute the same ldmatrix instruction before resuming execution.

The mandatory .aligned qualifier indicates that all threads in the warp must execute the same ldmatrix instruction. In conditionally executed code, an ldmatrix instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise the behavior is undefined.

The behavior of ldmatrix is undefined if all threads do not use the same qualifiers, or if any thread in the warp has exited.

The destination operand r is a brace-enclosed vector expression consisting of 1, 2, or 4 32-bit registers as per the value of .num. Each component of the vector expression holds a fragment from the corresponding matrix.

Supported addressing modes for p are described in *Addresses as Operands*.

Consecutive instances of row need not be stored contiguously in memory. The eight addresses required for each matrix are provided by eight threads, depending upon the value of .num as shown in the following table. Each address corresponds to the start of a matrix row. Addresses addr0–addr7 correspond to the rows of the first matrix, addresses addr8–addr15 correspond to the rows of the second matrix, and so on.

.num	Threads 0–7	Threads 8–15	Threads 16–23	Threads 24–31
.x1	addr0–addr7	–	–	–
.x2	addr0–addr7	addr8–addr15	–	–
.x4	addr0–addr7	addr8–addr15	addr16–addr23	addr24–addr31

Note: For .target sm_75 or below, all threads must contain valid addresses. Otherwise, the behavior is undefined. For .num = .x1 and .num = .x2, addresses contained in lower threads can be copied to higher threads to achieve the expected behavior.

When reading 8x8 matrices, a group of four consecutive threads loads 16 bytes. The matrix addresses must be naturally aligned accordingly.

Each thread in a warp loads fragments of a row, with thread 0 receiving the first fragment in its register r, and so on. A group of four threads loads an entire row of the matrix as shown in Figure 104.

Row\Col	0	1	2	3	4	5	6	7
0	T0:r	T0:r	T1:r	T1:r	T2:r	T2:r	T3:r	T3:r
1	T4:r	T4:r	T5:r	T5:r	T6:r	T6:r	T7:r	T7:r
2	T8:r	T8:r	T9:r	T9:r	T10:r	T10:r	T11:r	T11:r
3	T12:r	T12:r	T13:r	T13:r	T14:r	T14:r	T15:r	T15:r
4	T16:r	T16:r	T17:r	T17:r	T18:r	T18:r	T19:r	T19:r
5	T20:r	T20:r	T21:r	T21:r	T22:r	T22:r	T23:r	T23:r
6	T24:r	T24:r	T25:r	T25:r	T26:r	T26:r	T27:r	T27:r
7	T28:r	T28:r	T29:r	T29:r	T30:r	T30:r	T31:r	T31:r

Figure 104: ldmatrix fragment layout for one 8x8 Matrix with 16-bit elements

When `.num = .x2`, the elements of the second matrix are loaded in the next destination register in each thread as per the layout in above table. Similarly, when `.num = .x4`, elements of the third and fourth matrices are loaded in the subsequent destination registers in each thread.

For matrix shape 16x16, two destination registers `r0` and `r1` of type `.b32` must be specified and in each register four 8-bit elements are loaded. For 4-bit or 6-bit data, 8-bit element will have 4 bits or 2 bits of padding respectively. Refer *Optional Decompression* for more details on these formats.

An entire row of the matrix can be loaded by a group of four consecutive and aligned threads. Each thread in a warp loads 4 consecutive columns across 2 rows as shown in the Figure 105.

Row\Col	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	T0:r0	T0:r0	T0:r0	T0:r0	T1:r0	T1:r0	T1:r0	T1:r0	T2:r0	T2:r0	T2:r0	T2:r0	T3:r0	T3:r0	T3:r0	T3:r0
1	T4:r0	T4:r0	T4:r0	T4:r0	T5:r0	T5:r0	T5:r0	T5:r0	T6:r0	T6:r0	T6:r0	T6:r0	T7:r0	T7:r0	T7:r0	T7:r0
2	T8:r0	T8:r0	T8:r0	T8:r0	T9:r0	T9:r0	T9:r0	T9:r0	T10:r0	T10:r0	T10:r0	T10:r0	T11:r0	T11:r0	T11:r0	T11:r0
3	T12:r0	T12:r0	T12:r0	T12:r0	T13:r0	T13:r0	T13:r0	T13:r0	T14:r0	T14:r0	T14:r0	T14:r0	T15:r0	T15:r0	T15:r0	T15:r0
4	T16:r0	T16:r0	T16:r0	T16:r0	T17:r0	T17:r0	T17:r0	T17:r0	T18:r0	T18:r0	T18:r0	T18:r0	T19:r0	T19:r0	T19:r0	T19:r0
5	T20:r0	T20:r0	T20:r0	T20:r0	T21:r0	T21:r0	T21:r0	T21:r0	T22:r0	T22:r0	T22:r0	T22:r0	T23:r0	T23:r0	T23:r0	T23:r0
6	T24:r0	T24:r0	T24:r0	T24:r0	T25:r0	T25:r0	T25:r0	T25:r0	T26:r0	T26:r0	T26:r0	T26:r0	T27:r0	T27:r0	T27:r0	T27:r0
7	T28:r0	T28:r0	T28:r0	T28:r0	T29:r0	T29:r0	T29:r0	T29:r0	T30:r0	T30:r0	T30:r0	T30:r0	T31:r0	T31:r0	T31:r0	T31:r0
8	T0:r1	T0:r1	T0:r1	T0:r1	T1:r1	T1:r1	T1:r1	T1:r1	T2:r1	T2:r1	T2:r1	T2:r1	T3:r1	T3:r1	T3:r1	T3:r1
9	T4:r1	T4:r1	T4:r1	T4:r1	T5:r1	T5:r1	T5:r1	T5:r1	T6:r1	T6:r1	T6:r1	T6:r1	T7:r1	T7:r1	T7:r1	T7:r1
10	T8:r1	T8:r1	T8:r1	T8:r1	T9:r1	T9:r1	T9:r1	T9:r1	T10:r1	T10:r1	T10:r1	T10:r1	T11:r1	T11:r1	T11:r1	T11:r1
11	T12:r1	T12:r1	T12:r1	T12:r1	T13:r1	T13:r1	T13:r1	T13:r1	T14:r1	T14:r1	T14:r1	T14:r1	T15:r1	T15:r1	T15:r1	T15:r1
12	T16:r1	T16:r1	T16:r1	T16:r1	T17:r1	T17:r1	T17:r1	T17:r1	T18:r1	T18:r1	T18:r1	T18:r1	T19:r1	T19:r1	T19:r1	T19:r1
13	T20:r1	T20:r1	T20:r1	T20:r1	T21:r1	T21:r1	T21:r1	T21:r1	T22:r1	T22:r1	T22:r1	T22:r1	T23:r1	T23:r1	T23:r1	T23:r1
14	T24:r1	T24:r1	T24:r1	T24:r1	T25:r1	T25:r1	T25:r1	T25:r1	T26:r1	T26:r1	T26:r1	T26:r1	T27:r1	T27:r1	T27:r1	T27:r1
15	T28:r1	T28:r1	T28:r1	T28:r1	T29:r1	T29:r1	T29:r1	T29:r1	T30:r1	T30:r1	T30:r1	T30:r1	T31:r1	T31:r1	T31:r1	T31:r1

Figure 105: ldmatrix fragment layout for one 16x16 matrix with 8-bit elements

For matrix shape 8x16, one destination register `r0` of type `.b32` must be specified where four 8-bit elements are loaded in the register. For 4-bit or 6-bit data, 8-bit element will have 4 bits or 2 bits of padding respectively.

An entire row of the matrix can be loaded by a group of four consecutive and aligned threads. Each

thread in a warp loads 4 consecutive columns as shown in Figure 106.

Row\Col	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	T0:r0	T0:r0	T0:r0	T0:r0	T1:r0	T1:r0	T1:r0	T1:r0	T2:r0	T2:r0	T2:r0	T2:r0	T3:r0	T3:r0	T3:r0	T3:r0
1	T4:r0	T4:r0	T4:r0	T4:r0	T5:r0	T5:r0	T5:r0	T5:r0	T6:r0	T6:r0	T6:r0	T6:r0	T7:r0	T7:r0	T7:r0	T7:r0
2	T8:r0	T8:r0	T8:r0	T8:r0	T9:r0	T9:r0	T9:r0	T9:r0	T10:r0	T10:r0	T10:r0	T10:r0	T11:r0	T11:r0	T11:r0	T11:r0
3	T12:r0	T12:r0	T12:r0	T12:r0	T13:r0	T13:r0	T13:r0	T13:r0	T14:r0	T14:r0	T14:r0	T14:r0	T15:r0	T15:r0	T15:r0	T15:r0
4	T16:r0	T16:r0	T16:r0	T16:r0	T17:r0	T17:r0	T17:r0	T17:r0	T18:r0	T18:r0	T18:r0	T18:r0	T19:r0	T19:r0	T19:r0	T19:r0
5	T20:r0	T20:r0	T20:r0	T20:r0	T21:r0	T21:r0	T21:r0	T21:r0	T22:r0	T22:r0	T22:r0	T22:r0	T23:r0	T23:r0	T23:r0	T23:r0
6	T24:r0	T24:r0	T24:r0	T24:r0	T25:r0	T25:r0	T25:r0	T25:r0	T26:r0	T26:r0	T26:r0	T26:r0	T27:r0	T27:r0	T27:r0	T27:r0
7	T28:r0	T28:r0	T28:r0	T28:r0	T29:r0	T29:r0	T29:r0	T29:r0	T30:r0	T30:r0	T30:r0	T30:r0	T31:r0	T31:r0	T31:r0	T31:r0

Figure 106: ldmatrix fragment layout for one 8x16 matrix with 8-bit elements containing 4-bit/6-bit data

Optional qualifier `.trans` indicates that the matrix is loaded in column-major format. However, for 16x16 matrices, `.trans` is mandatory.

The `ldmatrix` instruction is treated as a weak memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 6.5.

Support for `::cta` sub-qualifier introduced in PTX ISA version 7.8.

Support for `.m16n16`, `.m8n16` shapes introduced in PTX ISA version 8.6.

Support for `.b8` type with `ldmatrix` is introduced in PTX ISA version 8.6.

Support for `.src_fmt`, `.dst_fmt` qualifiers introduced in PTX ISA version 8.6.

Target ISA Notes

Requires `sm_75` or higher.

Shapes `.m16n16`, `.m8n16` are supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And are supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Type `.b8` with `ldmatrix` is supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- And are supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

Qualifiers .src_fmt, .dst_fmt are supported on following architectures:

- sm_100a
- sm_101a
- sm_120a
- And are supported on following family-specific architectures from PTX ISA version 8.8:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family
  - sm_120f or higher in the same family

Examples

```
// Load a single 8x8 matrix using 64-bit addressing
.reg .b64 addr;
.reg .b32 d;
ldmatrix.sync.aligned.m8n8.x1.shared::cta.b16 {d}, [addr];

// Load two 8x8 matrices in column-major format
.reg .b64 addr;
.reg .b32 d<2>;
ldmatrix.sync.aligned.m8n8.x2.trans.shared.b16 {d0, d1}, [addr];

// Load four 8x8 matrices
.reg .b64 addr;
.reg .b32 d<4>;
ldmatrix.sync.aligned.m8n8.x4.b16 {d0, d1, d2, d3}, [addr];

// Load one 16x16 matrices of 64-bit elements and transpose them
.reg .b64 addr;
.reg .b32 d<2>;
ldmatrix.sync.aligned.m16n16.x1.trans.shared.b8 {d0, d1}, [addr];

// Load two 16x16 matrices of 64-bit elements and transpose them
.reg .b64 addr;
.reg .b32 d<4>;
ldmatrix.sync.aligned.m16n16.x2.trans.shared::cta.b8 {d0, d1, d2, d3}, [addr];

// Load two 16x16 matrices of 6-bit elements and transpose them
.reg .b64 addr;
.reg .b32 d<4>;
ldmatrix.sync.aligned.m16n16.x2.trans.shared::cta.b8x16.b6x16_p32 {d0, d1, d2, d3},
↪[addr];
```

9.7.14.5.16 Warp-level matrix store instruction: `stmatrix`

`stmatrix`

Collectively store one or more matrices to shared memory.

Syntax

```
stmatrix.sync.aligned.shape.num{.trans}{.ss}.type [p], r;

.shape  = {.m8n8, .m16n8};
.num    = {.x1, .x2, .x4};
.ss     = {.shared{::cta}};
.type   = {.b16, .b8};
```

Description

Collectively store one or more matrices across all threads in a warp to the location indicated by the address operand `p`, in `.shared` state space. If no state space is provided, generic addressing is used, such that the address in `p` points into `.shared` space. If the generic address doesn't fall in `.shared` state space, then the behavior is undefined.

The `.shape` qualifier indicates the dimensions of the matrices being loaded. Each matrix element holds 16-bit or 8-bit data as indicated by the `.type` qualifier.

`.m16n8` shape is valid only for `.b8` type.

The values `.x1`, `.x2` and `.x4` for `.num` indicate one, two or four matrices respectively.

The mandatory `.sync` qualifier indicates that `stmatrix` causes the executing thread to wait until all threads in the warp execute the same `stmatrix` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `stmatrix` instruction. In conditionally executed code, an `stmatrix` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise the behavior is undefined.

The behavior of `stmatrix` is undefined if all threads do not use the same qualifiers, or if any thread in the warp has exited.

The source operand `r` is a brace-enclosed vector expression consisting of 1, 2, or 4 32-bit registers as per the value of `.num`. Each component of the vector expression holds a fragment from the corresponding matrix.

Supported addressing modes for `p` are described in *Addresses as Operands*.

Consecutive instances of row need not be stored contiguously in memory. The eight addresses required for each matrix are provided by eight threads, depending upon the value of `.num` as shown in the following table. Each address corresponds to the start of a matrix row. Addresses addr0–addr7 correspond to the rows of the first matrix, addresses addr8–addr15 correspond to the rows of the second matrix, and so on.

.num	Threads 0–7	Threads 8–15	Threads 16–23	Threads 24–31
.x1	addr0–addr7	–	–	–
.x2	addr0–addr7	addr8–addr15	–	–
.x4	addr0–addr7	addr8–addr15	addr16–addr23	addr24–addr31

When storing 8x8 matrices, a group of four consecutive threads stores 16 bytes. The matrix addresses must be naturally aligned accordingly.

Each thread in a warp stores fragments of a row, with thread 0 storing the first fragment from its register `r`, and so on. A group of four threads stores an entire row of the matrix as shown in Figure 107.

Row\Col	0	1	2	3	4	5	6	7
0	T0:r	T0:r	T1:r	T1:r	T2:r	T2:r	T3:r	T3:r
1	T4:r	T4:r	T5:r	T5:r	T6:r	T6:r	T7:r	T7:r
2	T8:r	T8:r	T9:r	T9:r	T10:r	T10:r	T11:r	T11:r
3	T12:r	T12:r	T13:r	T13:r	T14:r	T14:r	T15:r	T15:r
4	T16:r	T16:r	T17:r	T17:r	T18:r	T18:r	T19:r	T19:r
5	T20:r	T20:r	T21:r	T21:r	T22:r	T22:r	T23:r	T23:r
6	T24:r	T24:r	T25:r	T25:r	T26:r	T26:r	T27:r	T27:r
7	T28:r	T28:r	T29:r	T29:r	T30:r	T30:r	T31:r	T31:r

Figure 107: stmatrix fragment layout for one 8x8 matrix with 16-bit elements

When `.num` = `.x2`, the elements of the second matrix are storedd from the next source register in each thread as per the layout in above table. Similarly, when `.num` = `.x4`, elements of the third and fourth matrices are stored from the subsequent source registers in each thread.

For 16x8 matrix shape, each of the 32 threads in the warp provides four elements of data per matrix.

Each element in the source operand `r` is of type `.b32` and contains four 8 bit elements `e0`, `e1`, `e2`, `e3` with `e0` and `e3` containing the LSB abd MSB respectively of register `r`.

Optional qualifier `.trans` indicates that the matrix is stored in column-major format. However, for 16x8 matrices, `.trans` is mandatory.

The `stmatrix` instruction is treated as a weak memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Support for `.m16n8` shape is introduced in PTX ISA version 8.6.

Support for `.b8` type with `stmatrix` is introduced in PTX ISA version 8.6.

Row\Col	0	1	2	3	4	5	6	7
0	T0:e0	T0:e1	T1:e0	T1:e1	T2:e0	T2:e1	T3:e0	T3:e1
1	T4:e0	T4:e1	T5:e0	T5:e1	T6:e0	T6:e1	T7:e0	T7:e1
2	T8:e0	T8:e1	T9:e0	T9:e1	T10:e0	T10:e1	T11:e0	T11:e1
3	T12:e0	T12:e1	T13:e0	T13:e1	T14:e0	T14:e1	T15:e0	T15:e1
4	T16:e0	T16:e1	T17:e0	T17:e1	T18:e0	T18:e1	T19:e0	T19:e1
5	T20:e0	T20:e1	T21:e0	T21:e1	T22:e0	T22:e1	T23:e0	T23:e1
6	T24:e0	T24:e1	T25:e0	T25:e1	T26:e0	T26:e1	T27:e0	T27:e1
7	T28:e0	T28:e1	T29:e0	T29:e1	T30:e0	T30:e1	T31:e0	T31:e1
8	T0:e2	T0:e3	T1:e2	T1:e3	T2:e2	T2:e3	T3:e2	T3:e3
9	T4:e2	T4:e3	T5:e2	T5:e3	T6:e2	T6:e3	T7:e2	T7:e3
10	T8:e2	T8:e3	T9:e2	T9:e3	T10:e2	T10:e3	T11:e2	T11:e3
11	T12:e2	T12:e3	T13:e2	T13:e3	T14:e2	T14:e3	T15:e2	T15:e3
12	T16:e2	T16:e3	T17:e2	T17:e3	T18:e2	T18:e3	T19:e2	T19:e3
13	T20:e2	T20:e3	T21:e2	T21:e3	T22:e2	T22:e3	T23:e2	T23:e3
14	T24:e2	T24:e3	T25:e2	T25:e3	T26:e2	T26:e3	T27:e2	T27:e3
15	T28:e2	T28:e3	T29:e2	T29:e3	T30:e2	T30:e3	T31:e2	T31:e3

Figure 108: stmatrix fragment layout for one 16x8 matrix with 8 bit elements

Target ISA Notes

Requires `sm_90` or higher.

Shape `.m16n8` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Type `.b8` with `stmatrix` is supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Examples

```
// Store a single 8x8 matrix using 64-bit addressing
.reg .b64 addr;
.reg .b32 r;
stmatrix.sync.aligned.m8n8.x1.shared.b16 [addr], {r};

// Store two 8x8 matrices in column-major format
.reg .b64 addr;
.reg .b32 r<2>;
stmatrix.sync.aligned.m8n8.x2.trans.shared::cta.b16 [addr], {r0, r1};

// Store four 8x8 matrices
.reg .b64 addr;
.reg .b32 r<4>;
stmatrix.sync.aligned.m8n8.x4.b16 [addr], {r0, r1, r2, r3};

// Store a single 16x8 matrix using generic addressing
.reg .b64 addr;
.reg .b32 r;
stmatrix.sync.aligned.m16n8.x1.trans.shared.b8 [addr], {r};

// Store two 16x8 matrices
.reg .b64 addr;
.reg .b32 r<2>;
stmatrix.sync.aligned.m16n8.x2.trans.shared::cta.b8 [addr],{r0, r1};

// Store four 16x8 matrices
.reg .b64 addr;
.reg .b32 r<4>;
stmatrix.sync.aligned.m16n8.x4.b8 [addr], {r0, r1, r2, r3};
```

9.7.14.5.17 Warp-level matrix transpose instruction: `movmatrix`

`movmatrix`

Transpose a matrix in registers across the warp.

Syntax

```
movmatrix.sync.aligned.shape.trans.type d, a;

.shape  = {.m8n8};
.type   = {.b16};
```

Description

Move a row-major matrix across all threads in a warp, reading elements from source a, and writing the transposed elements to destination d.

The `.shape` qualifier indicates the dimensions of the matrix being transposed. Each matrix element holds 16-bit data as indicated by the `.type` qualifier.

The mandatory `.sync` qualifier indicates that `movmatrix` causes the executing thread to wait until all threads in the warp execute the same `movmatrix` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `movmatrix` instruction. In conditionally executed code, a `movmatrix` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise the behavior is undefined.

Operands a and d are 32-bit registers containing fragments of the input matrix and the resulting matrix respectively. The mandatory qualifier `.trans` indicates that the resulting matrix in d is a transpose of the input matrix specified by a.

Each thread in a warp holds a fragment of a row of the input matrix, with thread 0 holding the first fragment in register a, and so on. A group of four threads holds an entire row of the input matrix as shown in Figure 109.

movmatrix: matrix fragment in source operand a

	col0	col1	col2	col3	col4	col5	col6	col7
row0	%laneid = 0 src=a		%laneid = 1 src=a		%laneid = 2 src=a		%laneid = 3 src=a	
row1	%laneid = 4 src=a		%laneid = 5 src=a		%laneid = 6 src=a		%laneid = 7 src=a	
row2	%laneid = 8 src=a		%laneid = 9 src=a		%laneid = 10 src=a		%laneid = 11 src=a	
row3	%laneid = 12 src=a		%laneid = 13 src=a		%laneid = 14 src=a		%laneid = 15 src=a	
row4	%laneid = 16 src=a		%laneid = 17 src=a		%laneid = 18 src=a		%laneid = 19 src=a	
row5	%laneid = 20 src=a		%laneid = 21 src=a		%laneid = 22 src=a		%laneid = 23 src=a	
row6	%laneid = 24 src=a		%laneid = 25 src=a		%laneid = 26 src=a		%laneid = 27 src=a	
row7	%laneid = 28 src=a		%laneid = 29 src=a		%laneid = 30 src=a		%laneid = 31 src=a	

Figure 109: movmatrix source matrix fragment layout

Each thread in a warp holds a fragment of a column of the result matrix, with thread 0 holding the first fragment in register d, and so on. A group of four threads holds an entire column of the result matrix as shown in Figure 110.

movmatrix: matrix fragment in destination operand d								
	row0	row1	row2	row3	row4	row5	row6	row7
col0	%laneid = 0 dst=d		%laneid = 1 dst=d		%laneid = 2 dst=d		%laneid = 3 dst=d	
col1	%laneid = 4 dst=d		%laneid = 5 dst=d		%laneid = 6 dst=d		%laneid = 7 dst=d	
col2	%laneid = 8 dst=d		%laneid = 9 dst=d		%laneid = 10 dst=d		%laneid = 11 dst=d	
col3	%laneid = 12 dst=d		%laneid = 13 dst=d		%laneid = 14 dst=d		%laneid = 15 dst=d	
col4	%laneid = 16 dst=d		%laneid = 17 dst=d		%laneid = 18 dst=d		%laneid = 19 dst=d	
col5	%laneid = 20 dst=d		%laneid = 21 dst=d		%laneid = 22 dst=d		%laneid = 23 dst=d	
col6	%laneid = 24 dst=d		%laneid = 25 dst=d		%laneid = 26 dst=d		%laneid = 27 dst=d	
col7	%laneid = 28 dst=d		%laneid = 29 dst=d		%laneid = 30 dst=d		%laneid = 31 dst=d	

Figure 110: movmatrix result matrix fragment layout

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires sm_75 or higher.

Examples

```
.reg .b32 d, a;
movmatrix.sync.aligned.m8n8.trans.b16 d, a;
```

9.7.14.6 Matrix multiply-accumulate operation using `mma.sp` instruction with sparse matrix A

This section describes warp-level `mma.sp{::ordered_metadata}` instruction with sparse matrix A. This variant of the `mma` operation can be used when A is a structured sparse matrix with 50% zeros in each row distributed in a shape-specific granularity. For an `MxNxK` sparse `mma.sp{::ordered_metadata}` operation, the `MxK` matrix A is packed into `MxK/2` elements. For each K-wide row of matrix A, 50% elements are zeros and the remaining K/2 non-zero elements are packed in the operand representing matrix A. The mapping of these K/2 elements to the corresponding K-wide row is provided explicitly as metadata.

9.7.14.6.1 Sparse matrix storage

Granularity of sparse matrix A is defined as the ratio of the number of non-zero elements in a sub-chunk of the matrix row to the total number of elements in that sub-chunk where the size of the sub-chunk is shape-specific. For example, in a `16x16` matrix A, sparsity is expected to be at 2:4 granularity, i.e. each 4-element vector (i.e. a sub-chunk of 4 consecutive elements) of a matrix row contains 2 zeros. Index of each non-zero element in a sub-chunk is stored in the metadata operand. Values `0b0000`, `0b0101`, `0b1010`, `0b1111` are invalid values for metadata and will result in undefined behavior. In a group of four consecutive threads, one or more threads store the metadata for the whole group depending upon the matrix shape. These threads are specified using an additional *sparsity selector* operand.

Figure 111 shows an example of a 16x16 matrix A represented in sparse format and sparsity selector indicating which thread in a group of four consecutive threads stores the metadata.

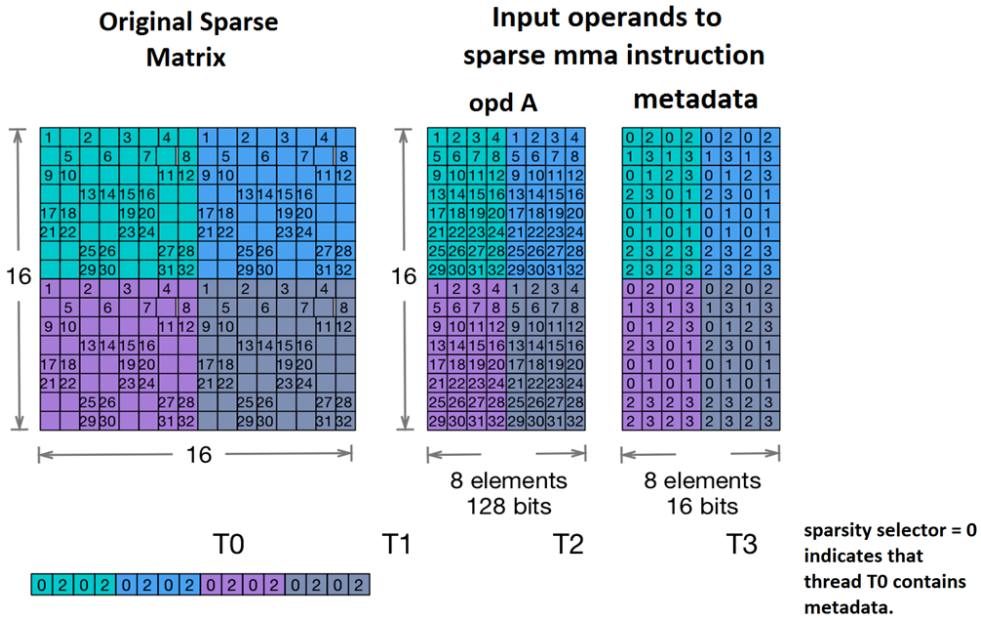

Figure 111: Sparse MMA storage example

Granularities for different matrix shapes and data types are described below.

Sparse mma.sp{::ordered_metadata} with half-precision and .bf16 type

For the .m16n8k16 and .m16n8k32 mma.sp{::ordered_metadata} operations, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A has two zeros and two non-zero elements. Only the two non-zero elements are stored in the operand representing matrix A and their positions in the four-wide chunk in matrix A are indicated by two 2-bit indices in the metadata operand. For mma.sp::ordered_metadata, 0b0100, 0b1000, 0b1001, 0b1100, 0b1101, 0b1110 are the meaningful values of indices; any other values result in an undefined behavior.

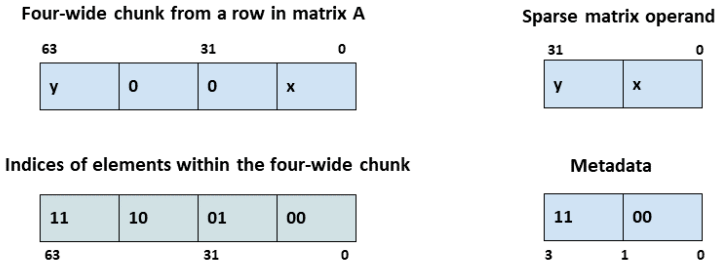

Figure 112: Sparse MMA metadata example for .f16/.bf16 type.

The sparsity selector indicates the threads which contribute metadata as listed below:

- m16n8k16: One thread within a group of four consecutive threads contributes the metadata for the entire group. This thread is indicated by a value in {0, 1, 2, 3}.
- m16n8k32: A thread-pair within a group of four consecutive threads contributes the sparsity metadata. Hence, the sparsity selector must be either 0 (threads T0, T1) or 1 (threads T2, T3); any other value results in an undefined behavior.

Sparse mma.sp{::ordered_metadata} with .tf32 type

When matrix A has .tf32 elements, matrix A is structured sparse at a granularity of 1:2. In other words, each chunk of two adjacent elements in a row of matrix A has one zero and one non-zero element. Only the non-zero elements are stored in the operand for matrix A and their positions in a two-wide chunk in matrix A are indicated by the 4-bit index in the metadata. 0b1110 and 0b0100 are the only meaningful index values; any other values result in an undefined behavior.

The sparsity selector indicates the threads which contribute metadata as listed below:

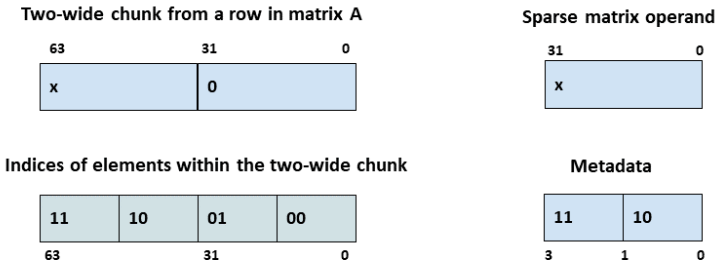

Figure 113: Sparse MMA metadata example for `.tf32` type.

- `m16n8k8`: One thread within a group of four consecutive threads contributes the metadata for the entire group. This thread is indicated by a value in {0, 1, 2, 3}.
- `m16n8k16`: A thread-pair within a group of four consecutive threads contributes the sparsity metadata. Hence, the sparsity selector must be either 0 (threads T0, T1) or 1 (threads T2, T3); any other value results in an undefined behavior.

Sparse `mma.sp{::ordered_metadata}` with integer type

When matrices A and B have `.u8/.s8` elements, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A have two zeroes and two non-zero elements. Only the two non-zero elements are stored in sparse matrix and their positions in the four-wide chunk are indicated by two 2-bit indices in the metadata. For `mma.sp::ordered_metadata`, `0b0100`, `0b1000`, `0b1001`, `0b1100`, `0b1101`, `0b1110` are the meaningful values of indices; any other values result in an undefined behavior.

when matrices A and B have `.u4/.s4` elements, matrix A is pair-wise structured sparse at a granularity of 4:8. In other words, each chunk of eight adjacent elements in a row of matrix A has four zeroes and four non-zero values. Further, the zero and non-zero values are clustered in sub-chunks of two elements each within the eight-wide chunk. i.e., each two-wide sub-chunk within the eight-wide chunk must be all zeroes or all non-zeros. Only the four non-zero values are stored in sparse matrix and the positions of the two two-wide sub-chunks with non-zero values in the eight-wide chunk of a row of matrix A are indicated by two 2-bit indices in the metadata. For `mma.sp::ordered_metadata`, `0b0100`, `0b1000`, `0b1001`, `0b1100`, `0b1101`, `0b1110` are the meaningful values of indices; any other values result in an undefined behavior.

The sparsity selector indicates the threads which contribute metadata as listed below:

- `m16n8k32` with `.u8/.s8` type and `m16n8k64` with `.u4/.s4` type: A thread-pair within a group of

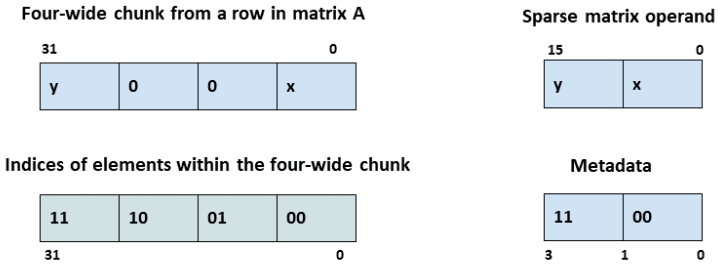

Figure 114: Sparse MMA metadata example for .u8/.s8 type.

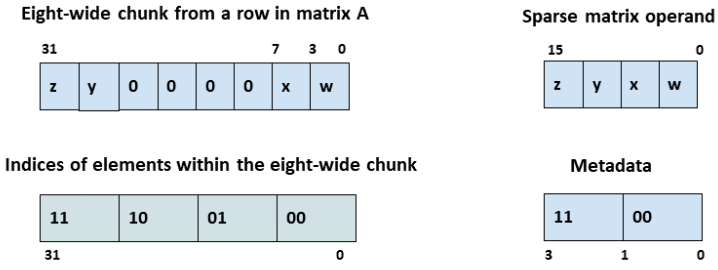

Figure 115: Sparse MMA metadata example for .u4/.s4 type.

four consecutive threads contributes the sparsity metadata. Hence, the sparsity selector must be either 0 (threads T0, T1) or 1 (threads T2, T3); any other value results in an undefined behavior.

- `m16n8k64` with `.u8/.s8` type and `m16n8k128` with `.u4/.s4` type: All threads within a group of four consecutive threads contribute the sparsity metadata. Hence, the sparsity selector in this case must be 0. Any other value of sparsity selector results in an undefined behavior.

Sparse `mma.sp{::ordered_metadata}` operating on `.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type with `.kind::f8f6f4` or `.kind::mxf8f6f4`

When matrices A and B have `.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` elements, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A have two zeroes and two non-zero elements. Only the two non-zero elements are stored in sparse matrix and their positions in the four-wide chunk are indicated by two 2-bit indices in the metadata. `0b0100`, `0b1000`, `0b1001`, `0b1100`, `0b1101`, `0b1110` are the meaningful values of indices; any other values result in an undefined behavior.

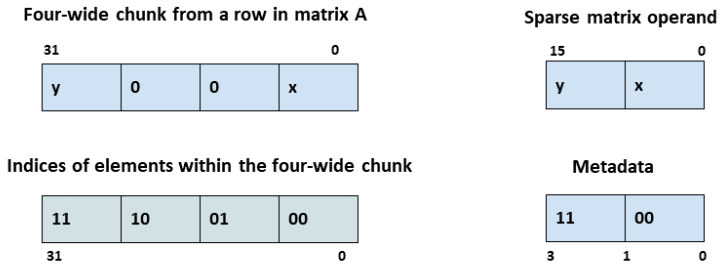

Figure 116: Sparse MMA metadata example for `.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

The sparsity selector indicates the threads which contribute metadata as listed below:

- `m16n8k64`: All threads within a group of four consecutive threads contribute the sparsity metadata. Hence, the sparsity selector in this case must be 0. Any other value of sparsity selector results in an undefined behavior.

Sparse mma.sp::ordered_metadata operating on .e2m1 type with .kind::mxf4 or .kind::mxf4nvf4

When matrices A and B have `.e2m1` elements, matrix A is pair-wise structured sparse at a granularity of 4:8. In other words, each chunk of eight adjacent elements in a row of matrix A has four zeroes and four non-zero values. Further, the zero and non-zero values are clustered in sub-chunks of two elements each within the eight-wide chunk. i.e., each two-wide sub-chunk within the eight-wide chunk must be all zeroes or all non-zeros. Only the four non-zero values are stored in sparse matrix and the positions of the two two-wide sub-chunks with non-zero values in the eight-wide chunk of a row of matrix A are indicated by two 2-bit indices in the metadata. `0b0100`, `0b1000`, `0b1001`, `0b1100`, `0b1101`, `0b1110` are the meaningful values of indices; any other values result in an undefined behavior.

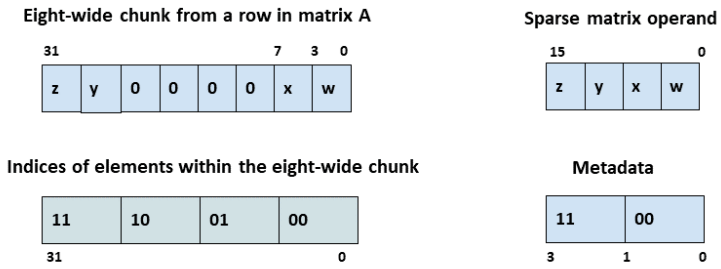

Figure 117: Sparse MMA metadata example for `.e2m1` type with `.kind::mxf4` or `.kind::mxf4nvf4`

The sparsity selector indicates the threads which contribute metadata as listed below:

- `m16n8k128`: All threads within a group of four consecutive threads contribute the sparsity metadata. Hence, the sparsity selector in this case must be 0. Any other value of sparsity selector results in an undefined behavior.

9.7.14.6.2 Matrix fragments for multiply-accumulate operation with sparse matrix A

In this section we describe how the contents of thread registers are associated with fragments of various matrices and the sparsity metadata. The following conventions are used throughout this section:

- For matrix A, only the layout of a fragment is described in terms of register vector sizes and their association with the matrix data.
- For matrix B, when the combination of matrix dimension and the supported data type is not already covered in *Matrix multiply-accumulate operation using mma instruction*, a pictorial representation of matrix fragments is provided.

- For matrices C and D, since the matrix dimension - data type combination is the same for all supported shapes, and is already covered in *Matrix multiply-accumulate operation using mma instruction*, the pictorial representations of matrix fragments are not included in this section.
- For the metadata operand, pictorial representations of the association between indices of the elements of matrix A and the contents of the metadata operand are included. `Tk: [m..n]` present in cell `[x][y..z]` indicates that bits `m` through `n` (with `m` being higher) in the metadata operand of thread with `%laneid=k` contains the indices of the non-zero elements from the chunk `[x][y]..[x][z]` of matrix A.

9.7.14.6.2.1 Matrix Fragments for sparse `mma.m16n8k16` with `.f16` and `.bf16` types

A warp executing sparse `mma.m16n8k16` with `.f16` / `.bf16` floating point type will compute an MMA operation of shape `.m16n8k16`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.f16` / `.bf16`	A vector expression containing two `.b32` registers, with each register containing two non-zero `.f16` / `.bf16` elements out of 4 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

The layout of the fragments held by different threads is shown in Figure 118.

Row\Column	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15
0	T0:{a0,a1}	T1:{a0,a1}	T2:{a0,a1}	T3:{a0,a1}
1	T4:{a0,a1}	T5:{a0,a1}	T6:{a0,a1}	T6:{a0,a1}
2				
...				
7	T28:{a0,a1}	T29:{a0,a1}	T30:{a0,a1}	T31:{a0,a1}
8	T0:{a2,a3}	T1:{a2,a3}	T2:{a2,a3}	T3:{a2,a3}
9	T4:{a2,a3}	T5:{a2,a3}	T6:{a2,a3}	T7:{a2,a3}
10				
...				
15	T28:{a2,a3}	T29:{a2,a3}	T30:{a2,a3}	T31:{a2,a3}

Figure 118: Sparse MMA .m16n8k16 fragment layout for matrix A with `.f16/.bf16` type.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID            for a0 and a1
           groupID + 8        for a2 and a3

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage

Where
firstcol = threadID_in_group * 4
lastcol  = firstcol + 3
```

- Matrix fragments for multiplicand B and accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k16 with floating point type* for `.f16/.b16` formats.
- Metadata: A `.b32` register containing 16 2-bit vectors each storing the index of a non-zero element of a 4-wide chunk of matrix A as shown in Figure 119.

Row\Column	0 1 2 3	4 5 6 7	8 9 10 11	12 13 14 15
0	T_i: [3..0]	T_i: [7..4]	T_i: [11..8]	T_i: [15..12]
1	T_{i+4}: [3..0]	T_{i+4}: [7..4]	T_{i+4}: [11..8]	T_{i+4}: [15..12]
2				
...				
7	T_{i+28}: [3..0]	T_{i+28}: [7..4]	T_{i+28}: [11..8]	T_{i+28}: [15..12]
8	T_i: [19..16]	T_i: [23..20]	T_i: [27..24]	T_i: [31..28]
9	T_{i+4}: [19..16]	T_{i+4}: [23..20]	T_{i+4}: [27..24]	T_{i+4}: [31..28]
10				
...				
15	T_{i+28}: [19..16]	T_{i+28}: [23..20]	T_{i+28}: [27..24]	T_{i+28}: [31..28]

Figure 119: Sparse MMA .m16n8k16 metadata layout for `.f16/.bf16` type.

9.7.14.6.2.2 Matrix Fragments for sparse mma.m16n8k32 with .f16 and .bf16 types

A warp executing sparse `mma.m16n8k32` with `.f16` / `.bf16` floating point type will compute an MMA operation of shape `.m16n8k32`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.f16` / `.bf16`	A vector expression containing four `.b32` registers, with each register containing two non-zero `.f16` / `.bf16` elements out of 4 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

The layout of the fragments held by different threads is shown in Figure 120.

Row\Column	0..3	4..7	8..11	12..15	16..19	20..23	24..27	28..31
0	T0:{a0,a1}	T1:{a0,a1}	T2:{a0,a1}	T3:{a0,a1}	T0:{a4,a5}	T1:{a4,a5}	T2:{a4,a5}	T3:{a4,a5}
1	T4:{a0,a1}	T5:{a0,a1}	T6:{a0,a1}	T7:{a0,a1}	T4:{a4,a5}	T5:{a4,a5}	T6:{a4,a5}	T7:{a4,a5}
2								
...								
7	T28:{a0,a1}	T29:{a0,a1}	T30:{a0,a1}	T31:{a0,a1}	T28:{a4,a5}	T29:{a4,a5}	T30:{a4,a5}	T31:{a4,a5}
8	T0:{a2,a3}	T1:{a2,a3}	T2:{a2,a3}	T3:{a2,a3}	T0:{a6,a7}	T1:{a6,a7}	T2:{a6,a7}	T3:{a6,a7}
9	T4:{a2,a3}	T5:{a2,a3}	T6:{a2,a3}	T7:{a2,a3}	T4:{a6,a7}	T5:{a6,a7}	T6:{a6,a7}	T7:{a6,a7}
10								
...								
15	T28:{a2,a3}	T29:{a2,a3}	T30:{a2,a3}	T31:{a2,a3}	T28:{a6,a7}	T29:{a6,a7}	T30:{a6,a7}	T31:{a6,a7}

Figure 120: Sparse MMA .m16n8k32 fragment layout for matrix A with `.f16`/`.bf16` type.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID            for ai where  0 <= i < 2 || 4 <= i < 6
           groupID + 8        Otherwise

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage
```

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```
Where
firstcol = threadID_in_group * 4           For ai where i <  4
           (threadID_in_group * 4) + 16    for ai where i >= 4
lastcol  = firstcol + 3
```

- Multiplicand B:

.atype	Fragment	Elements (low to high)
.f16 / .bf16	A vector expression containing four .b32 registers, each containing two .f16 / .bf16 elements from matrix B.	b0, b1, b2, b3

The layout of the fragments held by different threads is shown in Figure 121.

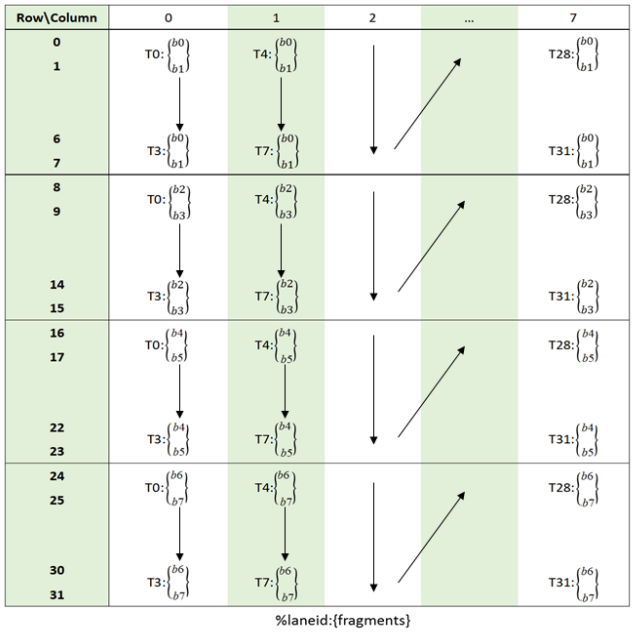

Figure 121: Sparse MMA .m16n8k32 fragment layout for matrix B with .f16/.bf16 type.

- Matrix fragments for accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k16 with floating point type* for .f16/.b16 formats.
- Metadata: A .b32 register containing 16 2-bit vectors with each pair of 2-bit vectors storing the indices of two non-zero element from a 4-wide chunk of matrix A as shown in Figure 122.

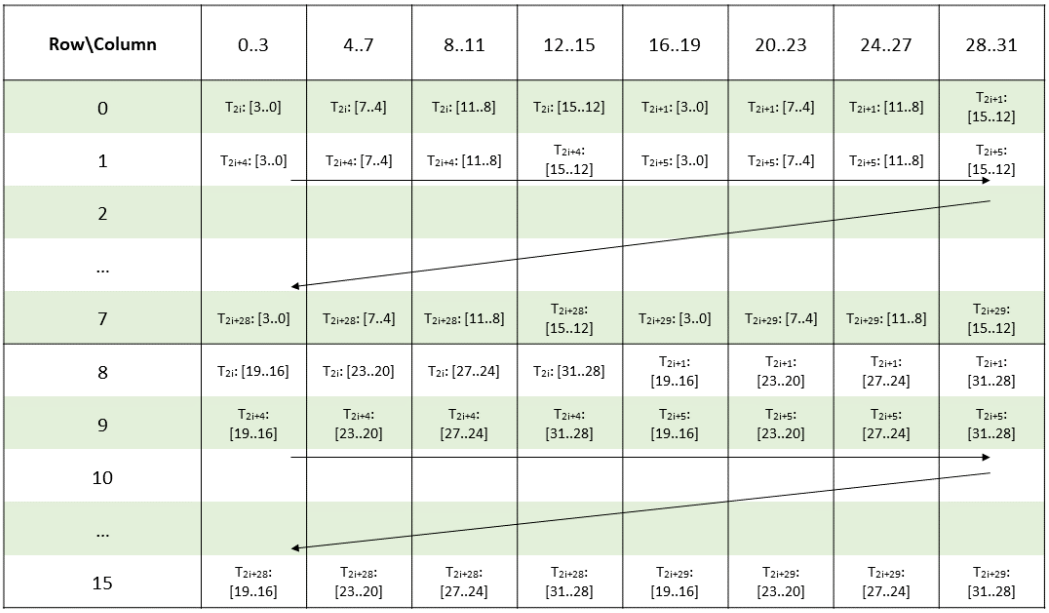

Figure 122: Sparse MMA .m16n8k32 metadata layout for `.f16`/`.bf16` type.

9.7.14.6.2.3 Matrix Fragments for sparse `mma.m16n8k16` with `.tf32` floating point type

A warp executing sparse `mma.m16n8k16` with `.tf32` floating point type will compute an MMA operation of shape `.m16n8k16`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.tf32`	A vector expression containing four `.b32` registers, with each register containing one non-zero `.tf32` element out of 2 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

The layout of the fragments held by different threads is shown in Figure 123.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for a0 and a2
           groupID + 8         for a1 and a3

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage
```

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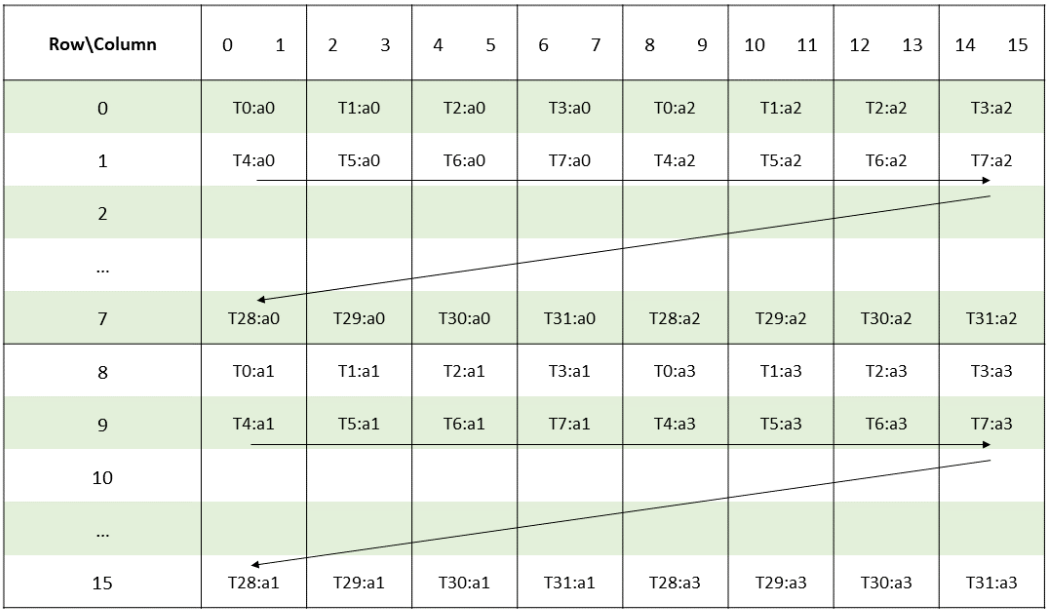

Row\Column	0 1	2 3	4 5	6 7	8 9	10 11	12 13	14 15
0	T0:a0	T1:a0	T2:a0	T3:a0	T0:a2	T1:a2	T2:a2	T3:a2
1	T4:a0	T5:a0	T6:a0	T7:a0	T4:a2	T5:a2	T6:a2	T7:a2
2								
...								
7	T28:a0	T29:a0	T30:a0	T31:a0	T28:a2	T29:a2	T30:a2	T31:a2
8	T0:a1	T1:a1	T2:a1	T3:a1	T0:a3	T1:a3	T2:a3	T3:a3
9	T4:a1	T5:a1	T6:a1	T7:a1	T4:a3	T5:a3	T6:a3	T7:a3
10								
...								
15	T28:a1	T29:a1	T30:a1	T31:a1	T28:a3	T29:a3	T30:a3	T31:a3

Figure 123: Sparse MMA .m16n8k16 fragment layout for matrix A with `.tf32` type.

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```
Where
firstcol = threadID_in_group * 2          for a0 and a1
           (threadID_in_group * 2) + 8    for a2 and a3
lastcol  = firstcol + 1
```

- Multiplicand B:

.atype	Fragment	Elements (low to high)
`.tf32`	A vector expression containing four `.b32` registers, each containing four `.tf32` elements from matrix B.	b0, b1, b2, b3

The layout of the fragments held by different threads is shown in Figure 124.

- Matrix fragments for accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k16 with floating point type*.
- Metadata: A `.b32` register containing 8 4-bit vectors each storing the index of a non-zero element of a 2-wide chunk of matrix A as shown in Figure 125.

Row\Column	0	1	2	...	7
0	T0:B0	T4:B0			T28:B0
1	T1:B0	T5:B0			T29:B0
2	T2:B0	T6:B0			T30:B0
3	T3:B0	T7:B0			T31:B0
4	T0:B1	T4:B1			T28:B1
5	T1:B1	T5:B1			T29:B1
6	T2:B1	T6:B1			T30:B1
7	T3:B1	T7:B1			T31:B1
8	T0:B2	T4:B2			T28:B2
9	T1:B2	T5:B2			T29:B2
10	T2:B2	T6:B2			T30:B2
11	T3:B2	T7:B2			T31:B2
12	T0:B3	T4:B3			T28:B3
13	T1:B3	T5:B3			T29:B3
14	T2:B3	T6:B3			T30:B3
15	T3:B3	T7:B3			T31:B3

%laneid:{fragments}

Figure 124: Sparse MMA .m16n8k16 fragment layout for matrix B with `.tf32` type.

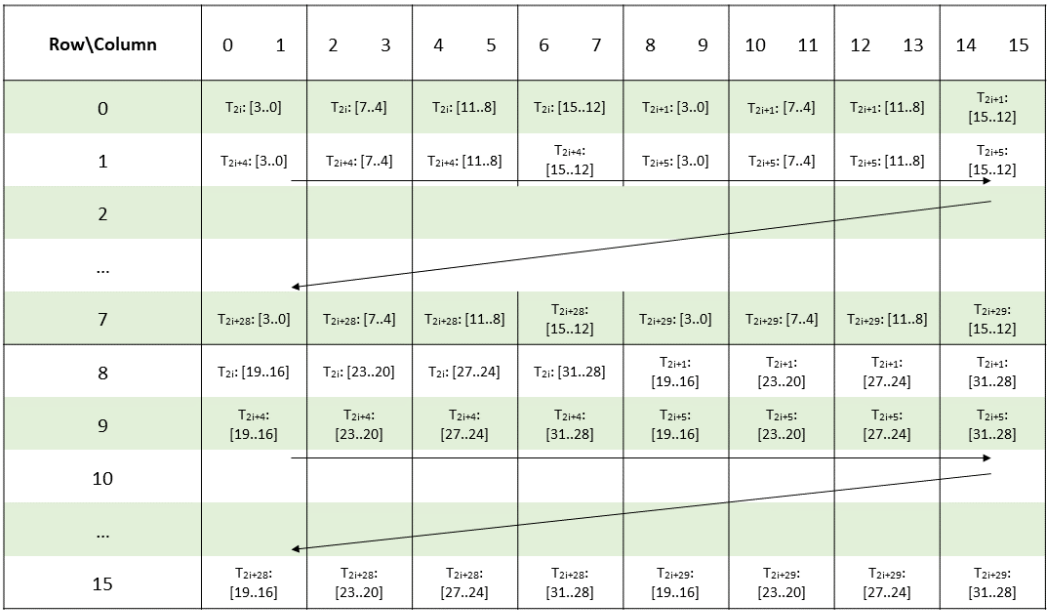

Figure 125: Sparse MMA .m16n8k16 metadata layout for `.tf32` type.

9.7.14.6.2.4 Matrix Fragments for sparse `mma.m16n8k8` with `.tf32` floating point type

A warp executing sparse `mma.m16n8k8` with `.tf32` floating point type will compute an MMA operation of shape `.m16n8k8`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.tf32`	A vector expression containing two `.b32` registers, each containing one non-zero `.tf32` element out of 2 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

The layout of the fragments held by different threads is shown in Figure 126.

The row and column of a matrix fragment can be computed as:

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for a0
           groupID + 8         for a1

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage
```

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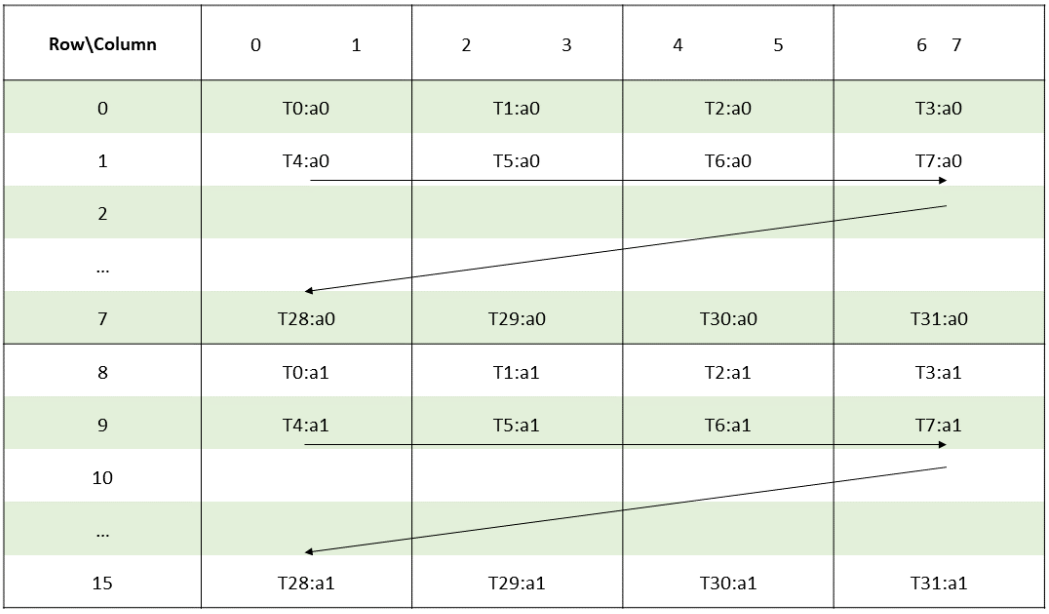

Figure 126: Sparse MMA .m16n8k8 fragment layout for matrix A with `.tf32` type.

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```
Where
firstcol = threadID_in_group * 2
lastcol  = firstcol + 1
```

- Matrix fragments for multiplicand B and accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k8* for `.tf32` format.
- Metadata: A `.b32` register containing 8 4-bit vectors each storing the index of a non-zero element of a 2-wide chunk of matrix A as shown in Figure 127.

9.7.14.6.2.5 Matrix Fragments for sparse `mma.m16n8k32` with `.u8 / .s8` integer type

A warp executing sparse `mma.m16n8k32` with `.u8 / .s8` integer type will compute an MMA operation of shape `.m16n8k32`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.u8 / .s8`	A vector expression containing two `.b32` registers, with each register containing four non-zero `.u8 / .s8` elements out of 8 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

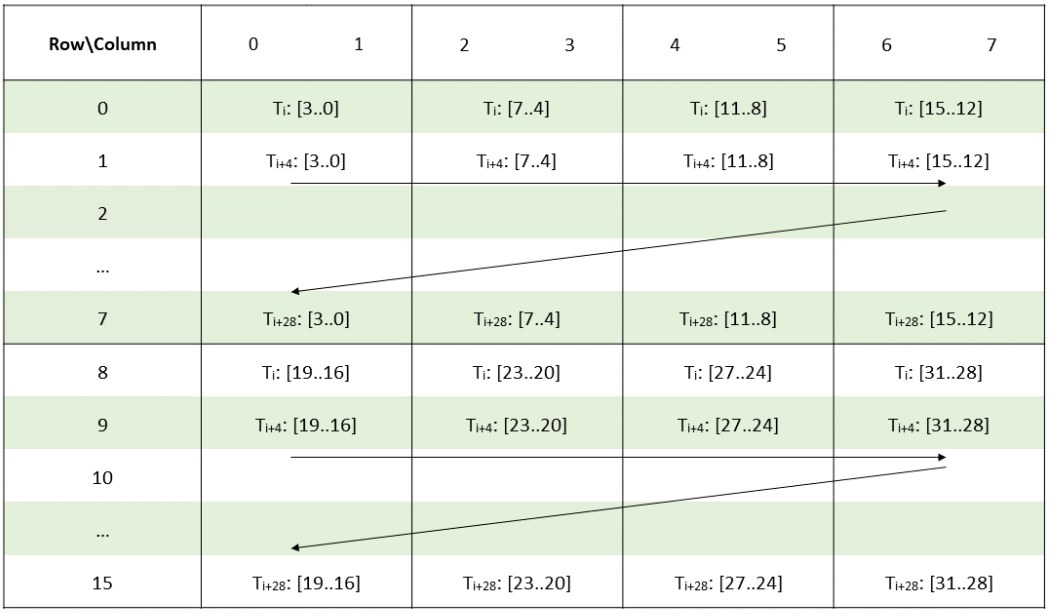

Figure 127: Sparse MMA .m16n8k8 metadata layout for `.tf32` type.

The layout of the fragments held by different threads is shown in Figure 128.

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for ai where  0 <= i < 4
           groupID + 8         Otherwise

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage

Where
firstcol = threadID_in_group * 8
lastcol  = firstcol + 7
```

- Matrix fragments for multiplicand B and accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k32*.
- Metadata: A `.b32` register containing 16 2-bit vectors with each pair of 2-bit vectors storing the indices of two non-zero elements from a 4-wide chunk of matrix A as shown in Figure 129.

Row\Column	0 … 7	8 … 15	16 … 23	24 … 31
0	T0:{a0,a1,a2,a3}	T1:{a0,a1,a2,a3}	T2:{a0,a1,a2,a3}	T3:{a0,a1,a2,a3}
1	T4:{a0,a1,a2,a3}	T5:{a0,a1,a2,a3}	T6:{a0,a1,a2,a3}	T7:{a0,a1,a2,a3}
2				
…				
7	T28:{a0,a1,a2,a3}	T29:{a0,a1,a2,a3}	T30:{a0,a1,a2,a3}	T31:{a0,a1,a2,a3}
8	T0:{a4,a5,a6,a7}	T1:{a4,a5,a6,a7}	T2:{a4,a5,a6,a7}	T3:{a4,a5,a6,a7}
9	T4:{a4,a5,a6,a7}	T5:{a4,a5,a6,a7}	T6:{a4,a5,a6,a7}	T7:{a4,a5,a6,a7}
10				
…				
15	T28:{a4,a5,a6,a7}	T29:{a4,a5,a6,a7}	T30:{a4,a5,a6,a7}	T31:{a4,a5,a6,a7}

Figure 128: Sparse MMA .m16n8k32 fragment layout for matrix A with `.u8/.s8` type.

Row\Column	0..3	4..7	8..11	12..15	16..19	20..23	24..27	28..31
0	T_{2i}: [3..0]	T_{2i}: [7..4]	T_{2i}: [11..8]	T_{2i}: [15..12]	T_{2i}: [19..16]	T_{2i}: [23..20]	T_{2i}: [27..24]	T_{2i}: [31..28]
1	T_{2i+4}: [3..0]	T_{2i+4}: [7..4]	T_{2i+4}: [11..8]	T_{2i+4}: [15..12]	T_{2i+4}: [19..16]	T_{2i+4}: [23..20]	T_{2i+4}: [27..24]	T_{2i+4}: [31..28]
2								
…								
7	T_{2i+28}: [3..0]	T_{2i+28}: [7..4]	T_{2i+28}: [11..8]	T_{2i+28}: [15..12]	T_{2i+28}: [19..16]	T_{2i+28}: [23..20]	T_{2i+28}: [27..24]	T_{2i+28}: [31..28]
8	T_{2i+1}: [3..0]	T_{2i+1}: [7..4]	T_{2i+1}: [11..8]	T_{2i+1}: [15..12]	T_{2i+1}: [19..16]	T_{2i+1}: [23..20]	T_{2i+1}: [27..24]	T_{2i+1}: [31..28]
9	T_{2i+5}: [3..0]	T_{2i+5}: [7..4]	T_{2i+5}: [11..8]	T_{2i+5}: [15..12]	T_{2i+5}: [19..16]	T_{2i+5}: [23..20]	T_{2i+5}: [27..24]	T_{2i+5}: [31..28]
10								
…								
15	T_{2i+29}: [3..0]	T_{2i+29}: [7..4]	T_{2i+29}: [11..8]	T_{2i+29}: [15..12]	T_{2i+29}: [19..16]	T_{2i+29}: [23..20]	T_{2i+29}: [27..24]	T_{2i+29}: [31..28]

Figure 129: Sparse MMA .m16n8k32 metadata layout for `.u8/.s8` type.

9.7.14.6.2.6 Matrix Fragments for sparse mma.m16n8k64 with .u8 / .s8 / .e4m3 / .e5m2 type

A warp executing sparse mma.m16n8k64 with .u8 / .s8/ .e4m3/ .e5m2 / .e3m2 / .e2m3 / .e2m1 type will compute an MMA operation of shape .m16n8k64.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
.u8 / .s8	A vector expression containing four .b32 registers, with each register containing four non-zero .u8 / .s8 elements out of 8 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.
.e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1	A vector expression containing four .b32 registers, with each register containing four non-zero .e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1 elements out of 8 consecutive elements from matrix A.	

The layout of the fragments held by different threads is shown in Figure 130 and Figure 131.

Row\Column	0 ... 7	8 ... 15	16 ... 23	24 ... 31
0	T0:{a0,a1,a2,a3}	T1:{a0,a1,a2,a3}	T2:{a0,a1,a2,a3}	T3:{a0,a1,a2,a3}
1	T4:{a0,a1,a2,a3}	T5:{a0,a1,a2,a3}	T6:{a0,a1,a2,a3}	T7:{a0,a1,a2,a3}
2				
...				
7	T28:{a0,a1,a2,a3}	T29:{a0,a1,a2,a3}	T30:{a0,a1,a2,a3}	T31:{a0,a1,a2,a3}
8	T0:{a4,a5,a6,a7}	T1:{a4,a5,a6,a7}	T2:{a4,a5,a6,a7}	T3:{a4,a5,a6,a7}
9	T4:{a4,a5,a6,a7}	T5:{a4,a5,a6,a7}	T6:{a4,a5,a6,a7}	T7:{a4,a5,a6,a7}
10				
...				
15	T28:{a4,a5,a6,a7}	T29:{a4,a5,a6,a7}	T30:{a4,a5,a6,a7}	T31:{a4,a5,a6,a7}

Figure 130: Sparse MMA .m16n8k64 fragment layout for columns 0–31 of matrix A with .u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1 type.

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID            for ai where  0 <= i < 4 || 8 <= i < 12
```

(continues on next page)

Row\Column	32 ... 39	40 ... 47	48 ... 55	56 ... 63
0	T0:{a8,a9,a10,a11}	T1:{a8,a9,a10,a11}	T2:{a8,a9,a10,a11}	T3:{a8,a9,a10,a11}
1	T4:{a8,a9,a10,a11}	T5:{a8,a9,a10,a11}	T6:{a8,a9,a10,a11}	T7:{a8,a9,a10,a11}
2				
...				
7	T28:{a8,a9,a10,a11}	T29:{a8,a9,a10,a11}	T30:{a8,a9,a10,a11}	T31:{a8,a9,a10,a11}
8	T0:{a12,a13,a14,a15}	T1:{a12,a13,a14,a15}	T2:{a12,a13,a14,a15}	T3:{a12,a13,a14,a15}
9	T4:{a12,a13,a14,a15}	T5:{a12,a13,a14,a15}	T6:{a12,a13,a14,a15}	T7:{a12,a13,a14,a15}
10				
...				
15	T28:{a12,a13,a14,a15}	T29:{a12,a13,a14,a15}	T30:{a12,a13,a14,a15}	T31:{a12,a13,a14,a15}

Figure 131: Sparse MMA .m16n8k64 fragment layout for columns 32–63 of matrix A with `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

(continued from previous page)

```
           groupID + 8        Otherwise

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage

Where
firstcol = threadID_in_group * 8           For ai where i <  8
           (threadID_in_group * 8) + 32    For ai where i >= 8
lastcol  = firstcol + 7
```

- Multiplicand B:

.btype	Fragment	Elements (low to high)
.u8 / .s8	A vector expression containing four .b32 registers, each containing four .u8 / .s8 elements from matrix B.	b0, b1, b2, b3, ..., b15
.e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1	A vector expression containing four .b32 registers, each containing four .e4m3 / .e5m2 / .e3m2 / .e2m3 / .e2m1 elements from matrix B.	

The layout of the fragments held by different threads is shown in Figure 132, Figure 133, Figure 134 and Figure 135.

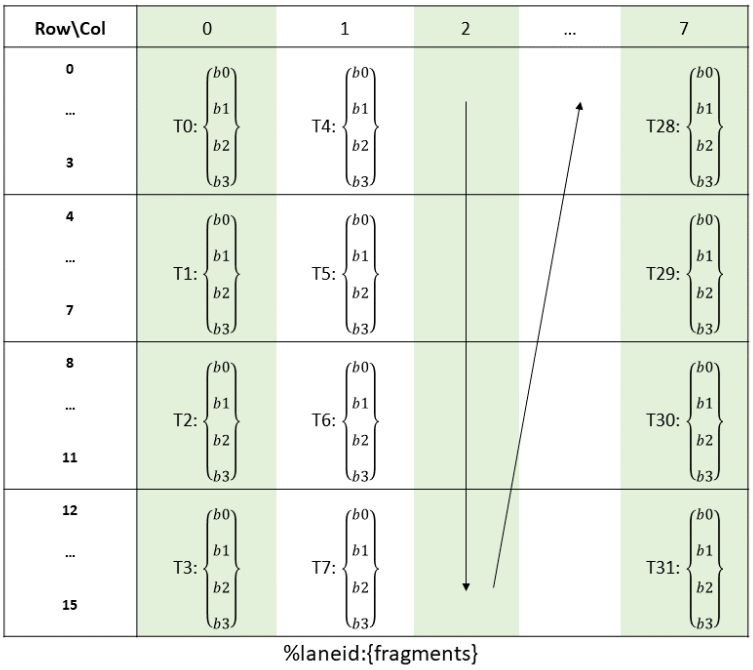

Figure 132: Sparse MMA .m16n8k64 fragment layout for rows 0–15 of matrix B with `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

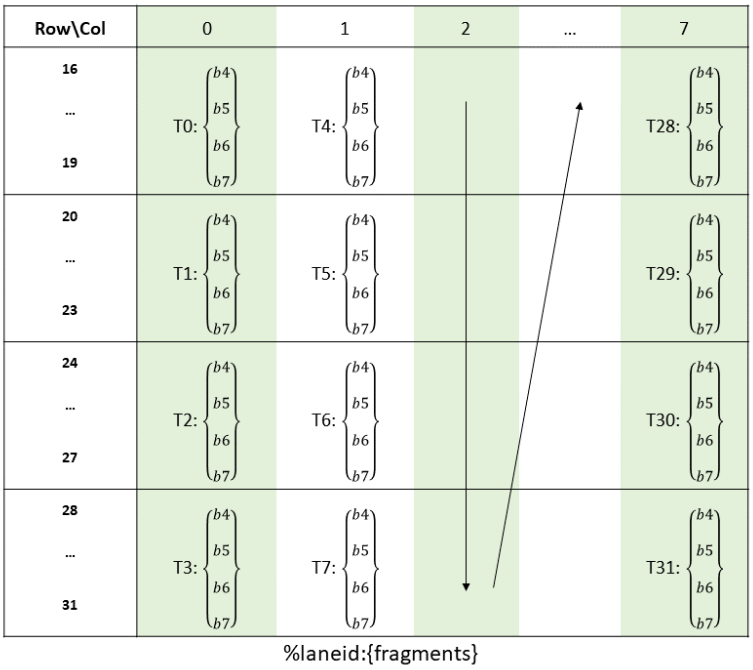

Figure 133: Sparse MMA .m16n8k64 fragment layout for rows 16–31 of matrix B with `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

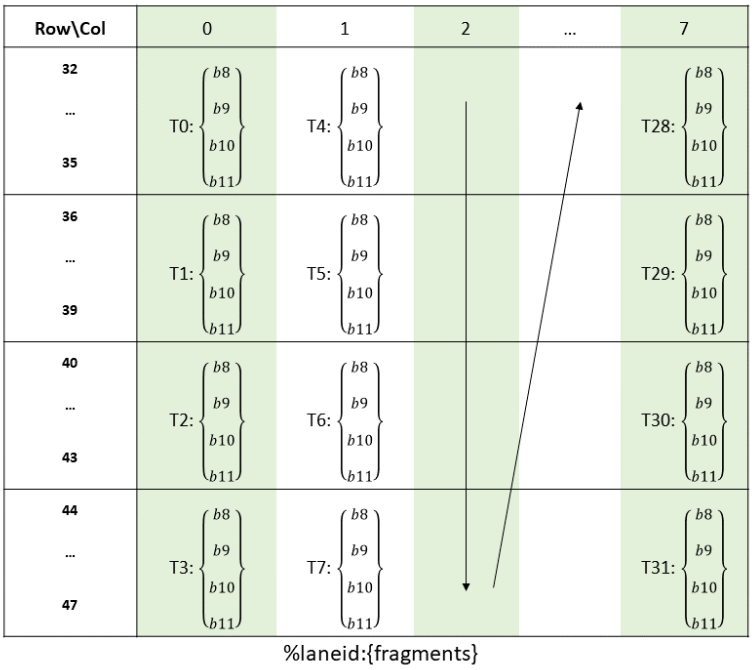

Figure 134: Sparse MMA .m16n8k64 fragment layout for rows 32–47 of matrix B with `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

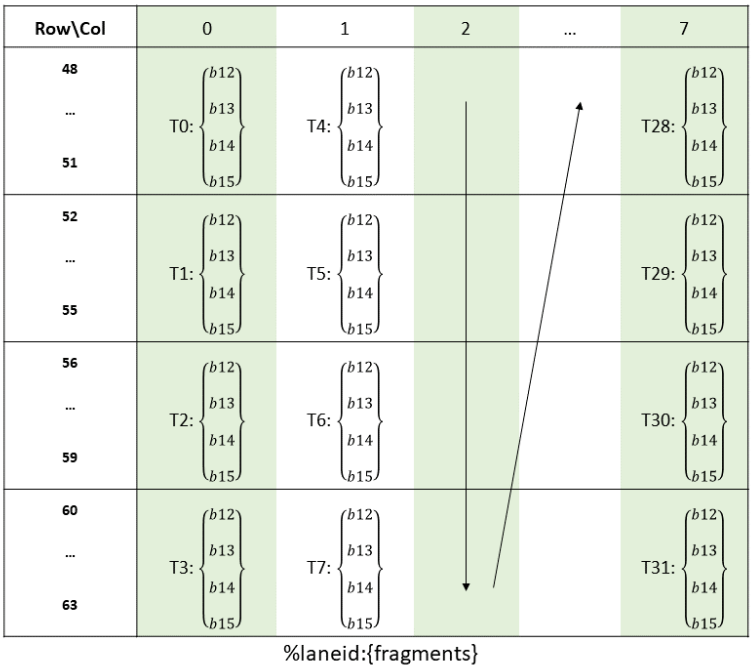

Figure 135: Sparse MMA .m16n8k64 fragment layout for rows 48–63 of matrix B with `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

- Matrix fragments for accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k16 with integer type*.
- Metadata: A `.b32` register containing 16 2-bit vectors with each pair of 2-bit vectors storing the indices of two non-zero elements from a 4-wide chunk of matrix A as shown in Figure 136 and Figure 137.

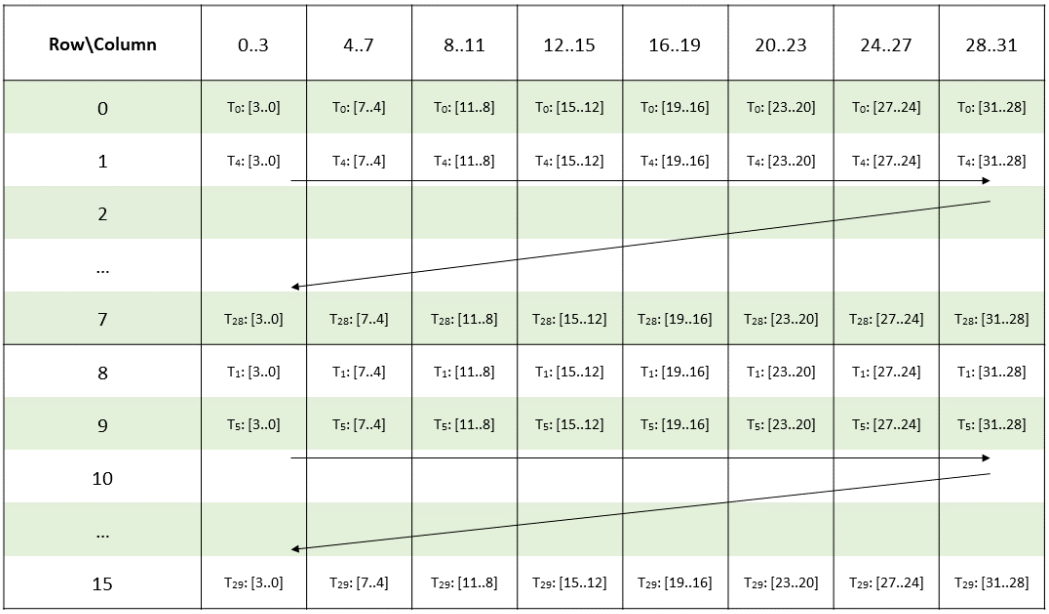

Figure 136: Sparse MMA .m16n8k64 metadata layout for columns 0–31 for `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

9.7.14.6.2.7 Matrix Fragments for sparse `mma.m16n8k64` with `.u4 / .s4` integer type

A warp executing sparse `mma.m16n8k64` with `.u4 / .s4` integer type will compute an MMA operation of shape `.m16n8k64`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.u4 / .s4`	A vector expression containing two `.b32` registers, with each register containing eight non-zero `.u4 / .s4` elements out of 16 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.

The layout of the fragments held by different threads is shown in Figure 138.

Row\Column	35..32	39..36	43..40	47..44	51..48	55..52	59..56	63..60
0	T_2: [3..0]	T_2: [7..4]	T_2: [11..8]	T_2: [15..12]	T_2: [19..16]	T_2: [23..20]	T_2: [27..24]	T_2: [31..28]
1	T_6: [3..0]	T_6: [7..4]	T_6: [11..8]	T_6: [15..12]	T_6: [19..16]	T_6: [23..20]	T_6: [27..24]	T_6: [31..28]
2								
...								
7	T_{30}: [3..0]	T_{30}: [7..4]	T_{30}: [11..8]	T_{30}: [15..12]	T_{30}: [19..16]	T_{30}: [23..20]	T_{30}: [27..24]	T_{30}: [31..28]
8	T_3: [3..0]	T_3: [7..4]	T_3: [11..8]	T_3: [15..12]	T_3: [19..16]	T_3: [23..20]	T_3: [27..24]	T_3: [31..28]
9	T_7: [3..0]	T_7: [7..4]	T_7: [11..8]	T_7: [15..12]	T_7: [19..16]	T_7: [23..20]	T_7: [27..24]	T_7: [31..28]
10								
...								
15	T_{31}: [3..0]	T_{31}: [7..4]	T_{31}: [11..8]	T_{31}: [15..12]	T_{31}: [19..16]	T_{31}: [23..20]	T_{31}: [27..24]	T_{31}: [31..28]

Figure 137: Sparse MMA .m16n8k64 metadata layout for columns 32–63 for `.u8/.s8/.e4m3/.e5m2/.e3m2/.e2m3/.e2m1` type.

Row\Column	0 ... 15	16 ... 31	32 ... 47	48 ... 63
0	T0:{a0 ... a7}	T1:{a0 ... a7}	T2:{a0 ... a7}	T3:{a0 ... a7}
1	T4:{a0 ... a7}	T5:{a0 ... a7}	T6:{a0 ... a7}	T7:{a0 ... a7}
2				
...				
7	T28:{a0 ... a7}	T29:{a0 ... a7}	T30:{a0 ... a7}	T31:{a0 ... a7}
8	T0:{a8 ... a15}	T1:{a8 ... a15}	T2:{a8 ... a15}	T3:{a8 ... a15}
9	T4:{a8 ... a15}	T5:{a8 ... a15}	T6:{a8 ... a15}	T7:{a8 ... a15}
10				
...				
15	T28:{a8 ... a15}	T29:{a8 ... a15}	T30:{a8 ... a15}	T31:{a8 ... a15}

Figure 138: Sparse MMA .m16n8k64 fragment layout for matrix A with `.u4/.s4` type.

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for ai where  0 <= i < 8
           groupID + 8         Otherwise

col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage

Where
firstcol = threadID_in_group * 16
lastcol  = firstcol + 15
```

- Matrix fragments for multiplicand B and accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k64*.
- Metadata: A `.b32` register containing 16 2-bit vectors with each pair of 2-bit vectors storing the indices of four non-zero elements from a 8-wide chunk of matrix A as shown in Figure 139.

Row\Column	0..7	8..15	16..23	24..31	32..39	40..47	48..55	56..63
0	T_{2i}: [3..0]	T_{2i}: [7..4]	T_{2i}: [11..8]	T_{2i}: [15..12]	T_{2i}: [19..16]	T_{2i}: [23..20]	T_{2i}: [27..24]	T_{2i}: [31..28]
1	T_{2i+4}: [3..0]	T_{2i+4}: [7..4]	T_{2i+4}: [11..8]	T_{2i+4}: [15..12]	T_{2i+4}: [19..16]	T_{2i+4}: [23..20]	T_{2i+4}: [27..24]	T_{2i+4}: [31..28]
2								
...								
7	T_{2i+28}: [3..0]	T_{2i+28}: [7..4]	T_{2i+28}: [11..8]	T_{2i+28}: [15..12]	T_{2i+28}: [19..16]	T_{2i+28}: [23..20]	T_{2i+28}: [27..24]	T_{2i+28}: [31..28]
8	T_{2i+1}: [3..0]	T_{2i+1}: [7..4]	T_{2i+1}: [11..8]	T_{2i+1}: [15..12]	T_{2i+1}: [19..16]	T_{2i+1}: [23..20]	T_{2i+1}: [27..24]	T_{2i+1}: [31..28]
9	T_{2i+5}: [3..0]	T_{2i+5}: [7..4]	T_{2i+5}: [11..8]	T_{2i+5}: [15..12]	T_{2i+5}: [19..16]	T_{2i+5}: [23..20]	T_{2i+5}: [27..24]	T_{2i+5}: [31..28]
10								
...								
15	T_{2i+29}: [3..0]	T_{2i+29}: [7..4]	T_{2i+29}: [11..8]	T_{2i+29}: [15..12]	T_{2i+29}: [19..16]	T_{2i+29}: [23..20]	T_{2i+29}: [27..24]	T_{2i+29}: [31..28]

Figure 139: Sparse MMA .m16n8k64 metadata layout for `.u4/.s4` type.

9.7.14.6.2.8 Matrix Fragments for sparse mma.m16n8k128 with .u4 / .s4 integer type

A warp executing sparse `mma.m16n8k128` with `.u4` / `.s4` / `.e2m1` integer type will compute an MMA operation of shape `.m16n8k128`.

Elements of the matrix are distributed across the threads in a warp so each thread of the warp holds a fragment of the matrix.

- Multiplicand A:

.atype	Fragment	Elements
`.u4` / `.s4`	A vector expression containing four `.b32` registers, with each register containing eight non-zero `.u4` / `.s4` elements out of 16 consecutive elements from matrix A.	Mapping of the non-zero elements is as described in *Sparse matrix storage*.
`.e2m1`	A vector expression containing four `.b32` registers, with each register containing eight non-zero `.e2m1` elements out of 16 consecutive elements from matrix A.	

The layout of the fragments held by different threads is shown in Figure 140 and Figure 141.

Row\Column	0 ... 15	16 ... 31	32 ... 47	48 ... 63
0	T0:{a0 ... a7}	T1:{a0 ... a7}	T2:{a0 ... a7}	T3:{a0 ... a7}
1	T4:{a0 ... a7}	T5:{a0 ... a7}	T6:{a0 ... a7}	T7:{a0 ... a7}
2				
...				
7	T28:{a0 ... a7}	T29:{a0 ... a7}	T30:{a0 ... a7}	T31:{a0 ... a7}
8	T0:{a8 ... a15}	T1:{a8 ... a15}	T2:{a8 ... a15}	T3:{a8 ... a15}
9	T4:{a8 ... a15}	T5:{a8 ... a15}	T6:{a8 ... a15}	T7:{a8 ... a15}
10				
...				
15	T28:{a8 ... a15}	T29:{a8 ... a15}	T30:{a8 ... a15}	T31:{a8 ... a15}

Figure 140: Sparse MMA .m16n8k128 fragment layout for columns 0–63 of matrix A with `.u4/.s4/.e2m1` type.

```
groupID = %laneid >> 2
threadID_in_group = %laneid % 4

row =      groupID             for ai where  0 <= i < 8 || 16 <= i < 24
           groupID + 8         Otherwise
```

(continues on next page)

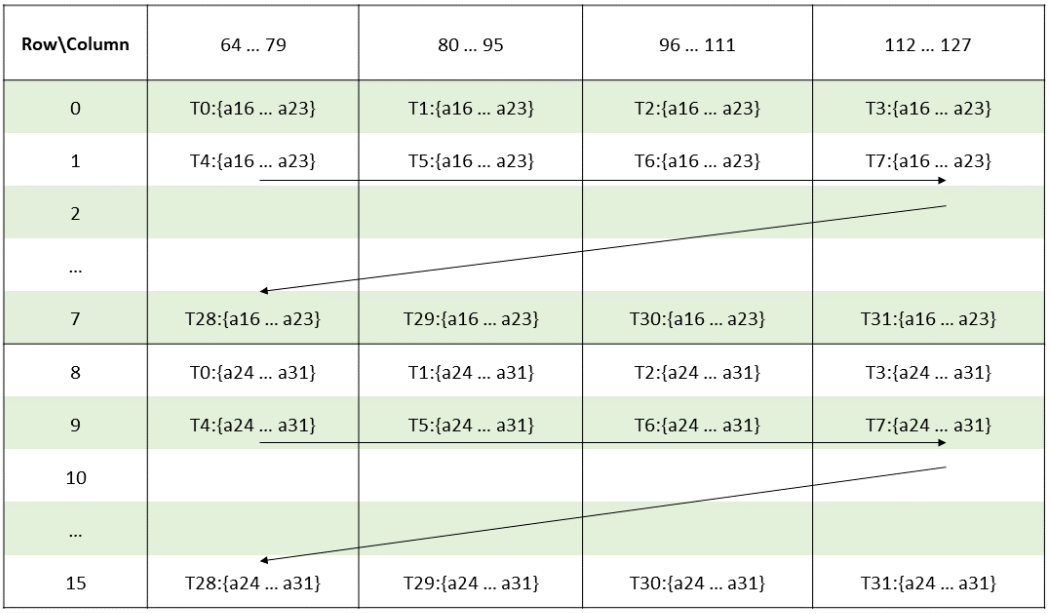

Figure 141: Sparse MMA .m16n8k128 fragment layout for columns 64–127 of matrix A with `.u4/.s4/.e2m1` type.

(continued from previous page)

```
col = [firstcol ... lastcol]  // As per the mapping of non-zero elements
                              // as described in Sparse matrix storage

Where
firstcol = threadID_in_group * 16           For ai where i <  16
           (threadID_in_group * 16) + 64    For ai where i >= 16
lastcol  = firstcol + 15
```

- Multiplicand B:

.atype	Fragment	Elements (low to high)
`.u4` / `.s4`	A vector expression containing four `.b32` registers, each containing eight `.u4` / `.s4` elements from matrix B.	b0, b1, b2, b3, ..., b31
`.e2m1`	A vector expression containing four `.b32` registers, each containing eight `.e2m1` elements from matrix B.	

  The layout of the fragments held by different threads is shown in Figure 142, Figure 143, Figure 144, Figure 145.

- Matrix fragments for accumulators C and D are the same as in case of *Matrix Fragments for mma.m16n8k64*.
- Metadata: A `.b32` register containing 16 2-bit vectors with each pair of 2-bit vectors storing the indices of four non-zero elements from a 8-wide chunk of matrix A as shown in Figure 146 and Figure 147.

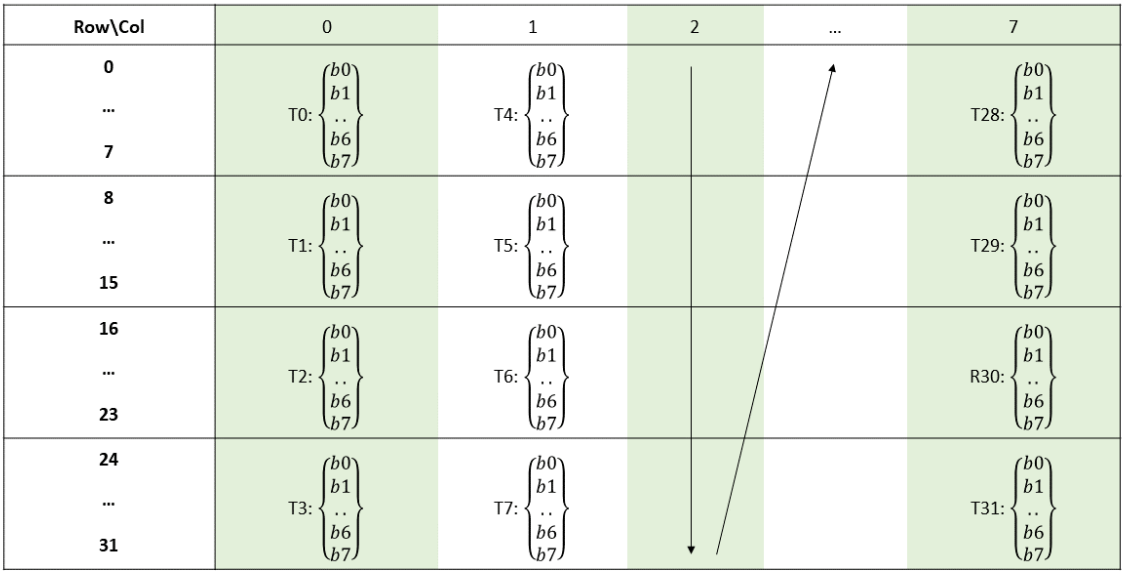

Figure 142: Sparse MMA .m16n8k128 fragment layout for rows 0–31 of matrix B with `.u4/.s4/.e2m1` type.

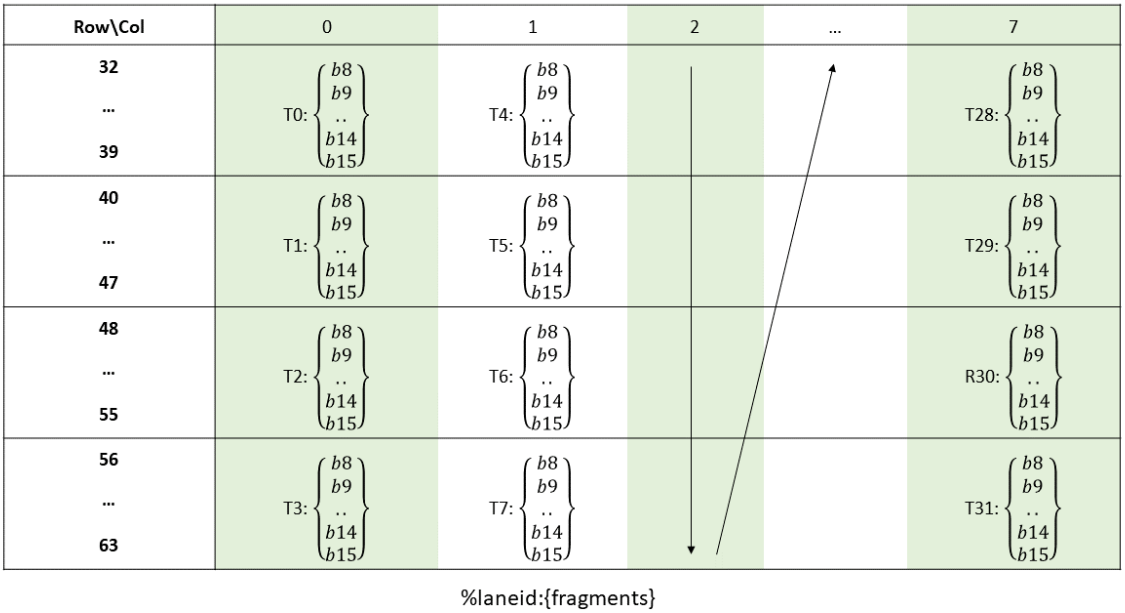

Figure 143: Sparse MMA .m16n8k128 fragment layout for rows 32–63 of matrix B with `.u4/.s4/.e2m1` type.

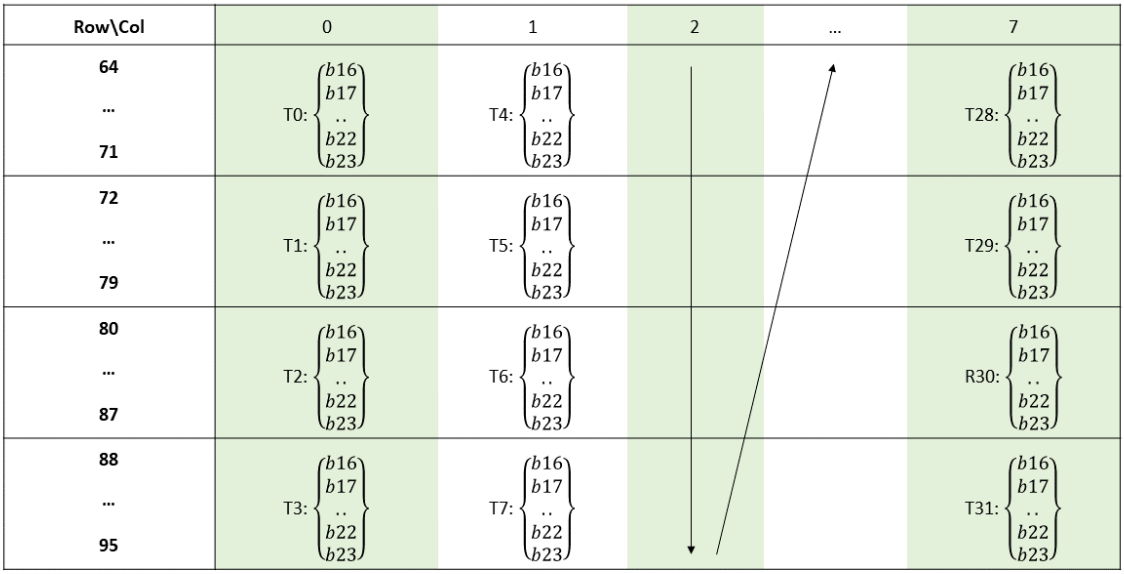

Figure 144: Sparse MMA .m16n8k128 fragment layout for rows 64–95 of matrix B with `.u4/.s4/.e2m1` type.

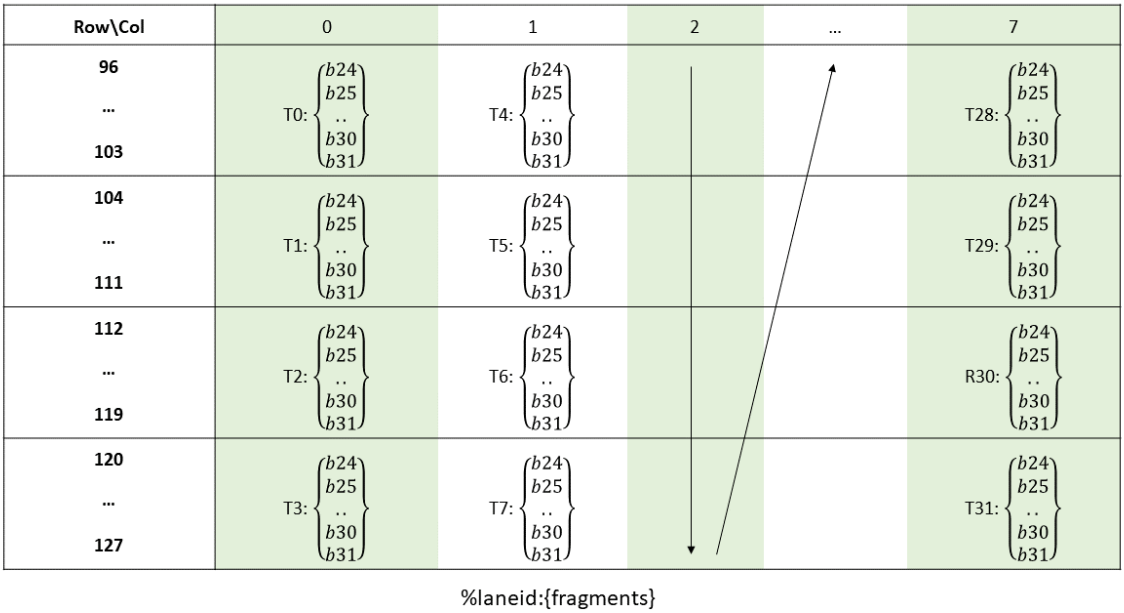

Figure 145: Sparse MMA .m16n8k128 fragment layout for rows 96–127 of matrix B with `.u4/.s4/.e2m1` type.

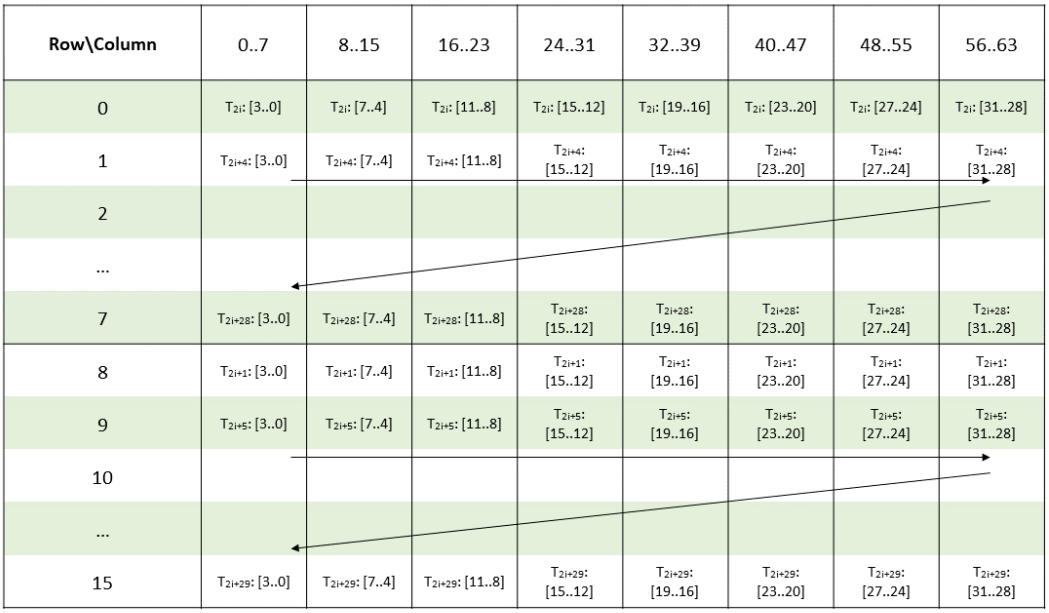

Figure 146: Sparse MMA .m16n8k128 metadata layout for columns 0–63 for `.u4/.s4/.e2m1` type.

9.7.14.6.3 Multiply-and-Accumulate Instruction: `mma.sp` / `mma.sp::ordered_metadata`

`mma.sp, mma.sp::ordered_metadata`

Perform matrix multiply-and-accumulate operation with sparse matrix A

Syntax

Half precision floating point type:

```
mma.spvariant.sync.aligned.m16n8k16.row.col.dtype.f16.f16.ctype  d, a, b, c, e, f;
mma.spvariant.sync.aligned.m16n8k32.row.col.dtype.f16.f16.ctype  d, a, b, c, e, f;

.ctype     = {.f16, .f32};
.dtype     = {.f16, .f32};
.spvariant = {.sp, .sp::ordered_metadata};
```

Alternate floating point type:

```
mma.spvariant.sync.aligned.m16n8k16.row.col.f32.bf16.bf16.f32     d, a, b, c, e, f;
mma.spvariant.sync.aligned.m16n8k32.row.col.f32.bf16.bf16.f32     d, a, b, c, e, f;
mma.spvariant.sync.aligned.m16n8k8.row.col.f32.tf32.tf32.f32      d, a, b, c, e, f;
mma.spvariant.sync.aligned.m16n8k16.row.col.f32.tf32.tf32.f32     d, a, b, c, e, f;
mma.spvariant.sync.aligned.m16n8k64.row.col.f32.f8type.f8type.f32 d, a, b, c, e, f;
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.kind.dtype.f8f6f4type.
↪f8f6f4type.ctype d, a, b, c, e, f;
```

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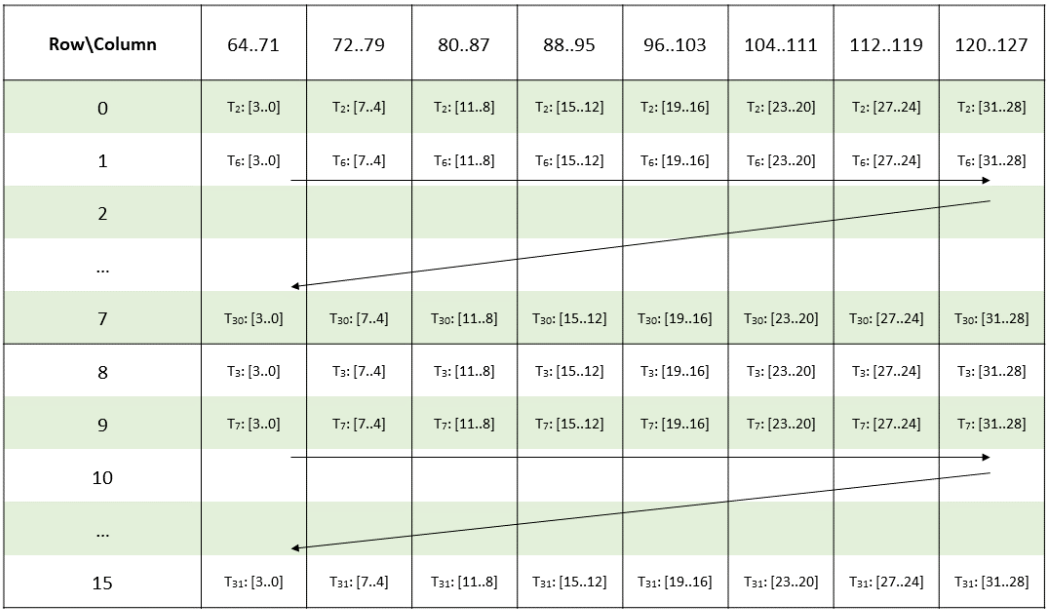

Figure 147: Sparse MMA .m16n8k128 metadata layout for columns 64–127 for `.u4/.s4/.e2m1` type.

(continued from previous page)

```
.f8type     = {.e4m3, .e5m2};
.spvariant  = {.sp, .sp::ordered_metadata};
.f8f6f4type = {.e4m3, .e5m2, .e3m2, .e2m3, .e2m1};
.kind       = {kind::f8f6f4};
.ctype      = {.f16, .f32};
.dtype      = {.f16, .f32};
```

Alternate floating point type with block scaling:

```
mma.spvariant.sync.aligned.m16n8k128.row.col.kind.block_scale{.scale_vec_size}.f32.
↪e2m1.e2m1.f32.stype d, a, b, c, e, f, scale-a-data, {byte-id-a, thread-id-a}, scale-
↪b-data, {byte-id-b, thread-id-b};

.spvariant      = {.sp::ordered_metadata};
.kind           = {.kind::mxf4};
.scale_vec_size = {.scale_vec::2X};
.stype          = {.ue8m0};

mma.spvariant.sync.aligned.m16n8k128.row.col.kind.block_scale.scale_vec_size.f32.e2m1.
↪e2m1.f32.stype d, a, b, c, e, f, scale-a-data, {byte-id-a, thread-id-a}, scale-b-
↪data, {byte-id-b, thread-id-b};

.spvariant      = {.sp::ordered_metadata};
.kind           = {.kind::mxf4nvf4};
.scale_vec_size = {.scale_vec::2X, .scale_vec::4X};
.stype          = {.ue8m0, .ue4m3};

mma.spvariant.sync.aligned.m16n8k64.row.col.kind.block_scale{.scale_vec_size}.f32.
↪f8f6f4type.f8f6f4type.f32.stype d, a, b, c, e, f, scale-a-data, {byte-id-a, thread-
↪id-a}, scale-b-data, {byte-id-b, thread-id-b};
```

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```
.spvariant      = {.sp::ordered_metadata};
.kind           = {.kind::mxf8f6f4};
.scale_vec_size = {.scale_vec::1X};
.f8f6f4type     = {.e4m3, .e5m2, .e3m2, .e2m3, .e2m1};
.stype          = {.ue8m0};
```

Integer type:

```
mma.spvariant.sync.aligned.shape.row.col{.satfinite}.s32.atype.btype.s32 d, a, b, c,
↪e, f;

.shape     = {.m16n8k32, .m16n8k64}
.atype     = {.u8, .s8};
.btype     = {.u8, .s8};
.spvariant = {.sp, .sp::ordered_metadata};

mma.spvariant.sync.aligned.shape.row.col{.satfinite}.s32.atype.btype.s32 d, a, b, c,
↪e, f;

.shape     = {.m16n8k64, .m16n8k128}
.atype     = {.u4, .s4};
.btype     = {.u4, .s4};
.spvariant = {.sp, .sp::ordered_metadata};
```

Description

Perform a `MxNxK` matrix multiply and accumulate operation, `D = A*B+C`, where the A matrix is `MxK`, the B matrix is `KxN`, and the C and D matrices are `MxN`.

A warp executing `mma.sp.sync/mma.sp::ordered_metadata.sync` instruction compute a single matrix multiply and accumulate operation.

Qualifier `.block_scale` specifies that the matrices A and B are scaled with `scale_A` and `scale_B` matrices respectively before performing the matrix multiply and accumulate operation as specified in the section *Block Scaling*. The data type corresponding to each of the element within `scale_A` and `scale_B` matrices is specified by `.stype`. Qualifier `.scale_vec_size` specifies the number of columns of `scale_A` matrix and number of rows in the matrix `scale_B`.

The valid combinations of `.kind`, `.stype` and `.scale_vec_size` are described in Table 38. For `mma` with `.kind::mxf4` when the qualifier `.scale_vec_size` is not specified, then it defaults to 2X. In contrast, when `.kind` is specified as `.kind::mxf8f6f4` then the qualifier `.scale_vec_size` defaults to 1X. However, for `.kind::mxf4nvf4`, it is mandatory to provide valid `.scale_vec_size`.

Operands `a` and `b` represent two multiplicand matrices A and B, while `c` and `d` represent the accumulator and destination matrices, distributed across the threads in warp. Matrix A is structured sparse as described in *Sparse matrix storage* Operands `e` and `f` represent sparsity metadata and sparsity selector respectively. Operand `e` is a 32-bit integer and operand `f` is a 32-bit integer constant with values in the range 0..3. When `.block_scale` qualifier is specified, operand `scale-a-data`, `scale-b-data` represents the scale matrix metadata corresponding to `scale_A` and `scale_B` matrices respectively. The tuple `{byte-id-a, thread-id-a}` and `{byte-id-b, thread-id-b}` represent selectors for matrices `scale_A` and `scale_B` respectively from their corresponding metadata arguments `scale-a-data`, `scale-b-data`. The operands `scale-a-data`, `scale-b-data` are of type `.b32`. The operands `byte-id-a`, `thread-id-a`, `byte-id-b`, `thread-id-b` are unsigned 16-bit integer values. For more details on selector arguments refer *Block Scaling* section.

Instruction `mma.sp::ordered_metadata` requires the indices in the sparsity metadata to be sorted in an increasing order starting from LSB, otherwise behavior is undefined.

The registers in each thread hold a fragment of matrix as described in *Matrix fragments for multiply-accumulate operation with sparse matrix A*.

The qualifiers `.dtype`, `.atype`, `.btype` and `.ctype` indicate the data-type of the elements in the matrices D, A, B and C respectively. The qualifier `.stype` indicate the data-type of the elements in the matrices `scale_A` and `scale_B`. In case of shapes `.m16n8k16` and `.m16n8k32`, `.dtype` must be the same as `.ctype`.

When `.kind` is either of `.kind::mxf8f6f4` or `.kind::f8f6f4`, the individual 4-bit and the 6-bit floating point type elements must be packed in an 8-bit container. The matrix element of type `.e2m1` resides in central 4 bits of the 8-bit container with padding in the upper 2 bits and lower 2 bits of the container. When the matrix element is of type `.e3m2` or `.e2m3`, the matrix element resides in the lower 6 bits of the 8-bit container with padding in the upper 2 bits of the container. In contrast, note that when using `mma` with `.kind::mxf4` or `.kind::mxf4nvf4`, no explicit padding is necessary even though matrix elements are of type `.e2m1`.

Precision and rounding :

- `.f16` floating point operations :

  Element-wise multiplication of matrix A and B is performed with at least single precision. When `.ctype` or `.dtype` is `.f32`, accumulation of the intermediate values is performed with at least single precision. When both `.ctype` and `.dtype` are specified as `.f16`, the accumulation is performed with at least half precision.

  The accumulation order, rounding and handling of subnormal inputs are unspecified.

- `.e4m3`, `.e5m2`, `.e3m2`, `.e2m3`, `.e2m1` floating point operations :

  Element-wise multiplication of matrix A and B is performed with specified precision. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- `.bf16` and `.tf32` floating point operations :

  Element-wise multiplication of matrix A and B is performed with specified precision. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- Integer operations :

  The integer `mma.sp/mma.sp::ordered_metadata` operation is performed with `.s32` accumulators. The `.satfinite` qualifier indicates that on overflow, the accumulated value is limited to the range *MIN_INT32*.. *MAX_INT32* (where the bounds are defined as the minimum negative signed 32-bit integer and the maximum positive signed 32-bit integer respectively).

  If `.satfinite` is not specified, the accumulated value is wrapped instead.

The mandatory `.sync` qualifier indicates that `mma.sp/mma.sp::ordered_metadata` instruction causes the executing thread to wait until all threads in the warp execute the same `mma.sp/mma.sp::ordered_metadata` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `mma.sp/mma.sp::ordered_metadata` instruction. In conditionally executed code, a `mma.sp/mma.sp::ordered_metadata` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of `mma.sp/mma.sp::ordered_metadata` instruction is undefined if all threads in the same warp do not use the same qualifiers, or if any thread in the warp has exited.

Notes

`mma.sp` instruction may have substantially reduced performance on some target architectures. Hence, it is advised to use `mma.sp::ordered_metadata` instruction.

PTX ISA Notes

Introduced in PTX ISA version 7.1.

Support for `.e4m3` and `.e5m2` alternate floating point type `mma` operation introduced in PTX ISA version 8.4.

`mma.sp::ordered_metadata` introduced in PTX ISA version 8.5.

Support for shape `.m16n8k32` and `.f16` dtype/ctype with `.e4m3`/`.e5m2` alternate floating point type `mma` operation introduced in PTX ISA version 8.7.

Support for `.e3m2`, `.e2m3`, `.e2m1` alternate floating point type `mma` operation introduced in PTX ISA version 8.7.

Support for `.kind`, `.block_scale`, `.scale_vec_size` qualifier introduced in PTX ISA version 8.7.

Target ISA Notes

Requires `sm_80` or higher.

`.e4m3` and `.e5m2` alternate floating point type `mma` operation requires `sm_89` or higher.

`mma.sp::ordered_metadata` requires `sm_80` or higher.

Support for shape `.m16n8k32` and `.f16` dtype/ctype with `.e4m3`/`.e5m2` alternate floating point type `mma` operation requires `sm_120`.

`.e3m2`, `.e2m3` and `.e2m1` alternate floating point type `mma` operation requires `sm_120a` and are supported on `sm_120f` or higher in the same family from PTX ISA version 8.8.

Support for `.kind`, `.block_scale`, `.scale_vec_size` qualifier requires `sm_120a` and are supported on `sm_120f` and later generation targets in the same family from PTX ISA version 8.8 except for `.kind::mxf4nvf4`/`.kind::mxf4`.

Qualifiers `.kind::mxf4nvf4` and `.kind::mxf4` are supported on following architectures:

- `sm_120a`
- `sm_121a`

Examples of half precision floating point type

```
// f16 elements in C and D matrix
.reg .f16x2 %Ra<2> %Rb<2> %Rc<2> %Rd<2>
.reg .b32 %Re;
mma.sp.sync.aligned.m16n8k16.row.col.f16.f16.f16.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1}, %Re, 0x1;

.reg .f16x2 %Ra<2> %Rb<2> %Rc<2> %Rd<2>
.reg .b32 %Re;

mma.sp::ordered_metadata.sync.aligned.m16n8k16.row.col.f16.f16.f16.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1}, %Re, 0x1;
```

Examples of alternate floating point type

```
.reg .b32 %Ra<2>, %Rb<2>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp.sync.aligned.m16n8k8.row.col.f32.tf32.tf32.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

.reg .b32 %Ra<2>, %Rb<2>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp.sync.aligned.m16n8k16.row.col.f32.bf16.bf16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp.sync.aligned.m16n8k32.row.col.f32.bf16.bf16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp.sync.aligned.m16n8k64.row.col.f32.e5m2.e4m3.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
```

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```
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0;

.reg .b32 %Ra<2>, %Rb<2>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k16.row.col.f32.bf16.bf16.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.kind::f8f6f4.f32.e3m2.e2m3.f32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0;

.reg .b32 %Ra<4>, %Rb<4>;
.reg .b32 %Rc<4>, %Rd<4>;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.kind::f8f6f4.f16.e2m3.e2m1.f16
  {%Rd0, %Rd1},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1}, %Re, 0;
```

Examples of integer type

```
.reg .b32 %Ra<4>, %Rb<4>, %Rc<4>, %Rd<4>;
.reg .u32 %Re;

// u8 elements in A and B matrix
mma.sp.sync.aligned.m16n8k32.row.col.satfinite.s32.u8.u8.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

// s8 elements in A and B matrix
mma.sp.sync.aligned.m16n8k64.row.col.satfinite.s32.s8.s8.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x0;

// s8 elements in A and B matrix with ordered metadata
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.satfinite.s32.s8.s8.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
```

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```
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x0;

// u4 elements in A and B matrix
mma.sp.sync.aligned.m16n8k64.row.col.s32.s4.s4.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1},
  {%Rb0, %Rb1},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x1;

// u4 elements in A and B matrix
mma.sp.sync.aligned.m16n8k128.row.col.satfinite.s32.u4.u4.s32
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3}, %Re, 0x0;
```

Examples of mma with block scale

```
.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k128.row.col.kind::mxf4.block_scale.f32.
↪e2m1.e2m1.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  %Re, 0,
  scaleAData, {2, 1}, scaleBData, {2, 3};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
.reg .u16 bidA, bidB, tidA, tidB;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k128.row.col.kind::mxf4nvf4.block_scale.
↪scale_vec::4X.f32.e2m1.e2m1.f32.ue4m3
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  %Re, 0,
  scaleAData, {bidA, tidA}, scaleBData, {bidB, tidB};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.kind::mxf8f6f4.block_scale.
↪scale_vec::1X.f32.e3m2.e2m1.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2, %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
```

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```
  {%Rc0, %Rc1, %Rc2, %Rc3},
  %Re, 0,
  scaleAData, {0, 1}, scaleBData, {0, 1};

.reg .b32 %Ra<4>, %Rb<4>;
.reg .f32 %Rc<4>, %Rd<4>;
.reg .b32 scaleAData, scaleBData;
.reg .b32 %Re;
mma.sp::ordered_metadata.sync.aligned.m16n8k64.row.col.kind::mxf8f6f4.block_scale.
↪scale_vec::1X.f32.e4m3.e5m2.f32.ue8m0
  {%Rd0, %Rd1, %Rd2, %Rd3},
  {%Ra0, %Ra1, %Ra2,  %Ra3},
  {%Rb0, %Rb1, %Rb2, %Rb3},
  {%Rc0, %Rc1, %Rc2, %Rc3},
  %Re, 0,
  scaleAData, {0, 1}, scaleBData, {0, 0};
```

9.7.15. Asynchronous Warpgroup Level Matrix Multiply-Accumulate Instructions

The warpgroup level matrix multiply and accumulate operation has either of the following forms, where matrix D is called accumulator:

- `D = A * B + D`
- `D = A * B`, where the input from accumulator D is disabled.

The `wgmma` instructions perform warpgroup level matrix multiply-and-accumulate operation by having all threads in a warpgroup collectively perform the following actions:

1. Load matrices A, B and D into registers or into shared memory.
2. Perform the following `fence` operations:
   - `wgmma.fence` operations to indicate that the register/shared-memory across the warpgroup have been written into.
   - `fence.proxy.async` operation to make the generic proxy operations visible to the async proxy.
3. Issue the asynchronous matrix multiply and accumulate operations using the `wgmma.mma_async` operation on the input matrices. The `wgmma.mma_async` operation is performed in the async proxy.
4. Create a wgmma-group and commit all the prior outstanding `wgmma.mma_async` operations into the group, by using `wgmma.commit_group` operation.
5. Wait for the completion of the required wgmma-group.
6. Once the wgmma-group completes, all the `wgmma.mma_async` operations have been performed and completed.

9.7.15.1 Warpgroup

A warpgroup is a set of four contiguous warps such that the *warp-rank* of the first warp is a multiple of 4.

warp-rank of a warp is defined as:

```
(%tid.x + %tid.y * %ntid.x  + %tid.z * %ntid.x * %ntid.y) / 32
```

9.7.15.2 Matrix Shape

The matrix multiply and accumulate operations support a limited set of shapes for the operand matrices A, B and D. The shapes of all three matrix operands are collectively described by the tuple `MxNxK`, where A is an `MxK` matrix, B is a `KxN` matrix, while D is a `MxN` matrix.

The following matrix shapes are supported for the specified types for the `wgmma.mma_async` operation:

Multiplicand Data type	Sparsity	Shape
Floating-point - `.f16`	Dense	`.m64n8k16`, `.m64n16k16`, `.m64n24k16`, `.m64n32k16`, `.m64n40k16`, `.m64n48k16`, `.m64n56k16`, `.m64n64k16`, `.m64n72k16`, `.m64n80k16`, `.m64n88k16`, `.m64n96k16`, `.m64n104k16`, `.m64n112k16`, `.m64n120k16`, `.m64n128k16`, `.m64n136k16`, `.m64n144k16`, `.m64n152k16`, `.m64n160k16`, `.m64n168k16`, `.m64n176k16`, `.m64n184k16`, `.m64n192k16`, `.m64n200k16`, `.m64n208k16`, `.m64n216k16`, `.m64n224k16`, `.m64n232k16`, `.m64n240k16`, `.m64n248k16`, `.m64n256k16`
Alternate floating-point format - `.bf16`		
Alternate floating-point format - `.tf32`	Sparse	
Alternate floating-point format - `.tf32`	Dense	`.m64n8k8`, `.m64n16k8`, `.m64n24k8`, `.m64n32k8`, `.m64n40k8`, `.m64n48k8`, `.m64n56k8`, `.m64n64k8`, `.m64n72k8`, `.m64n80k8`, `.m64n88k8`, `.m64n96k8`, `.m64n104k8`, `.m64n112k8`, `.m64n120k8`, `.m64n128k8`, `.m64n136k8`, `.m64n144k8`, `.m64n152k8`, `.m64n160k8`, `.m64n168k8`, `.m64n176k8`, `.m64n184k8`, `.m64n192k8`, `.m64n200k8`, `.m64n208k8`, `.m64n216k8`, `.m64n224k8`, `.m64n232k8`, `.m64n240k8`, `.m64n248k8`, `.m64n256k8`
Alternate floating-point format - `.e4m3`/`.e5m2`	Dense	`.m64n8k32`, `.m64n16k32`, `.m64n24k32`, `.m64n32k32`, `.m64n40k32`, `.m64n48k32`, `.m64n56k32`, `.m64n64k32`, `.m64n72k32`, `.m64n80k32`, `.m64n88k32`, `.m64n96k32`, `.m64n104k32`, `.m64n112k32`, `.m64n120k32`, `.m64n128k32`, `.m64n136k32`, `.m64n144k32`, `.m64n152k32`, `.m64n160k32`, `.m64n168k32`, `.m64n176k32`, `.m64n184k32`, `.m64n192k32`, `.m64n200k32`, `.m64n208k32`, `.m64n216k32`, `.m64n224k32`, `.m64n232k32`, `.m64n240k32`, `.m64n248k32`, `.m64n256k32`
Floating point - `.f16`	Sparse	
Alternname floating-point format - `.bf16`		

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Table 40 – continued from previous page

Multiplicand Data type	Sparsity	Shape
Integer - .u8/.s8	Dense	.m64n8k32, .m64n16k32, .m64n24k32, .m64n32k32, .m64n48k32, .m64n64k32, .m64n80k32, .m64n96k32, .m64n112k32, .m64n128k32, .m64n144k32, .m64n160k32, .m64n176k32, .m64n192k32, .m64n208k32, .m64n224k32, .m64n240k32, .m64n256k32
Alternate floating-point format - .e4m3/.e5m2	Sparse	.m64n8k64, .m64n16k64, .m64n24k64, .m64n32k64, .m64n40k64, .m64n48k64, .m64n56k64, .m64n64k64, .m64n72k64, .m64n80k64, .m64n88k64, .m64n96k64, .m64n104k64, .m64n112k64, .m64n120k64, .m64n128k64, .m64n136k64, .m64n144k64, .m64n152k64, .m64n160k64, .m64n168k64, .m64n176k64, .m64n184k64, .m64n192k64, .m64n200k64, .m64n208k64, .m64n216k64, .m64n224k64, .m64n232k64, .m64n240k64, .m64n248k64, .m64n256k64
Integer - .u8/.s8	Sparse	.m64n8k64, .m64n16k64, .m64n24k64, .m64n32k64, .m64n48k64, .m64n64k64, .m64n80k64, .m64n96k64, .m64n112k64, .m64n128k64, .m64n144k64, .m64n160k64, .m64n176k64, .m64n192k64, .m64n208k64, .m64n224k64, .m64n240k64, .m64n256k64
Single-bit - .b1	Dense	.m64n8k256, .m64n16k256, .m64n24k256, .m64n32k256, .m64n48k256, .m64n64k256, .m64n80k256, .m64n96k256, .m64n112k256, .m64n128k256, .m64n144k256, .m64n160k256, .m64n176k256, .m64n192k256, .m64n208k256, .m64n224k256, .m64n240k256, .m64n256k256

9.7.15.3 Matrix Data-types

The matrix multiply and accumulate operation is supported separately on integer, floating-point, sub-byte integer and single bit data-types. All operands must contain the same basic type kind, i.e., integer or floating-point.

For floating-point matrix multiply and accumulate operation, different matrix operands may have different precision, as described later.

For integer matrix multiply and accumulate operation, both multiplicand matrices (A and B) must have elements of the same data-type, e.g. both signed integer or both unsigned integer.

Data-type	Multiplicands (A or B)	Accumulator (D)
Integer	both .u8 or both .s8	.s32
Floating Point	.f16	.f16, .f32
Alternate floating Point	.bf16	.f32
Alternate floating Point	.tf32	.f32
Alternate floating Point	.e4m3, .e5m2	.f16, .f32
Single-bit integer	.b1	.s32

9.7.15.4 Async Proxy

The `wgmma.mma_async` operations are performed in the asynchronous proxy (or async proxy).

Accessing the same memory location across multiple proxies needs a cross-proxy fence. For the async proxy, `fence.proxy.async` should be used to synchronize memory between generic proxy and the async proxy.

The completion of a `wgmma.mma_async` operation is followed by an implicit generic-async proxy fence. So the result of the asynchronous operation is made visible to the generic proxy as soon as its completion is observed. `wgmma.commit_group` and `wgmma.wait_group` operations must be used to wait for the completion of the `wgmma.mma_async` instructions.

9.7.15.5 Asynchronous Warpgroup Level Matrix Multiply-Accumulate Operation using `wgmma.mma_async` instruction

This section describes warpgroup level `wgmma.mma_async` instruction and the organization of various matrices involved in this instruction.

9.7.15.5.1 Register Fragments and Shared Memory Matrix Layouts

The input matrix A of the warpgroup wide MMA operations can be either in registers or in the shared memory. The input matrix B of the warpgroup wide MMA operations must be in the shared memory. This section describes the layouts of register fragments and shared memory expected by the warpgroup MMA instructions.

When the matrices are in shared memory, their starting addresses must be aligned to 16 bytes.

9.7.15.5.1.1 Register Fragments

This section describes the organization of various matrices located in register operands of the `wgmma.mma_async` instruction.

9.7.15.5.1.2 Matrix Fragments for `wgmma.mma_async.m64nNk16`

A warpgroup executing `wgmma.mma_async.m64nNk16` will compute an MMA operation of shape `.m64nNk16` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A in registers:

.atype	Fragment	Elements (low to high)
`.f16/.bf16`	A vector expression containing four `.f16x2` registers, with each register containing two `.f16/ .bf16` elements from matrix A.	a0, a1, a2, a3, a4, a5, a6, a7

The layout of the fragments held by different threads is shown in Figure 148.

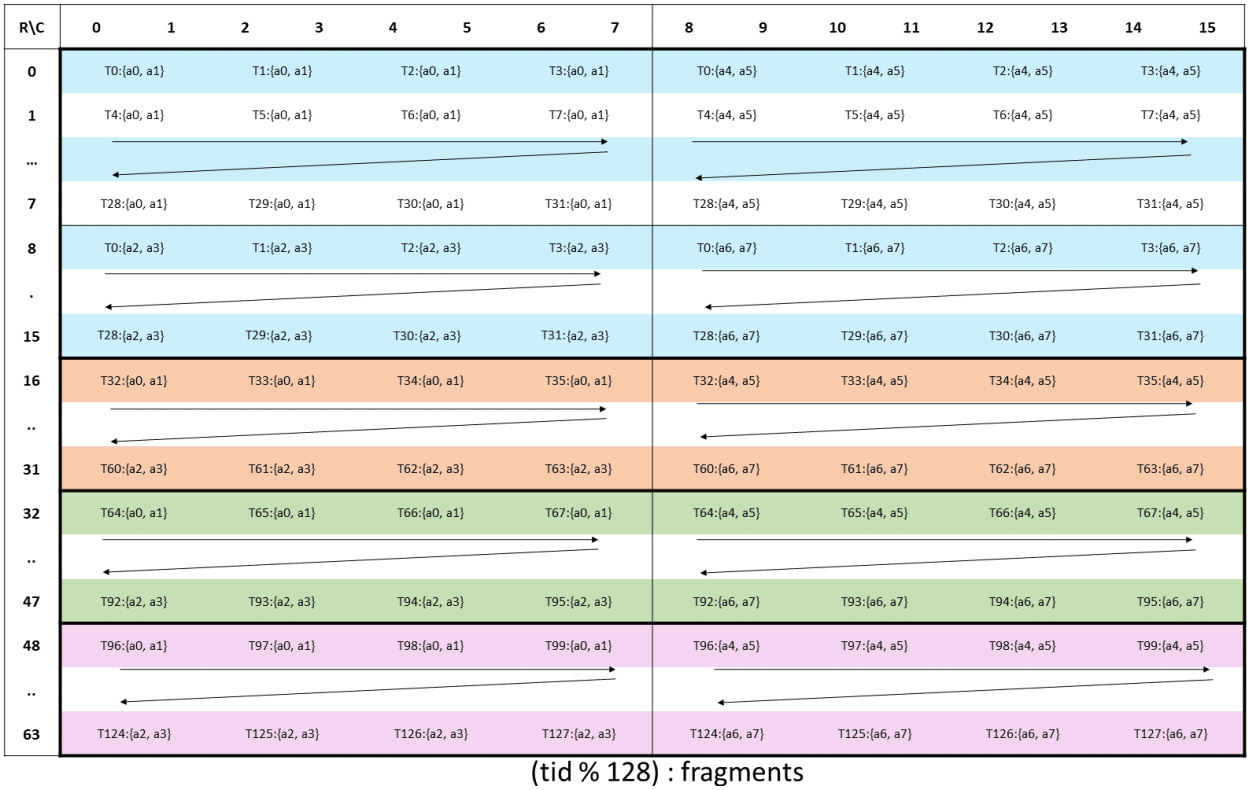


Figure 148: WGMMA .m64nNk16 register fragment layout for matrix A.

- Accumulator D:

.dtype	Fragment	Elements (low to high)
.f16	A vector expression containing N/4 number of .f16x2 registers, with each register containing two .f16 elements from matrix D.	d0, d1, d2, d3, ..., dX, dY, dZ, dW where X = N/2 - 4 Y = N/2 - 3 Z = N/2 - 2 W = N/2 - 1 N = 8*i where i = {1, 2, ... , 32}
.f32	A vector expression containing N/2 number of .f32 registers.	

The layout of the fragments held by different threads is shown in Figure 149.

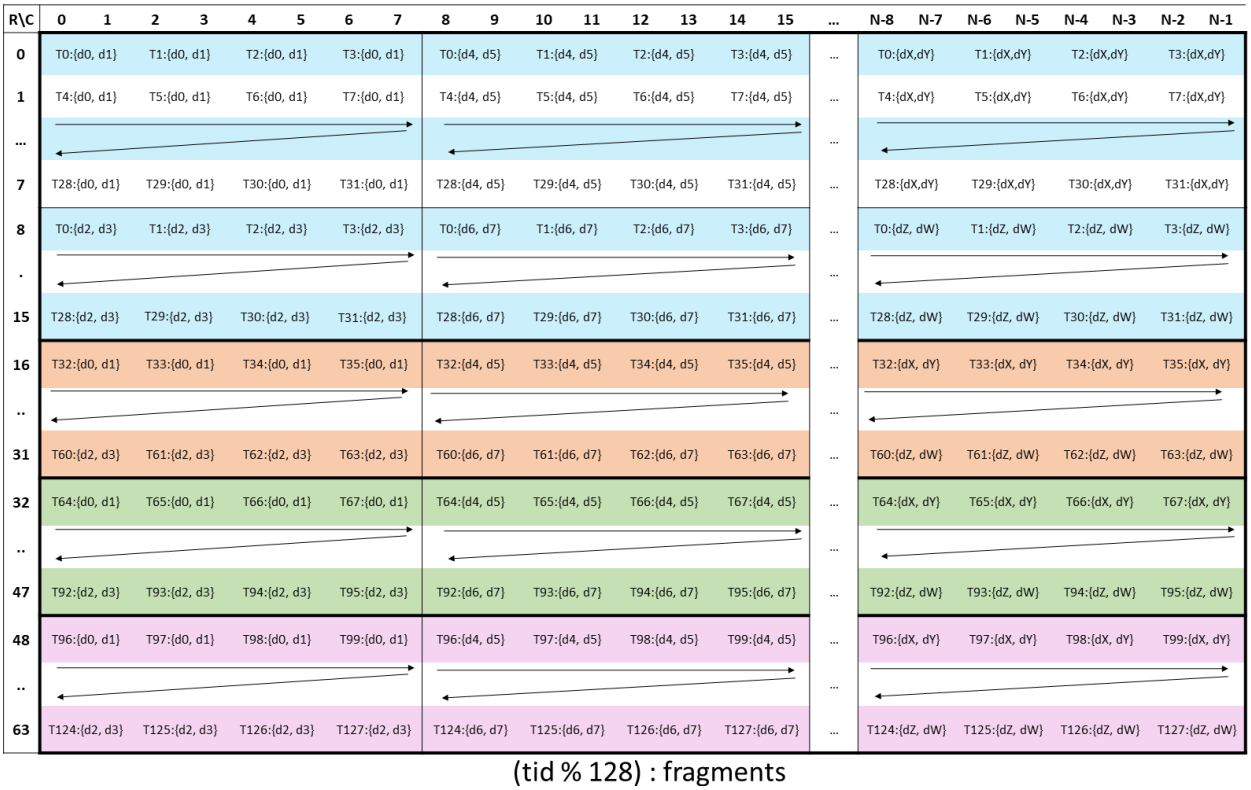


Figure 149: WGMMA .m64nNk16 register fragment layout for accumulator matrix D.

9.7.15.5.1.3 Matrix Fragments for `wgmma.mma_async.m64nNk8`

A warpgroup executing `wgmma.mma_async.m64nNk8` will compute an MMA operation of shape `.m64nNk8` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A in registers:

.atype	Fragment	Elements (low to high)
`.tf32`	A vector expression containing four `.b32` registers containing four `.tf32` elements from matrix A.	a0, a1, a2, a3

The layout of the fragments held by different threads is shown in Figure 150.

- Accumulator D:

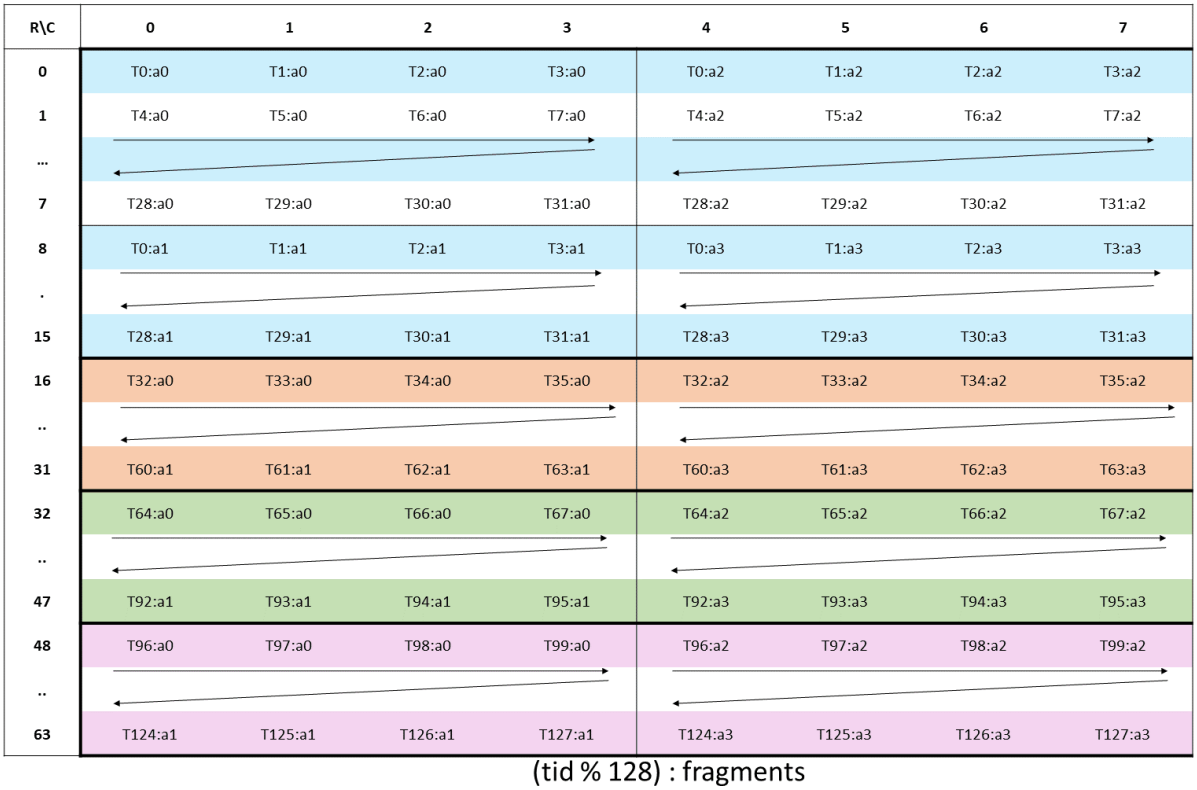


Figure 150: WGMMA .m64nNk8 register fragment layout for matrix A.

.dtype	Fragment	Elements (low to high)
.f32	A vector expression containing N/2 number of .f32 registers.	d0, d1, d2, d3, ..., dX, dY, dZ, dW where X = N/2 - 4 Y = N/2 - 3 Z = N/2 - 2 W = N/2 - 1 N = 8*i where i = {1, 2, ... , 32}

The layout of the fragments held by different threads is shown in Figure 151.

9.7.15.5.1.4 Matrix Fragments for wgmma.mma_async.m64nNk32

A warpgroup executing wgmma.mma_async.m64nNk32 will compute an MMA operation of shape .m64nNk32 where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A in registers:

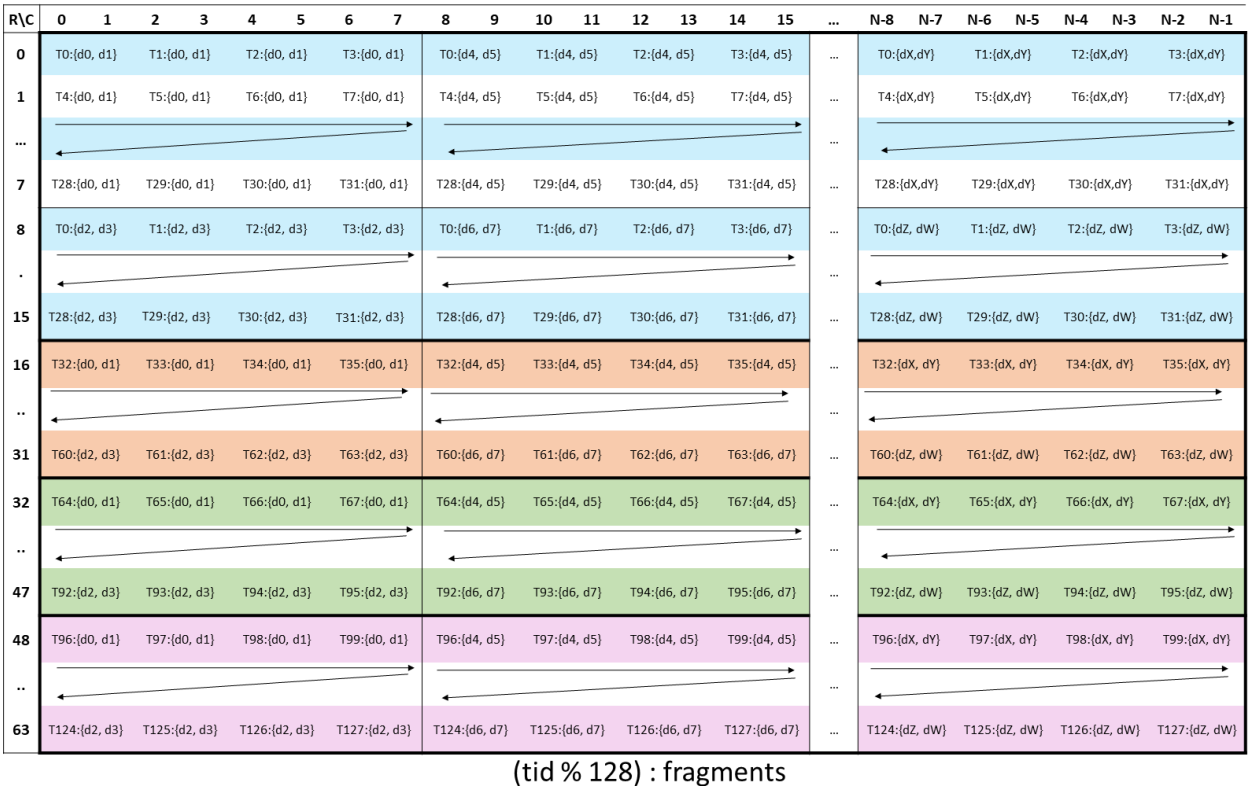


Figure 151: WGMMA .m64nNk8 register fragment layout for accumulator matrix D.

.atype	Fragment	Elements (low to high)
.s8/.u8	A vector expression containing four .b32 registers, with each register containing four .u8/ .s8 elements from matrix A.	a0, a1, a2, a3, … , a14, a15
.e4m3/ .e5m2	A vector expression containing four .b32 registers, with each register containing four .e4m3/ .e5m2 elements from matrix A.	

The layout of the fragments held by different threads is shown in Figure 152.

- Accumulator D:

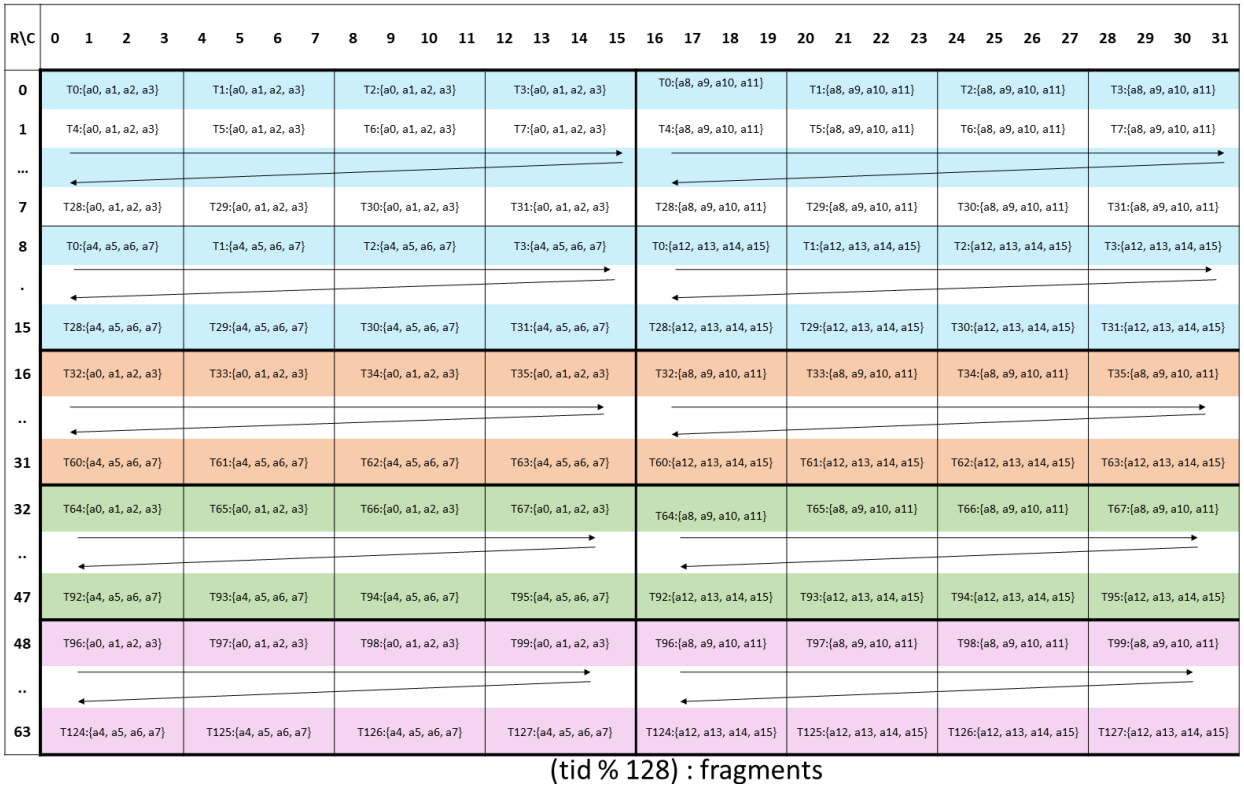


Figure 152: WGMMA .m64nNk32 register fragment layout for matrix A.

.dtype	Fragment	Elements (low to high)	Miscellaneous Information
.s32	A vector expression containing N/2 number of .s32 registers.	d0, d1, d2, d3, ..., dX, dY, dZ, dW where X = N/2 - 4 Y = N/2 - 3 Z = N/2 - 2 W = N/2 - 1 N depends on .dtype, as described in the next column.	N = 8*i where i = {1, 2, 3, 4} = 16*i where i = {3, 4, ..., 15, 16}
.f32	A vector expression containing N/2 number of .f32 registers.		N = 8*i where i = {1, 2, ... , 32}
.f16	A vector expression containing N/4 number of .f16x2 registers, with each register containing two .f16 elements from matrix D.		

The layout of the fragments held by different threads is shown in Figure 153.

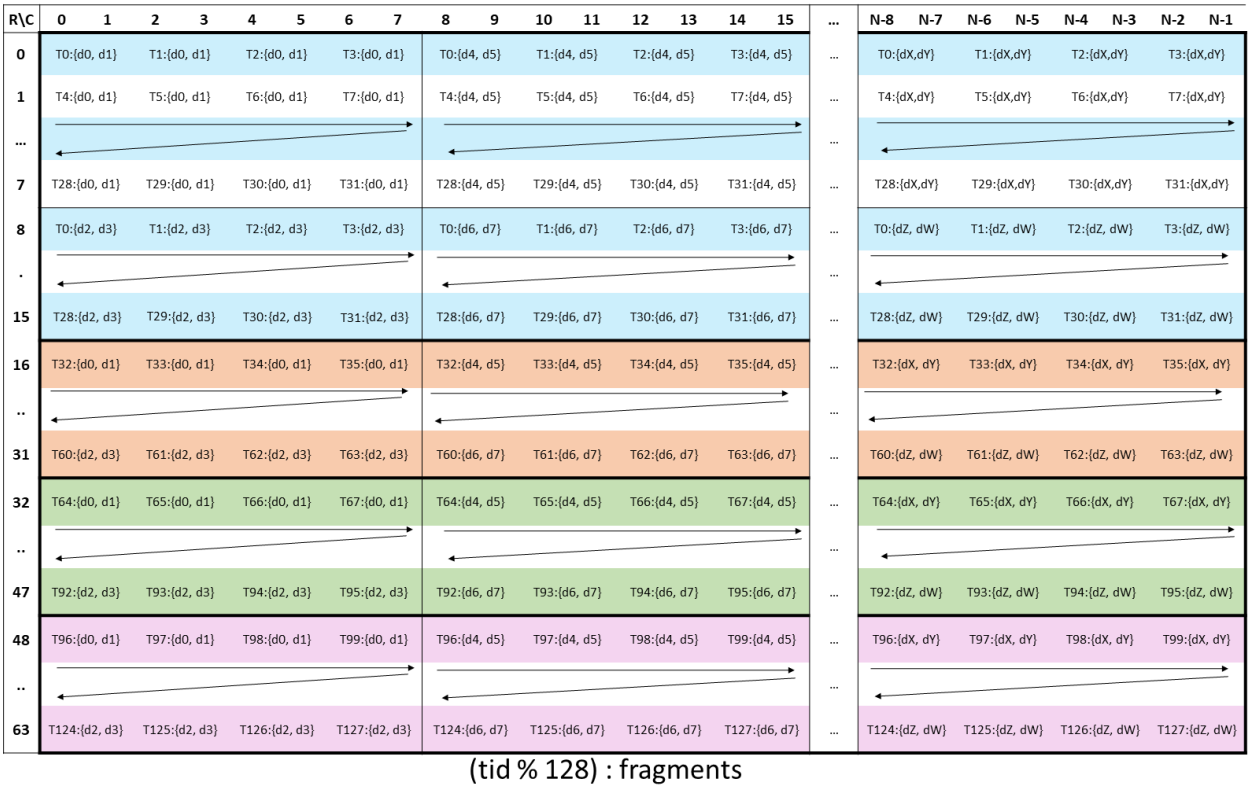


Figure 153: WGMMA .m64nNk32 register fragment layout for accumulator matrix D.

9.7.15.5.1.5 Matrix Fragments for `wgmma.mma_async.m64nNk256`

A warpgroup executing `wgmma.mma_async.m64nNk256` will compute an MMA operation of shape `.m64nNk256` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A in registers:

.atype	Fragment	Elements (low to high)
.b1	A vector expression containing four .b32 registers, with each register containing thirty two .b1 element from matrix A.	a0, a1, a2, ..., a127

The layout of the fragments held by different threads is shown in Figure 154.

- Accumulator D:

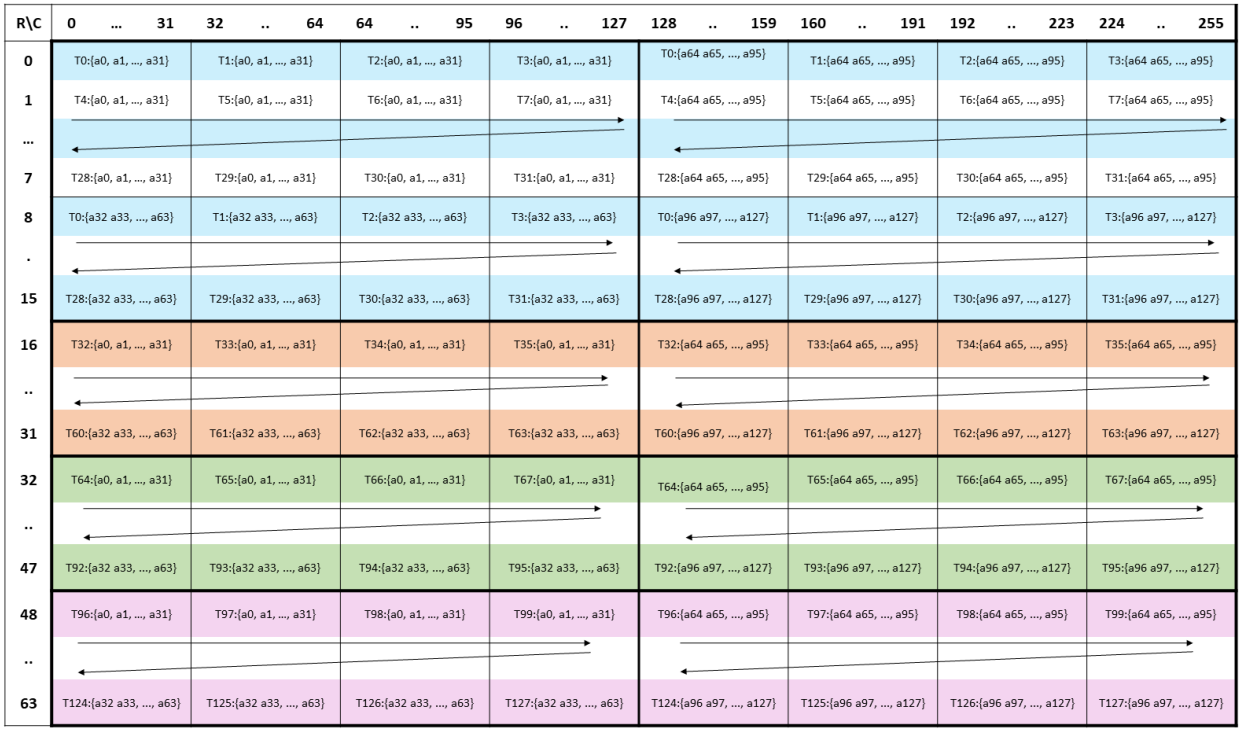


Figure 154: WGMMA .m64nNk256 register fragment layout for matrix A.

.dtype	Fragment	Elements (low to high)
.s32	A vector expression containing N/2 number of .s32 registers.	d0, d1, d2, d3, ..., dX, dY, dZ, dW where X = N/2 - 4 Y = N/2 - 3 Z = N/2 - 2 W = N/2 - 1 N = 8*i where i = {1, 2, 3, 4} = 16*i where i = {3, 4, ..., 15, 16}

The layout of the fragments held by different threads is shown in Figure 155.

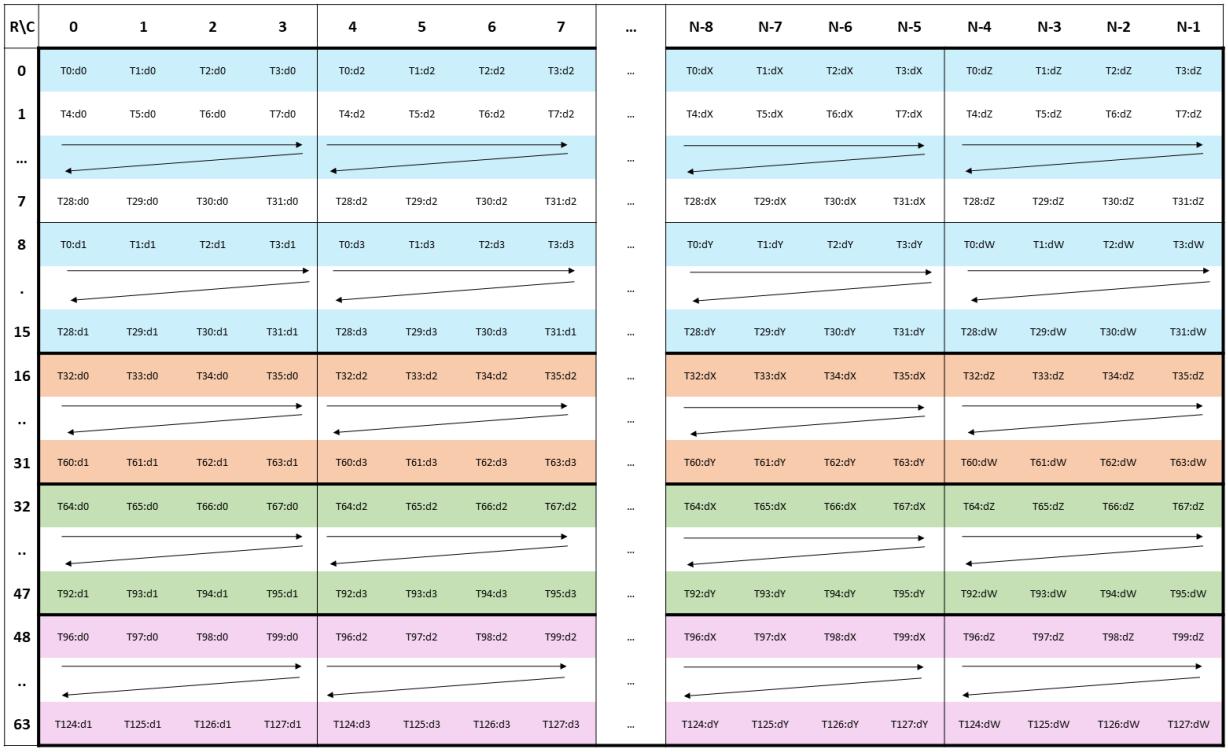


Figure 155: WGMMA .m64nNk256 register fragment layout for accumulator matrix D.

9.7.15.5.1.6 Shared Memory Matrix Layout

If the argument `imm-trans-a` / `imm-trans-b` of the instruction `wgmma.mma_async{.sp}` is 0, then *K-major* is used for matrix A / B respectively. If the value of argument `imm-trans-a` is 1 then *M-major* is used for matrix A. If the value of the argument `imm-trans-b` is 1, then *N-major* is used for matrix B.

In a column-major default BLAS library such as cuBLAS, the matrices A and B with and without transpose can be classified as either *K-Major* or *M-or-N-Major* as shown in the following table:

	Non-Transposed	**Transposed**
A	K-major	M-major
B	K-major	N-major

To avoid confusion with A, B, `row-major`, `col-major`, `transpose`, and `non-transpose`, we will use *MN-Major* and *K-Major* throughout this section.

The matrices in the shared memory are made up of one or more “swizzle layout atom”. The exact layout of these swizzle atoms depends on the swizzling mode, swizzle-atomicity, and the leading dimension. The layout of the swizzle are shown in Table 41.

Table 41: Various combinations of swizzling mode, leading dimension and swizzle-atom layout

Swizzling mode	Leading Dimension / Major-ness	Swizzle atom layout (128b element)
128B Swizzling Mode	M/N	8x8
	K	8x8
64B Swizzling Mode	M/N	4x8
	K	8x4
32B Swizzling Mode	M/N	2x8
	K	8x2
None	M/N	1x8
	K	8x1

The above shapes are for elements of size 128 bits. For smaller elements sizes, the same shapes would get multiplied along the leading dimension by a factor of `128/sizeof_bits(Element)`. For example, 128B MN major swizzle atom would have a shape of `(8*(128/32))x8 = 32x8` for `tf32` tensor core inputs.

Examples

The following are some example layouts of *MxK* or *KxN* matrices with various swizzling modes, and are in units of 128b elements as shown by each colored cell as shown in Figure 156, Figure 157, Figure 158, Figure 159, Figure 160, Figure 161, Figure 162, Figure 163.

Following are some of the examples of the 128B swizzling layout for `tf32` element type.

- K-Major: Figure 164
- MN-Major: Figure 165

9.7.15.5.1.7 Major-ness supported by Strides

There are two strides involved while accessing a matrix from shared memory:

1. Leading dimension byte offset
2. Stride dimension byte offset

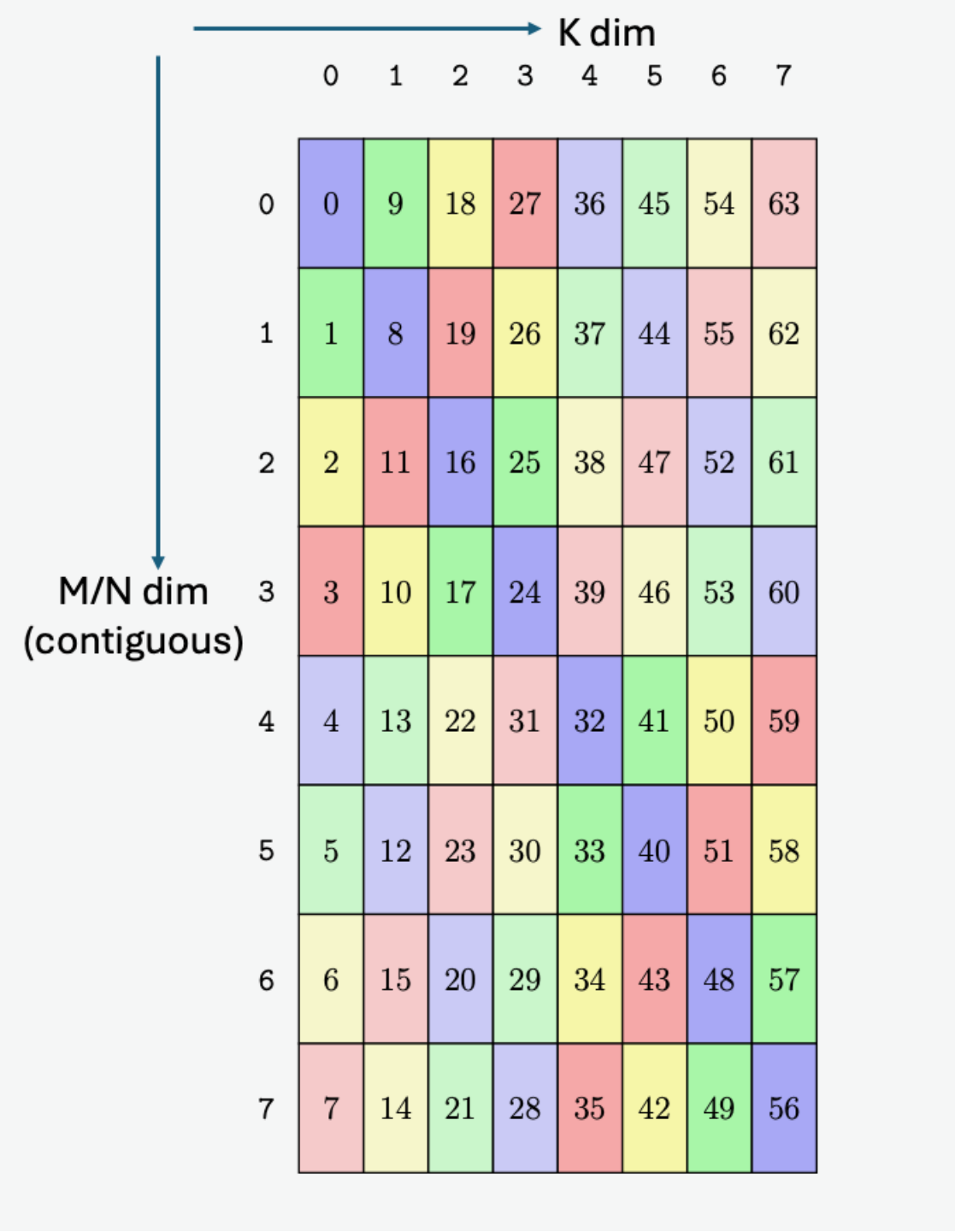


Figure 156: MN major 128B swizzling

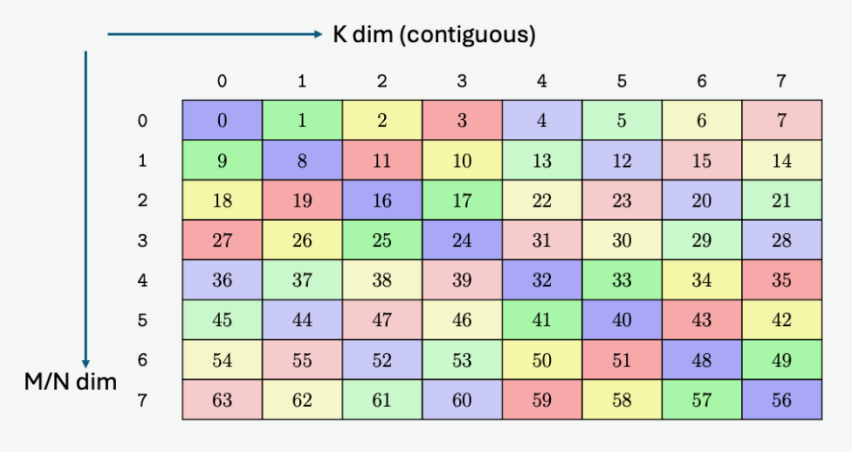


Figure 157: K major 128B swizzling

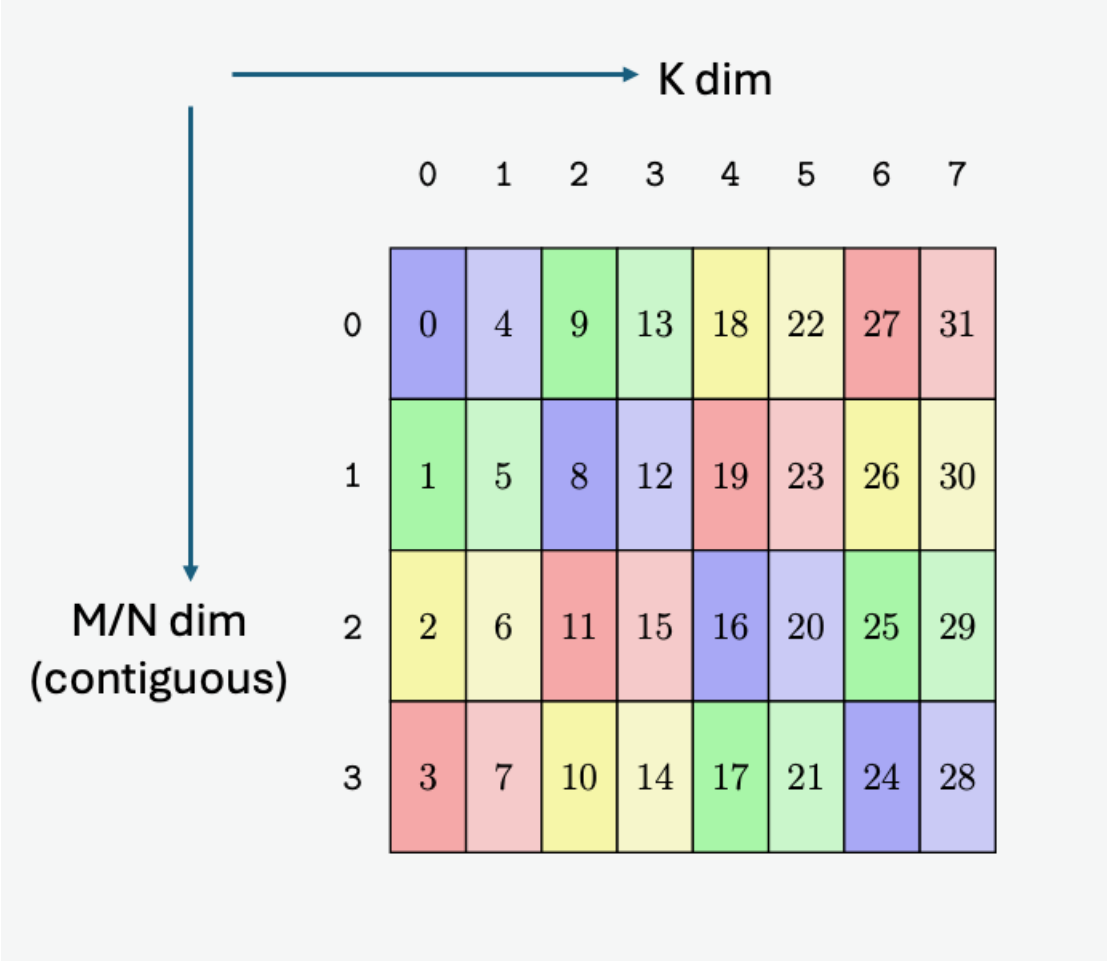


Figure 158: MN major 64B swizzling

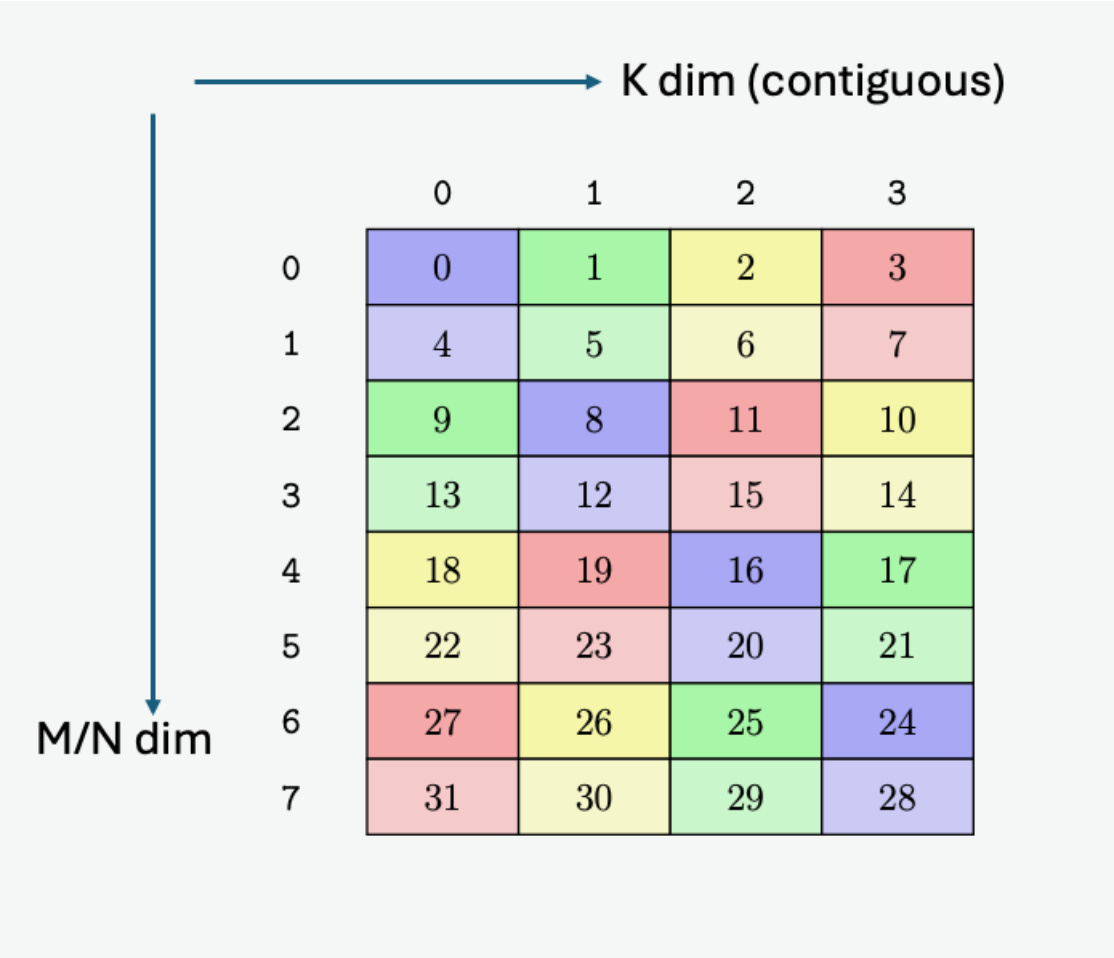


Figure 159: K major 64B swizzling

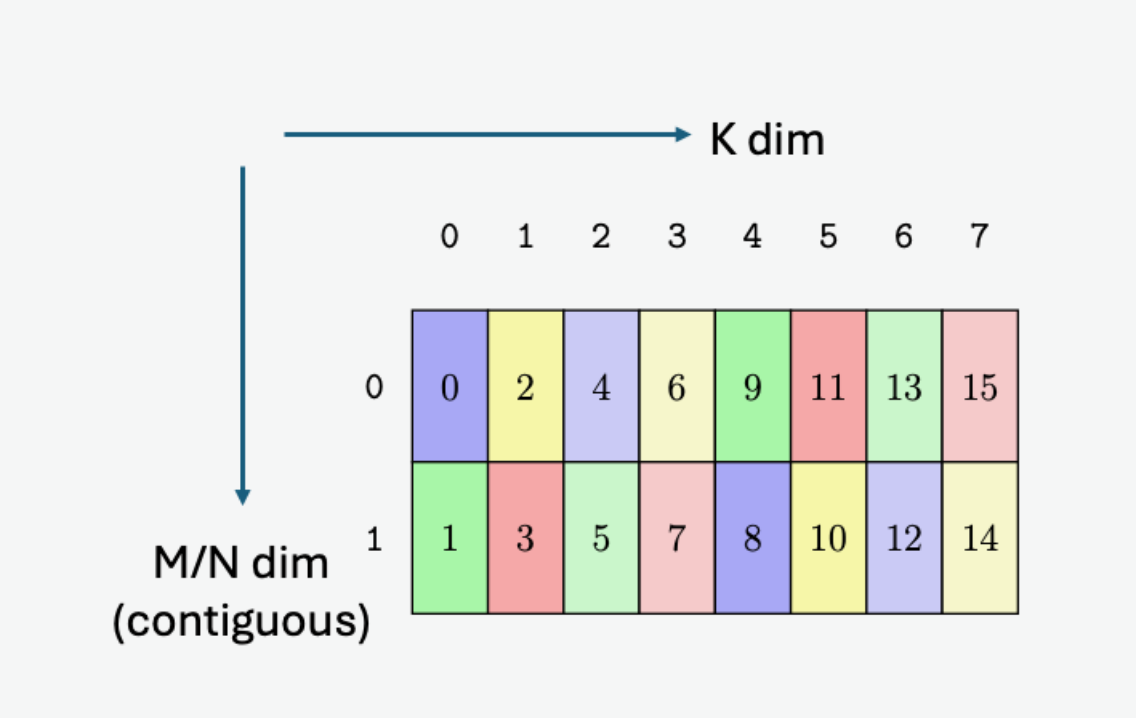


Figure 160: MN major 32B swizzling

9.7.15.5.1.8 Leading Dimension Byte Offset

The leading dimension byte offset is defined differently for transposed and non-transposed matrices. The leading byte offset is defined as follows for matrices whose element types are normalized to 128-bits:

Major-ness	Definition
K-Major	▶ No-Swizzling: the offset from the first column to the second columns of the 8x2 tile in the 128-bit element type normalized matrix. ▶ Swizzled layouts: not used, assumed to be 1.
MN-Major	▶ Interleave: offset from the first 8 columns to the next 8 columns. ▶ Swizzled layouts: offset from the first (swizzle-byte-size/16) rows to the next (swizzle-byte-size/16) rows.

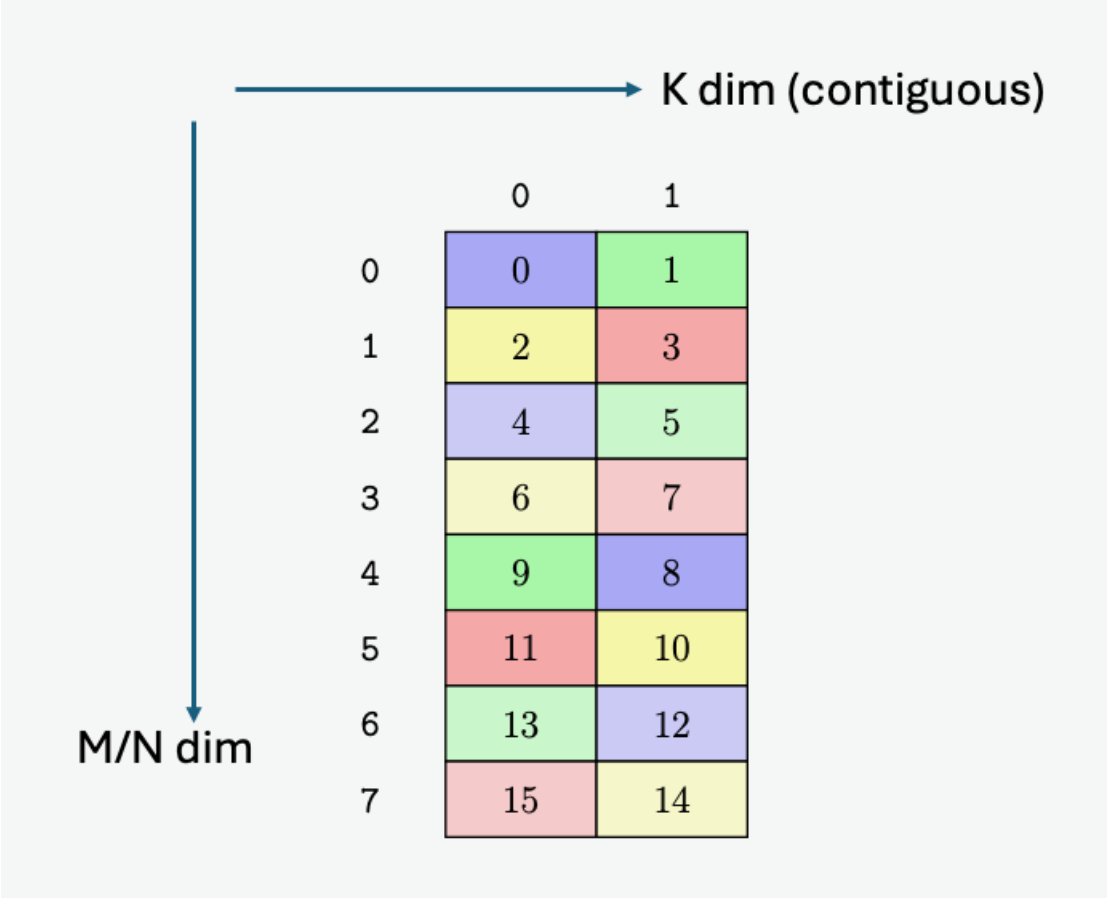


Figure 161: K major 32B swizzling

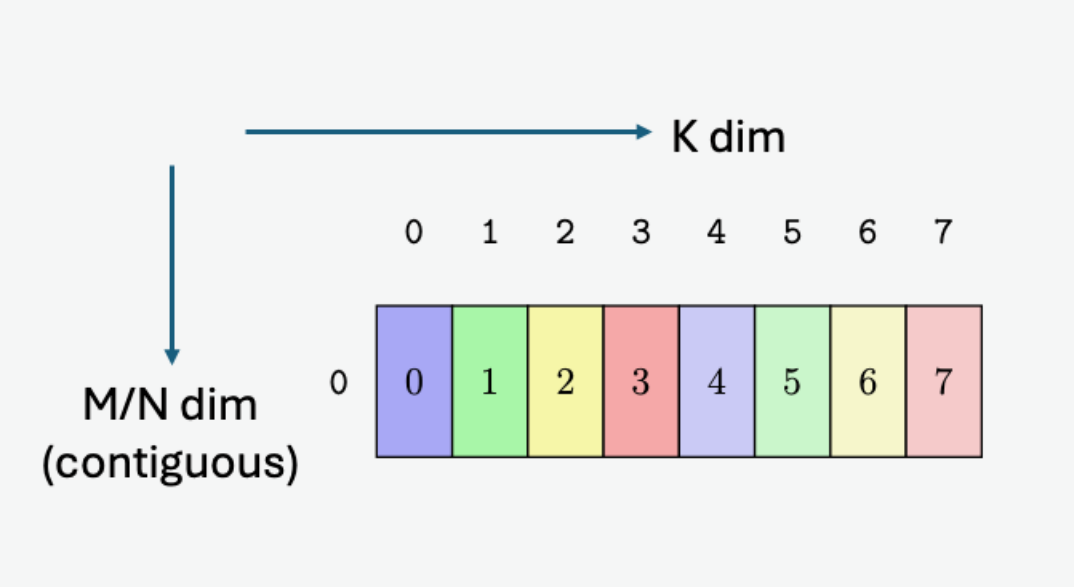


Figure 162: MN major interleaved

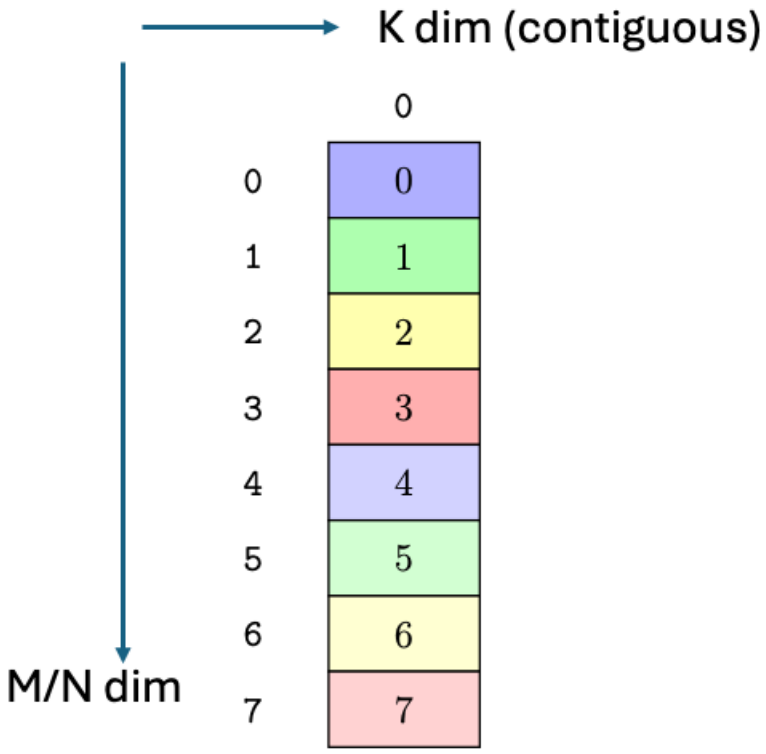


Figure 163: K major interleaved

Figure 164: K major

K dim

M/N dim (contiguous)

	0	1	2	3	4	5	6	7
0	0	36	72	108	144	180	216	252
1	1	37	73	109	145	181	217	253
2	2	38	74	110	146	182	218	254
3	3	39	75	111	147	183	219	255
4	4	32	76	104	148	176	220	248
5	5	33	77	105	149	177	221	249
6	6	34	78	106	150	178	222	250
7	7	35	79	107	151	179	223	251
8	8	44	64	100	152	188	208	244
9	9	45	65	101	153	189	209	245
10	10	46	66	102	154	190	210	246
11	11	47	67	103	155	191	211	247
12	12	40	68	96	156	184	212	240
13	13	41	69	97	157	185	213	241
14	14	42	70	98	158	186	214	242
15	15	43	71	99	159	187	215	243
16	16	52	88	124	128	164	200	236
17	17	53	89	125	129	165	201	237
18	18	54	90	126	130	166	202	238
19	19	55	91	127	131	167	203	239
20	20	48	92	120	132	160	204	232
21	21	49	93	121	133	161	205	233
22	22	50	94	122	134	162	206	234
23	23	51	95	123	135	163	207	235
24	24	60	80	116	136	172	192	228
25	25	61	81	117	137	173	193	229
26	26	62	82	118	138	174	194	230
27	27	63	83	119	139	175	195	231
28	28	56	84	112	140	168	196	224
29	29	57	85	113	141	169	197	225
30	30	58	86	114	142	170	198	226
31	31	59	87	115	143	171	199	227

Figure 165: MN major

9.7.15.5.1.9 Stride Dimension Byte Offset

The stride dimension byte offset is defined differently for transposed and non-transposed matrices. The stride dimension byte offset is defined as follows for matrices whose element types are normalized to 128-bits:

Major-ness	Definition
K-Major	The offset from the first 8 rows to the next 8 rows.
MN-Major	▶ Interleave: offset from the first row to the next row. ▶ Swizzled layout: offset from the first 8 columns to the next 8 columns

9.7.15.5.1.10 Canonical Layouts

In terms of CuTe layouts the canonical layout can be expressed as follows:

Major-ness	Swizzling mode	Canonical Layout without swizzling	Swizzling on the previous column
MN- major	No-swizzling or Interleaved	((T,1,m),(8,k)):((1,T,SBO),(1T,LBO))	Swizzle<0, 4, 3>
	32B Swizzling	((T,2,m),(8,k)):((1,T,LBO),(2T,SBO))	Swizzle<1, 4, 3>
	64B Swizzling	((T,4,m),(8,k)):((1,T,LBO),(4T,SBO))	Swizzle<2, 4, 3>
	128B Swizzling	((T,8,m),(8,k)):((1,T,LBO),(8T,SBO))	Swizzle<3, 4, 3>
K- major	No-swizzling or Interleaved	((8,m),(T,2k)):((1T,SBO),(1,LBO))	Swizzle<0, 4, 3>
	32B Swizzling	((8,m),(T,2k)):((2T,SBO),(1,T))	Swizzle<1, 4, 3>
	64B Swizzling	((8,m),(T,2k)):((4T,SBO),(1,T))	Swizzle<2, 4, 3>
	128B Swizzling	((8,m),(T,2k)):((8T,SBO),(1,T))	Swizzle<3, 4, 3>

where

- T = 128 / sizeof-elements-in-bits T represents scale factor which normalizes matrix element types to 128-bits.
- m represents the number of repeating patterns across rows.
- k represents the number of repeating patterns across columns.

Examples

- K-Major, no-swizzling and tf32 type: Figure 166

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	64	65	66	67	128	129	130	131	192	193	194	195
1	4	5	6	7	68	69	70	71	132	133	134	135	196	197	198	199
2	8	9	10	11	72	73	74	75	136	137	138	139	200	201	202	203
3	12	13	14	15	76	77	78	79	140	141	142	143	204	205	206	207
4	16	17	18	19	80	81	82	83	144	145	146	147	208	209	210	211
5	20	21	22	23	84	85	86	87	148	149	150	151	212	213	214	215
6	24	25	26	27	88	89	90	91	152	153	154	155	216	217	218	219
7	28	29	30	31	92	93	94	95	156	157	158	159	220	221	222	223
8	32	33	34	35	96	97	98	99	160	161	162	163	224	225	226	227
9	36	37	38	39	100	101	102	103	164	165	166	167	228	229	230	231
10	40	41	42	43	104	105	106	107	168	169	170	171	232	233	234	235
11	44	45	46	47	108	109	110	111	172	173	174	175	236	237	238	239
12	48	49	50	51	112	113	114	115	176	177	178	179	240	241	242	243
13	52	53	54	55	116	117	118	119	180	181	182	183	244	245	246	247
14	56	57	58	59	120	121	122	123	184	185	186	187	248	249	250	251
15	60	61	62	63	124	125	126	127	188	189	190	191	252	253	254	255

Figure 166: K major, no-swizzling and tf32 type

the strides and related details are as follows:

Exact layout : Swizzle<0,4,3> o ((8,2),(4,4)):((4,32),(1,64))

Canonical Layout :Swizzle<0,4,3> o ((8,m),(T,2k)):((1T,SBO),(1,LBO))

Parameters	Value
T	4
m	2
k	2
LBO	32*sizeof(tf32)
SBO	64*sizeof(tf32)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 8

- K-Major, 32B swizzling and tf32 type: Figure 167

  the strides and related details are as follows:

  Exact layout : Swizzle<1,4,3> o ((8,2),(4,4)):((8,64),(1,4))

  Canonical Layout :Swizzle<1,4,3> o ((8,m),(T,2k)):((2T,SBO),(1,T))

Parameters	Value
T	4
m	2
k	2
LBO	NA
SBO	64*sizeof(tf32)
Encoding of LBO in descriptor	1 (assumed)
Encoding of SBO in descriptor	(SBO) >> 4 = 16

- MN-Major, no-swizzling and bf16 type: Figure 168

  the strides and related details are as follows:

  Exact layout : Swizzle<0,4,3> o ((8,1,2),(8,2)):((1,8,64),(8,128))

  Canonical Layout :Swizzle<0,4,3> o ((T,1,m),(8,k)):((1,T,SBO),(1T,LBO))

Parameters	Value
T	8
m	2
k	2
LBO	128*sizeof(bf16)
SBO	64*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	4	5	6	7	128	129	130	131	132	133	134	135
1	8	9	10	11	12	13	14	15	136	137	138	139	140	141	142	143
2	16	17	18	19	20	21	22	23	144	145	146	147	148	149	150	151
3	24	25	26	27	28	29	30	31	152	153	154	155	156	157	158	159
4	36	37	38	39	32	33	34	35	164	165	166	167	160	161	162	163
5	44	45	46	47	40	41	42	43	172	173	174	175	168	169	170	171
6	52	53	54	55	48	49	50	51	180	181	182	183	176	177	178	179
7	60	61	62	63	56	57	58	59	188	189	190	191	184	185	186	187
8	64	65	66	67	68	69	70	71	192	193	194	195	196	197	198	199
9	72	73	74	75	76	77	78	79	200	201	202	203	204	205	206	207
10	80	81	82	83	84	85	86	87	208	209	210	211	212	213	214	215
11	88	89	90	91	92	93	94	95	216	217	218	219	220	221	222	223
12	100	101	102	103	96	97	98	99	228	229	230	231	224	225	226	227
13	108	109	110	111	104	105	106	107	236	237	238	239	232	233	234	235
14	116	117	118	119	112	113	114	115	244	245	246	247	240	241	242	243
15	124	125	126	127	120	121	122	123	252	253	254	255	248	249	250	251

Figure 167: K major, 32B swizzling and tf32 type

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	8	16	24	32	40	48	56	128	136	144	152	160	168	176	184
1	1	9	17	25	33	41	49	57	129	137	145	153	161	169	177	185
2	2	10	18	26	34	42	50	58	130	138	146	154	162	170	178	186
3	3	11	19	27	35	43	51	59	131	139	147	155	163	171	179	187
4	4	12	20	28	36	44	52	60	132	140	148	156	164	172	180	188
5	5	13	21	29	37	45	53	61	133	141	149	157	165	173	181	189
6	6	14	22	30	38	46	54	62	134	142	150	158	166	174	182	190
7	7	15	23	31	39	47	55	63	135	143	151	159	167	175	183	191
8	64	72	80	88	96	104	112	120	192	200	208	216	224	232	240	248
9	65	73	81	89	97	105	113	121	193	201	209	217	225	233	241	249
10	66	74	82	90	98	106	114	122	194	202	210	218	226	234	242	250
11	67	75	83	91	99	107	115	123	195	203	211	219	227	235	243	251
12	68	76	84	92	100	108	116	124	196	204	212	220	228	236	244	252
13	69	77	85	93	101	109	117	125	197	205	213	221	229	237	245	253
14	70	78	86	94	102	110	118	126	198	206	214	222	230	238	246	254
15	71	79	87	95	103	111	119	127	199	207	215	223	231	239	247	255

Figure 168: MN major, no-swizzling and bf16 type

- MN-Major, 32B swizzling and bf16 type: Figure 169

  the strides and related details are as follows:

  Exact layout : Swizzle<1,4,3> o ((8,2,2),(8,2)):((1,8,128),(16,256))

  Canonical Layout :Swizzle<1,4,3> o ((T,2,m),(8,k)):((1,T,LBO),(2T,SBO))

Parameters	Value
T	8
m	2
k	2
LBO	128*sizeof(bf16)
SBO	256*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 32

- MN-Major, 64B swizzling and bf16 type: Figure 170

  the strides and related details are as follows:

  Exact layout : Swizzle<2,4,3> o ((8,4,2),(8,2)):((1,8,256),(32,512))

  Canonical Layout :Swizzle<2,4,3> o ((T,4,m),(8,k)):((1,T,LBO),(4T,SBO))

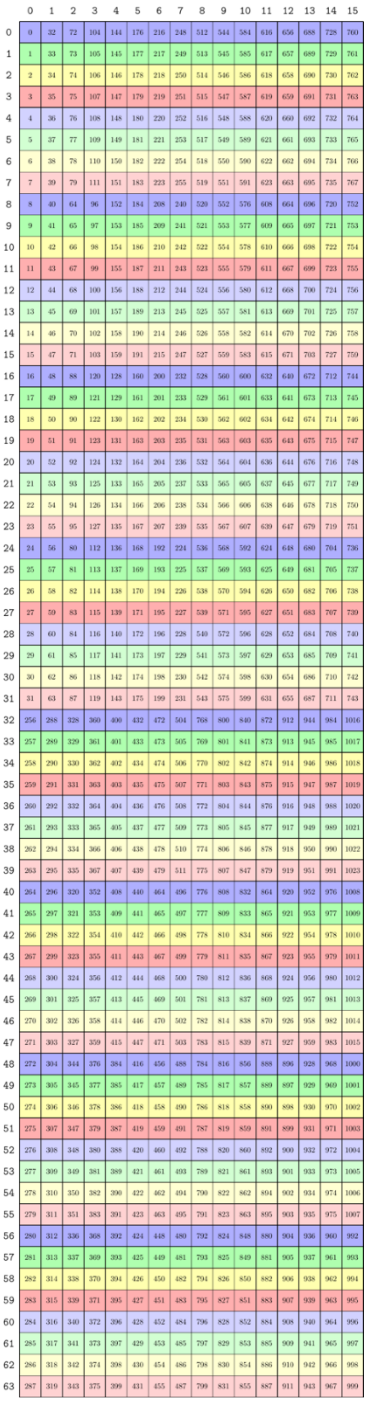
Parameters	Value
T	8
m	2
k	2
LBO	256*sizeof(bf16)
SBO	512*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 32
Encoding of SBO in descriptor	(SBO) >> 4 = 64

9.7.15.5.1.11 Matrix Descriptor Format

Matrix descriptor specifies the properties of the matrix in shared memory that is a multiplicand in the matrix multiply and accumulate operation. It is a 64-bit value contained in a register with the following layout:

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	16	32	48	72	88	104	120	256	272	288	304	328	344	360	376
1	1	17	33	49	73	89	105	121	257	273	289	305	329	345	361	377
2	2	18	34	50	74	90	106	122	258	274	290	306	330	346	362	378
3	3	19	35	51	75	91	107	123	259	275	291	307	331	347	363	379
4	4	20	36	52	76	92	108	124	260	276	292	308	332	348	364	380
5	5	21	37	53	77	93	109	125	261	277	293	309	333	349	365	381
6	6	22	38	54	78	94	110	126	262	278	294	310	334	350	366	382
7	7	23	39	55	79	95	111	127	263	279	295	311	335	351	367	383
8	8	24	40	56	64	80	96	112	264	280	296	312	320	336	352	368
9	9	25	41	57	65	81	97	113	265	281	297	313	321	337	353	369
10	10	26	42	58	66	82	98	114	266	282	298	314	322	338	354	370
11	11	27	43	59	67	83	99	115	267	283	299	315	323	339	355	371
12	12	28	44	60	68	84	100	116	268	284	300	316	324	340	356	372
13	13	29	45	61	69	85	101	117	269	285	301	317	325	341	357	373
14	14	30	46	62	70	86	102	118	270	286	302	318	326	342	358	374
15	15	31	47	63	71	87	103	119	271	287	303	319	327	343	359	375
16	128	144	160	176	200	216	232	248	384	400	416	432	456	472	488	504
17	129	145	161	177	201	217	233	249	385	401	417	433	457	473	489	505
18	130	146	162	178	202	218	234	250	386	402	418	434	458	474	490	506
19	131	147	163	179	203	219	235	251	387	403	419	435	459	475	491	507
20	132	148	164	180	204	220	236	252	388	404	420	436	460	476	492	508
21	133	149	165	181	205	221	237	253	389	405	421	437	461	477	493	509
22	134	150	166	182	206	222	238	254	390	406	422	438	462	478	494	510
23	135	151	167	183	207	223	239	255	391	407	423	439	463	479	495	511
24	136	152	168	184	192	208	224	240	392	408	424	440	448	464	480	496
25	137	153	169	185	193	209	225	241	393	409	425	441	449	465	481	497
26	138	154	170	186	194	210	226	242	394	410	426	442	450	466	482	498
27	139	155	171	187	195	211	227	243	395	411	427	443	451	467	483	499
28	140	156	172	188	196	212	228	244	396	412	428	444	452	468	484	500
29	141	157	173	189	197	213	229	245	397	413	429	445	453	469	485	501
30	142	158	174	190	198	214	230	246	398	414	430	446	454	470	486	502
31	143	159	175	191	199	215	231	247	399	415	431	447	455	471	487	503

Figure 169: MN major, 32B swizzling and bf16 type



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	32	72	104	144	176	216	248	512	544	584	616	656	688	728	760
1	1	33	73	105	145	177	217	249	513	545	585	617	657	689	729	761
2	2	34	74	106	146	178	218	250	514	546	586	618	658	690	730	762
3	3	35	75	107	147	179	219	251	515	547	587	619	659	691	731	763
4	4	36	76	108	148	180	220	252	516	548	588	620	660	692	732	764
5	5	37	77	109	149	181	221	253	517	549	589	621	661	693	733	765
6	6	38	78	110	150	182	222	254	518	550	590	622	662	694	734	766
7	7	39	79	111	151	183	223	255	519	551	591	623	663	695	735	767
8	8	40	64	96	152	184	208	240	520	552	576	608	664	696	720	752
9	9	41	65	97	153	185	209	241	521	553	577	609	665	697	721	753
10	10	42	66	98	154	186	210	242	522	554	578	610	666	698	722	754
11	11	43	67	99	155	187	211	243	523	555	579	611	667	699	723	755
12	12	44	68	100	156	188	212	244	524	556	580	612	668	700	724	756
13	13	45	69	101	157	189	213	245	525	557	581	613	669	701	725	757
14	14	46	70	102	158	190	214	246	526	558	582	614	670	702	726	758
15	15	47	71	103	159	191	215	247	527	559	583	615	671	703	727	759
16	16	48	88	120	128	160	200	232	528	560	600	632	640	672	712	744
17	17	49	89	121	129	161	201	233	529	561	601	633	641	673	713	745
18	18	50	90	122	130	162	202	234	530	562	602	634	642	674	714	746
19	19	51	91	123	131	163	203	235	531	563	603	635	643	675	715	747
20	20	52	92	124	132	164	204	236	532	564	604	636	644	676	716	748
21	21	53	93	125	133	165	205	237	533	565	605	637	645	677	717	749
22	22	54	94	126	134	166	206	238	534	566	606	638	646	678	718	750
23	23	55	95	127	135	167	207	239	535	567	607	639	647	679	719	751
24	24	56	80	112	136	168	192	224	536	568	592	624	648	680	704	736
25	25	57	81	113	137	169	193	225	537	569	593	625	649	681	705	737
26	26	58	82	114	138	170	194	226	538	570	594	626	650	682	706	738
27	27	59	83	115	139	171	195	227	539	571	595	627	651	683	707	739
28	28	60	84	116	140	172	196	228	540	572	596	628	652	684	708	740
29	29	61	85	117	141	173	197	229	541	573	597	629	653	685	709	741
30	30	62	86	118	142	174	198	230	542	574	598	630	654	686	710	742
31	31	63	87	119	143	175	199	231	543	575	599	631	655	687	711	743
32	256	288	328	360	400	432	472	504	768	800	840	872	912	944	984	1016
33	257	289	329	361	401	433	473	505	769	801	841	873	913	945	985	1017
34	258	290	330	362	402	434	474	506	770	802	842	874	914	946	986	1018
35	259	291	331	363	403	435	475	507	771	803	843	875	915	947	987	1019
36	260	292	332	364	404	436	476	508	772	804	844	876	916	948	988	1020
37	261	293	333	365	405	437	477	509	773	805	845	877	917	949	989	1021
38	262	294	334	366	406	438	478	510	774	806	846	878	918	950	990	1022
39	263	295	335	367	407	439	479	511	775	807	847	879	919	951	991	1023
40	264	296	320	352	408	440	464	496	776	808	832	864	920	952	976	1008
41	265	297	321	353	409	441	465	497	777	809	833	865	921	953	977	1009
42	266	298	322	354	410	442	466	498	778	810	834	866	922	954	978	1010
43	267	299	323	355	411	443	467	499	779	811	835	867	923	955	979	1011
44	268	300	324	356	412	444	468	500	780	812	836	868	924	956	980	1012
45	269	301	325	357	413	445	469	501	781	813	837	869	925	957	981	1013
46	270	302	326	358	414	446	470	502	782	814	838	870	926	958	982	1014
47	271	303	327	359	415	447	471	503	783	815	839	871	927	959	983	1015
48	272	304	344	376	384	416	456	488	784	816	856	888	896	928	968	1000
49	273	305	345	377	385	417	457	489	785	817	857	889	897	929	969	1001
50	274	306	346	378	386	418	458	490	786	818	858	890	898	930	970	1002
51	275	307	347	379	387	419	459	491	787	819	859	891	899	931	971	1003
52	276	308	348	380	388	420	460	492	788	820	860	892	900	932	972	1004
53	277	309	349	381	389	421	461	493	789	821	861	893	901	933	973	1005
54	278	310	350	382	390	422	462	494	790	822	862	894	902	934	974	1006
55	279	311	351	383	391	423	463	495	791	823	863	895	903	935	975	1007
56	280	312	336	368	392	424	448	480	792	824	848	880	904	936	960	992
57	281	313	337	369	393	425	449	481	793	825	849	881	905	937	961	993
58	282	314	338	370	394	426	450	482	794	826	850	882	906	938	962	994
59	283	315	339	371	395	427	451	483	795	827	851	883	907	939	963	995
60	284	316	340	372	396	428	452	484	796	828	852	884	908	940	964	996
61	285	317	341	373	397	429	453	485	797	829	853	885	909	941	965	997
62	286	318	342	374	398	430	454	486	798	830	854	886	910	942	966	998
63	287	319	343	375	399	431	455	487	799	831	855	887	911	943	967	999

Figure 170: MN major, 64B swizzling and bf16 type

Bit-field	Size in bits	Description
13–0	14	matrix-descriptor-encode(Matrix start address)
29–16	14	matrix-descriptor-encode (*Leading dimension byte offset*)
45–32	14	matrix-descriptor-encode (*Stride dimension byte offset*)
51–49	3	Matrix base offset. This is valid for all swizzling modes except the no-swizzle mode.
63–62	2	Specifies the swizzling mode to be used: ▶ 0: No swizzle ▶ 1: 128-Byte swizzle ▶ 2: 64-Byte swizzle ▶ 3: 32-Byte swizzle

where

```
matrix-descriptor-encode(x) = (x & 0x3FFFF) >> 4
```

The value of base offset is 0 when the repeating pattern of the specified swizzling mode starts as per the below table:

Swizzling mode	Starting address of the repeating pattern
128-Byte swizzle	1024-Byte boundary
64-Byte swizzle	512-Byte boundary
32-Byte swizzle	256-Byte boundary

Otherwise, the base offset must be a non-zero value, computed using the following formula:

```
base offset = (pattern start addr >> 0x7) & 0x7
```

9.7.15.5.2 Asynchronous Multiply-and-Accumulate Instruction: wgmma.mma_async

wgmma.mma_async

Perform matrix multiply-and-accumulate operation across warpgroup

Syntax

Half precision floating point type:

```
wgmma.mma_async.sync.aligned.shape.dtype.f16.f16  d, a-desc, b-desc, scale-d, imm-
↪scale-a, imm-scale-b, imm-trans-a, imm-trans-b;

wgmma.mma_async.sync.aligned.shape.dtype.f16.f16  d, a, b-desc, scale-d, imm-scale-a,
↪imm-scale-b, imm-trans-b;

.shape   = {.m64n8k16, .m64n16k16, .m64n24k16, .m64n32k16,
            .m64n40k16, .m64n48k16, .m64n56k16, .m64n64k16,
            .m64n72k16, .m64n80k16, .m64n88k16, .m64n96k16,
            .m64n104k16, .m64n112k16, .m64n120k16, .m64n128k16,
            .m64n136k16, .m64n144k16, .m64n152k16, .m64n160k16,
            .m64n168k16, .m648176k16, .m64n184k16, .m64n192k16,
            .m64n200k16, .m64n208k16, .m64n216k16, .m64n224k16,
            .m64n232k16, .m64n240k16, .m64n248k16, .m64n256k16};
.dtype   = {.f16, .f32};
```

Alternate floating point type :

```
.bf16 floating point type:

wgmma.mma_async.sync.aligned.shape.dtype.bf16.bf16  d, a-desc, b-desc, scale-d, imm-
↪scale-a, imm-scale-b, imm-trans-a, imm-trans-b;

wgmma.mma_async.sync.aligned.shape.dtype.bf16.bf16  d, a, b-desc, scale-d, imm-scale-
↪a, imm-scale-b, imm-trans-b;

.shape   = {.m64n8k16, .m64n16k16, .m64n24k16, .m64n32k16,
            .m64n40k16, .m64n48k16, .m64n56k16, .m64n64k16,
            .m64n72k16, .m64n80k16, .m64n88k16, .m64n96k16,
            .m64n104k16, .m64n112k16, .m64n120k16, .m64n128k16,
            .m64n136k16, .m64n144k16, .m64n152k16, .m64n160k16,
            .m64n168k16, .m648176k16, .m64n184k16, .m64n192k16,
            .m64n200k16, .m64n208k16, .m64n216k16, .m64n224k16,
            .m64n232k16, .m64n240k16, .m64n248k16, .m64n256k16};
.dtype  = {.f32};

.tf32 floating point type:

wgmma.mma_async.sync.aligned.shape.dtype.tf32.tf32  d, a-desc, b-desc, scale-d, imm-
↪scale-a, imm-scale-b;

wgmma.mma_async.sync.aligned.shape.dtype.tf32.tf32  d, a, b-desc, scale-d, imm-scale-
↪a, imm-scale-b;

.shape   = {.m64n8k8, .m64n16k8, .m64n24k8, .m64n32k8,
            .m64n40k8, .m64n48k8, .m64n56k8, .m64n64k8,
```

(continues on next page)

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```
            .m64n72k8, .m64n80k8, .m64n88k8, .m64n96k8,
            .m64n104k8, .m64n112k8, .m64n120k8, .m64n128k8,
            .m64n136k8, .m64n144k8, .m64n152k8, .m64n160k8,
            .m64n168k8, .m648176k8, .m64n184k8, .m64n192k8,
            .m64n200k8, .m64n208k8, .m64n216k8, .m64n224k8,
            .m64n232k8, .m64n240k8, .m64n248k8, .m64n256k8};
.dtype  = {.f32};

FP8 floating point type

wgmma.mma_async.sync.aligned.shape.dtype.atype.btype  d, a-desc, b-desc, scale-d, imm-
↪scale-a, imm-scale-b;

wgmma.mma_async.sync.aligned.shape.dtype.atype.btype  d, a, b-desc, scale-d, imm-
↪scale-a, imm-scale-b;

.shape   = {.m64n8k32, .m64n16k32, .m64n24k32, .m64n32k32,
            .m64n40k32, .m64n48k32, .m64n56k32, .m64n64k32,
            .m64n72k32, .m64n80k32, .m64n88k32, .m64n96k32,
            .m64n104k32, .m64n112k32, .m64n120k32, .m64n128k32,
            .m64n136k32, .m64n144k32, .m64n152k32, .m64n160k32,
            .m64n168k32, .m648176k32, .m64n184k32, .m64n192k32,
            .m64n200k32, .m64n208k32, .m64n216k32, .m64n224k32,
            .m64n232k32, .m64n240k32, .m64n248k32, .m64n256k32};
.atype  = {.e4m3, .e5m2};
.btype  = {.e4m3, .e5m2};
.dtype  = {.f16, .f32};
```

Integer type:

```
wgmma.mma_async.sync.aligned.shape{.satfinite}.s32.atype.btype  d, a-desc, b-desc,
↪scale-d;

wgmma.mma_async.sync.aligned.shape{.satfinite}.s32.atype.btype  d, a, b-desc, scale-d;

.shape   = {.m64n8k32, .m64n16k32, .m64n24k32, .m64n32k32,
            .m64n48k32, .m64n64k32, .m64n80k32, .m64n96k32,
            .m64n112k32, .m64n128k32, .m64n144k32, .m64n160k32,
            .m648176k32, .m64n192k32, .m64n208k32, .m64n224k32};
.atype  = {.s8, .u8};
.btype  = {.s8, .u8};
```

Single bit:

```
wgmma.mma_async.sync.aligned.shape.s32.b1.b1.op.popc  d, a-desc, b-desc, scale-d;

wgmma.mma_async.sync.aligned.shape.s32.b1.b1.op.popc  d, a, b-desc, scale-d;

.shape   = {.m64n8k256, .m64n16k256, .m64n24k256, .m64n32k256,
            .m64n48k256, .m64n64k256, .m64n80k256, .m64n96k256,
            .m64n112k256, .m64n128k256, .m64n144k256, .m64n160k256,
            .m64n176k256, .m64n192k256, .m64n208k256, .m64n224k256,
            .m64n240k256, .m64n256k256};
.op   = {.and};
```

Description

Instruction `wgmma.mma_async` issues a `MxNxK` matrix multiply and accumulate operation, `D = A*B+D`, where the A matrix is `MxK`, the B matrix is `KxN`, and the D matrix is `MxN`.

The operation of the form `D = A*B` is issued when the input predicate argument `scale-d` is false.

`wgmma.fence` instruction must be used to fence the register accesses of `wgmma.mma_async` instruction from their prior accesses. Otherwise, the behavior is undefined.

`wgmma.commit_group` and `wgmma.wait_group` operations must be used to wait for the completion of the asynchronous matrix multiply and accumulate operations before the results are accessed.

Register operand `d` represents the accumulator matrix as well as the destination matrix, distributed across the participating threads. Register operand `a` represents the multiplicand matrix A in register distributed across the participating threads. The 64-bit register operands `a-desc` and `b-desc` are the matrix descriptors which represent the multiplicand matrices A and B in shared memory respectively. The contents of a matrix descriptor must be same across all the warps in the warpgroup. The format of the matrix descriptor is described in *Matrix Descriptor Format*.

Matrices A and B are stored in row-major and column-major format respectively. For certain floating point variants, the input matrices A and B can be transposed by specifying the value `1` for the immediate integer arguments `imm-trans-a` and `imm-trans-b` respectively. A value of `0` can be used to avoid the transpose operation. The valid values of `imm-trans-a` and `imm-trans-b` are `0` and `1`. The transpose operation is only supported for the `wgmma.mma_async` variants with `.f16`/ `.bf16` types on matrices accessed from shared memory using matrix descriptors.

For the floating point variants of the `wgmma.mma_async` operation, each element of the input matrices A and B can be negated by specifying the value `-1` for operands `imm-scale-a` and `imm-scale-b` respectively. A value of `1` can be used to avoid the negate operation. The valid values of `imm-scale-a` and `imm-scale-b` are `-1` and `1`.

The qualifiers `.dtype`, `.atype` and `.btype` indicate the data type of the elements in matrices D, A and B respectively. `.atype` and `.btype` must be the same for all floating point `wgmma.mma_async` variants except for the FP8 floating point variants. The sizes of individual data elements of matrices A and B in alternate floating point variants of the `wgmma.mma_async` operation are as follows:

- Matrices A and B have 8-bit data elements when `.atype`/ `.btype` is `.e4m3`/`.e5m2`.
- Matrices A and B have 16-bit data elements when `.atype`/ `.btype` is `.bf16`.
- Matrices A and B have 32-bit data elements when `.atype`/ `.btype` is `.tf32`.

Precision and rounding:

- Floating point operations:

  Element-wise multiplication of matrix A and B is performed with at least single precision. When `.dtype` is `.f32`, accumulation of the intermediate values is performed with at least single precision. When `.dtype` is `.f16`, the accumulation is performed with at least half precision.

  The accumulation order, rounding and handling of subnormal inputs are unspecified.

- `.bf16` and `.tf32` floating point operations:

  Element-wise multiplication of matrix A and B is performed with specified precision. `wgmma.mma_async` operation involving type `.tf32` will truncate lower 13 bits of the 32-bit input data before multiplication is issued. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- Integer operations:

  The integer `wgmma.mma_async` operation is performed with `.s32` accumulators. The `.satfinite` qualifier indicates that on overflow, the accumulated value is limited to the range *MIN_INT32*.. *MAX_INT32* (where the bounds are defined as the minimum negative signed 32-bit integer and the maximum positive signed 32-bit integer respectively).

  If `.satfinite` is not specified, the accumulated value is wrapped instead.

The mandatory `.sync` qualifier indicates that `wgmma.mma_async` instruction causes the executing thread to wait until all threads in the warp execute the same `wgmma.mma_async` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `wgmma.mma_async` instruction. In conditionally executed code, a `wgmma.mma_async` instruction should only be used if it is known that all threads in the warpgroup evaluate the condition identically, otherwise behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Support for `.u8.s8` and `.s8.u8` as .atype.btype introduced in PTX ISA version 8.4.

Target ISA Notes

Requires `sm_90a`.

Examples of half precision floating point type

```
.reg .f16x2 f16a<40>, f16d<40>;
.reg .f32   f32d<40>;
.reg .b64   descA, descB;
.reg .pred  scaleD;
wgmma.mma_async.sync.aligned.m64n8k16.f32.f16.f16
  {f32d0, f32d1, f32d2, f32d3},
  {f16a0, f16a1, f16a2, f16a3},
  descB,
  1, -1, -1, 1;

wgmma.mma_async.sync.aligned.m64n72k16.f16.f16.f16
  {f16d0, f16d1,  f16d2,  f16d3,  f16d4,  f16d5,  f16d6,  f16d7,  f16d8,
   f16d9, f16d10, f16d11, f16d12, f16d13, f16d14, f16d15, f16d16, f16d17},
  descA,
  descB,
  scaleD, -1, 1, 1, 0;
```

Examples of alternate floating point type

```
.reg .f32   f32d<40>;
.reg .b32   bf16a<40>
.reg .b64   descA, descB;

wgmma.mma_async.sync.aligned.m64n120k16.f32.bf16.bf16
  {f32d0, f32d1, f32d2, f32d3, f32d4, f32d5, f32d6, f32d7, f32d8, f32d9,
   f32d10, f32d11, f32d12, f32d13, f32d14, f32d15, f32d16, f32d17, f32d18, f32d19,
   f32d20, f32d21, f32d22, f32d23, f32d24, f32d25, f32d26, f32d27, f32d28, f32d29,
   f32d30, f32d31, f32d32, f32d33, f32d34, f32d35, f32d36, f32d37, f32d38, f32d39,
   f32d40, f32d41, f32d42, f32d43, f32d44, f32d45, f32d46, f32d47, f32d48, f32d49,
   f32d50, f32d51, f32d52, f32d53, f32d54, f32d55, f32d56, f32d57, f32d58, f32d59},
  {bf16a0, bf16a1, bf16a2, bf16a3},
  descB,
  scaleD, -1, -1, 0;

.reg .f32   f32d<40>;
.reg .b64   descA, descB;

wgmma.mma_async.sync.aligned.m64n16k8.f32.tf32.tf32
  {f32d0, f32d1, f32d2, f32d3, f32d4, f32d5, f32d6, f32d7},
  descA,
  descB,
  0, -1, -1;

.reg .b32 f16d<8>, f16a<8>;
.reg .f32 f32d<8>;
.reg .b64   descA, descB;

wgmma.mma_async.sync.aligned.m64n8k32.f16.e4m3.e5m2
  {f16d0, f16d1},
  descA,
  descB,
  scaleD, -1, 1;

wgmma.mma_async.sync.aligned.m64n8k32.f32.e5m2.e4m3
  {f32d0, f32d1, f32d2, f32d3},
  {f16a0, f16a1, f16a2, f16a3},
  descB,
  1, -1, -1;
```

Examples of integer type

```
.reg .s32 s32d<8>, s32a<8>;
.reg .u32 u32a<8>;
.reg .pred scaleD;
.reg .b64   descA, descB;

wgmma.mma_async.sync.aligned.m64n8k32.s32.s8.s8.satfinite
  {s32d0, s32d1, s32d2, s32d3},
  {s32a0, s32a1, s32a2, s32a3},
  descB,
  1;
```

(continues on next page)

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```
wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.u8
  {s32d0, s32d1, s32d2, s32d3},
  descA,
  descB,
  scaleD;

wgmma.mma_async.sync.aligned.m64n8k32.s32.s8.u8.satfinite
  {s32d0, s32d1, s32d2, s32d3},
  {s32a0, s32a1, s32a2, s32a3},
  descB,
  scaleD;

wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.s8
  {s32d0, s32d1, s32d2, s32d3},
  descA,
  descB,
  scaleD;
```

Examples of single bit type

```
.reg .s32 s32d<4>;
.reg .b32 b32a<4>;
.reg .pred scaleD;
.reg .b64   descA, descB;


wgmma.mma_async.sync.aligned.m64n8k256.s32.b1.b1.and.popc
  {s32d0, s32d1, s32d2, s32d3},
  {b32a0, b32a1, b32a2, b32a3},
  descB,
  scaleD;
```

9.7.15.6 Asynchronous Warpgroup Level Multiply-and-Accumulate Operation using `wgmma.mma_async.sp` instruction

This section describes warp-level `wgmma.mma_async.sp` instruction with sparse matrix A. This variant of the `wgmma.mma_async` operation can be used when A is a structured sparse matrix with 50% zeros in each row distributed in a shape-specific granularity. For an `MxNxK` sparse `wgmma.mma_async.sp` operation, the `MxK` matrix A is packed into `MxK/2` elements. For each K-wide row of matrix A, 50% elements are zeros and the remaining `K/2` non-zero elements are packed in the operand representing matrix A. The mapping of these `K/2` elements to the corresponding K-wide row is provided explicitly as metadata.

9.7.15.6.1 Sparse matrix storage

Granularity of sparse matrix A is defined as the ratio of the number of non-zero elements in a sub-chunk of the matrix row to the total number of elements in that sub-chunk where the size of the sub-chunk is shape-specific. For example, in a `64x32` matrix A used in floating point `wgmma.mma_async` operations, sparsity is expected to be at 2:4 granularity, i.e. each 4-element vector (i.e. a sub-chunk of 4 consecutive elements) of a matrix row contains 2 zeros. Index of each non-zero element in a sub-chunk is stored in the metadata operand. Values `0b0000`, `0b0101`, `0b1010`, `0b1111` are invalid values for metadata and will result in undefined behavior. In a group of four consecutive threads, one or more threads store the metadata for the whole group depending upon the matrix shape. These threads are specified using an additional sparsity selector operand.

Matrix A and its corresponding input operand to the sparse wgmma is similar to the diagram shown in Figure 111, with an appropriate matrix size.

Granularities for different matrix shapes and data types are described below.

Sparse `wgmma.mma_async.sp` with half-precision and `.bf16` type

For `.f16` and `.bf16` types, for all supported `64xNx32` shapes, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A have two zeroes and two non-zero elements. Only the two non-zero elements are stored in matrix A and their positions in the four-wide chunk in Matrix A are indicated by two 2-bits indices in the metadata operand.

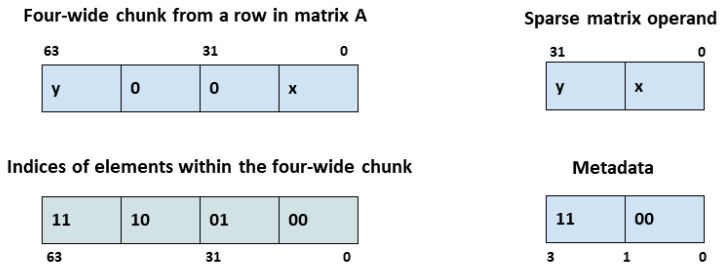

Figure 171: Sparse WGMMA metadata example for `.f16`/`.bf16` type.

The sparsity selector indicates a thread-pair within a group of four consecutive threads which contributes the sparsity metadata. Hence, the sparsity selector must be either 0 (threads T0, T1) or 1 (threads T2, T3); any other value results in an undefined behavior.

Sparse wgmma.mma_async.sp with .tf32 type

For .tf32 type, for all supported 64xNx16 shapes, matrix A is structured sparse at a granularity of 1:2. In other words, each chunk of two adjacent elements in a row of matrix A have one zero and one non-zero element. Only the non-zero element is stored in operand for matrix A and the 4-bit index in the metadata indicates the position of the non-zero element in the two-wide chunk. 0b1110 and 0b0100 are the only meaningful values of the index, the remaining values result in an undefined behavior.

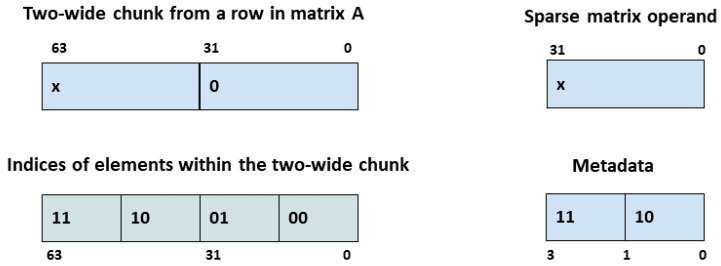

Figure 172: Sparse WGMMA metadata example for .tf32 type.

The sparsity selector indicates a thread-pair within a group of four consecutive threads which contributes the sparsity metadata. Hence, the sparsity selector must be either 0 (threads T0, T1) or 1 (threads T2, T3); any other value results in an undefined behavior.

Sparse wgmma.mma_async.sp with .e4m3 and .e5m2 floating point type

For .e4m3 and .e5m2 types, for all supported 64xNx64 shapes, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A have two zeroes and two non-zero elements. Only the two non-zero elements are stored in matrix A and their positions in the four-wide chunk in Matrix A are indicated by two 2-bits indices in the metadata operand.

All threads contribute the sparsity metadata and the sparsity selector must be 0; any other value results in an undefined behavior.

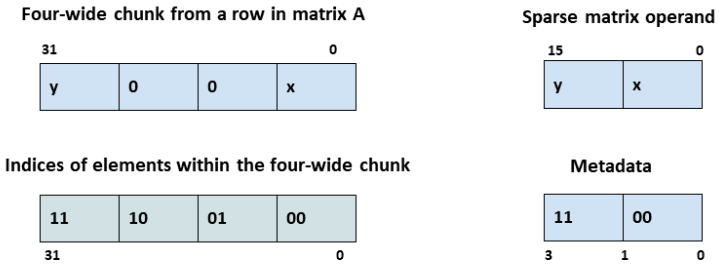

Figure 173: Sparse WGMMA metadata example for `.e4m3`/`.e5m2` type.

Sparse `wgmma.mma_async.sp` with integer type

For the integer type, for all supported 64xNx64 shapes, matrix A is structured sparse at a granularity of 2:4. In other words, each chunk of four adjacent elements in a row of matrix A have two zeroes and two non-zero elements. Only the two non-zero elements are stored in matrix A and two 2-bit indices in the metadata indicate the position of these two non-zero elements in the four-wide chunk.

All threads contribute the sparsity metadata and the sparsity selector must be 0; any other value results in an undefined behavior.

9.7.15.6.2 Matrix fragments for warpgroup-level multiply-accumulate operation with sparse matrix A

In this section we describe how the contents of thread registers are associated with fragments of A matrix and the sparsity metadata.

Each warp in the warpgroup provides sparsity information for 16 rows of matrix A. The following table shows the assignment of warps to rows of matrix A:

Warp	Sparsity information for rows of matrix A
`%warpid` % 4 = 3	48-63
`%warpid` % 4 = 2	32-47
`%warpid` % 4 = 1	16-31
`%warpid` % 4 = 0	0-15

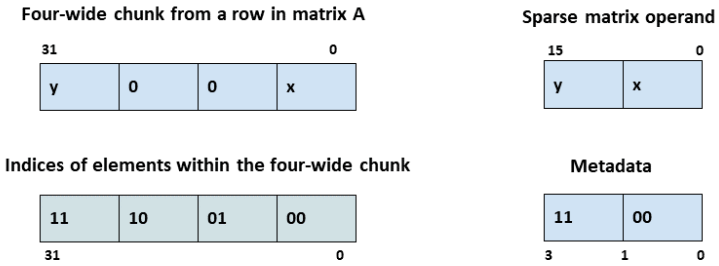

Figure 174: Sparse WGMMA metadata example for `.u8/.s8` type.

The following conventions are used throughout this section:

- For matrix A, only the layout of a fragment is described in terms of register vector sizes and their association with the matrix data.
- For matrix D, since the matrix dimension - data type combination is the same for all supported shapes, and is already covered in *Asynchronous Warpgroup Level Matrix Multiply-Accumulate Operation using wgmma.mma_async instruction*, the pictorial representations of matrix fragments are not included in this section.
- For the metadata operand, pictorial representations of the association between indices of the elements of matrix A and the contents of the metadata operand are included. `Tk: [m..n]` present in cell `[x][y..z]` indicates that bits `m` through `n` (with `m` being higher) in the metadata operand of thread with `%laneid=k` contains the indices of the non-zero elements from the chunk `[x][y]..[x][z]` of matrix A.

9.7.15.6.2.1 Matrix Fragments for sparse `wgmma.mma_async.m64nNk32`

A warpgroup executing sparse `wgmma.mma_async.m64nNk32` will compute an MMA operation of shape `.m64nNk32` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A, from shared memory is documented in *Shared Memory Matrix Layout*.
- Multiplicand A, from registers:

.atype	Fragments	Elements
.f16 / .bf16	A vector expression containing four .b32 registers, with each register containing two non-zero .f16 /.bf16 elements out of 4 consecutive elements from matrix A.	Non-zero elements: a0, a1, a2, a3, a4, a5, a6, a7 Mapping of the non-zero elements is as described in *Sparse matrix storage*

The layout of the fragments held by different threads is shown in Figure 175.

Figure 175: Sparse WGMMA .m64nNk32 fragment layout for matrix A with .f16/.bf16 type.

- Accumulator D:

  Matrix fragments for accumulator D are the same as in case of *Matrix Fragments for wgmma.mma_async.m64nNk32* for the same .dtype format.

- Multiplicand B:

  Shared memory layout for Matrix B is documented in *Shared Memory Matrix Layout*.

- Metadata operand is a .b32 register containing 16 2-bit vectors each storing the index of a non-zero element of a 4-wide chunk of matrix A.

  Figure 176 shows the mapping of the metadata bits to the elements of matrix A for a warp. In this figure, variable i represents the value of the sparsity selector operand.

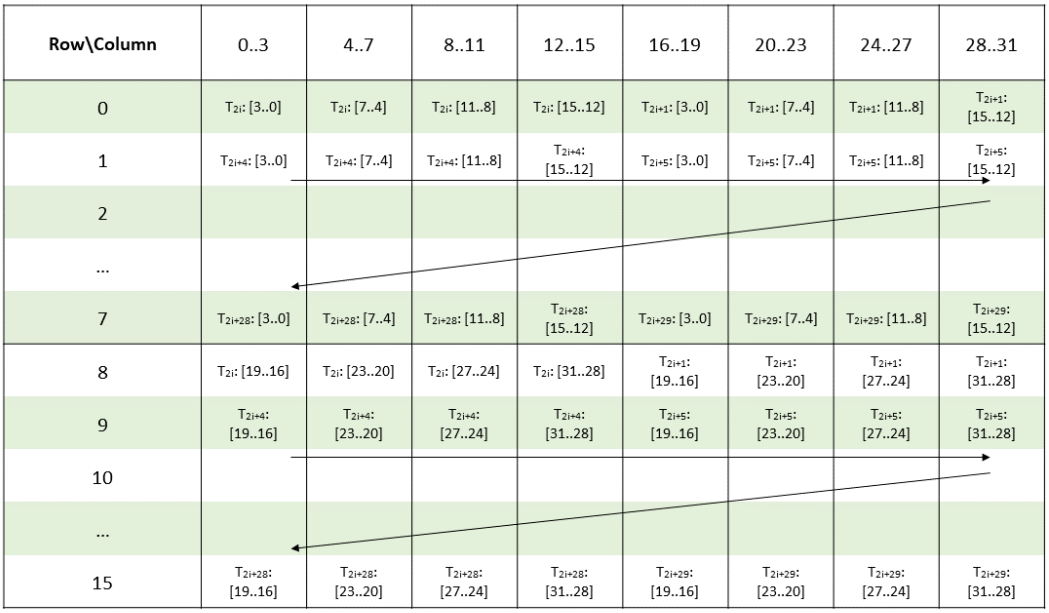

Figure 176: Sparse WGMMA .m64nNk32 metadata layout for `.f16/.bf16` type.

9.7.15.6.2.2 Matrix Fragments for sparse `wgmma.mma_async.m64nNk16`

A warpgroup executing sparse `wgmma.mma_async.m64nNk16` will compute an MMA operation of shape `.m64nNk16` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A, from shared memory is documented in *Shared Memory Matrix Layout*.
- Multiplicand A, from registers:

.atype	Fragments	Elements
`.tf32`	A vector expression containing four `.b32` registers, containing four non-zero `.tf32` elements out of eight consecutive elements from matrix A.	Non-zero elements: a0, a1, a2, a3 Mapping of the non-zero elements is as described in *Sparse matrix storage*

The layout of the fragments held by different threads is shown in Figure 177.

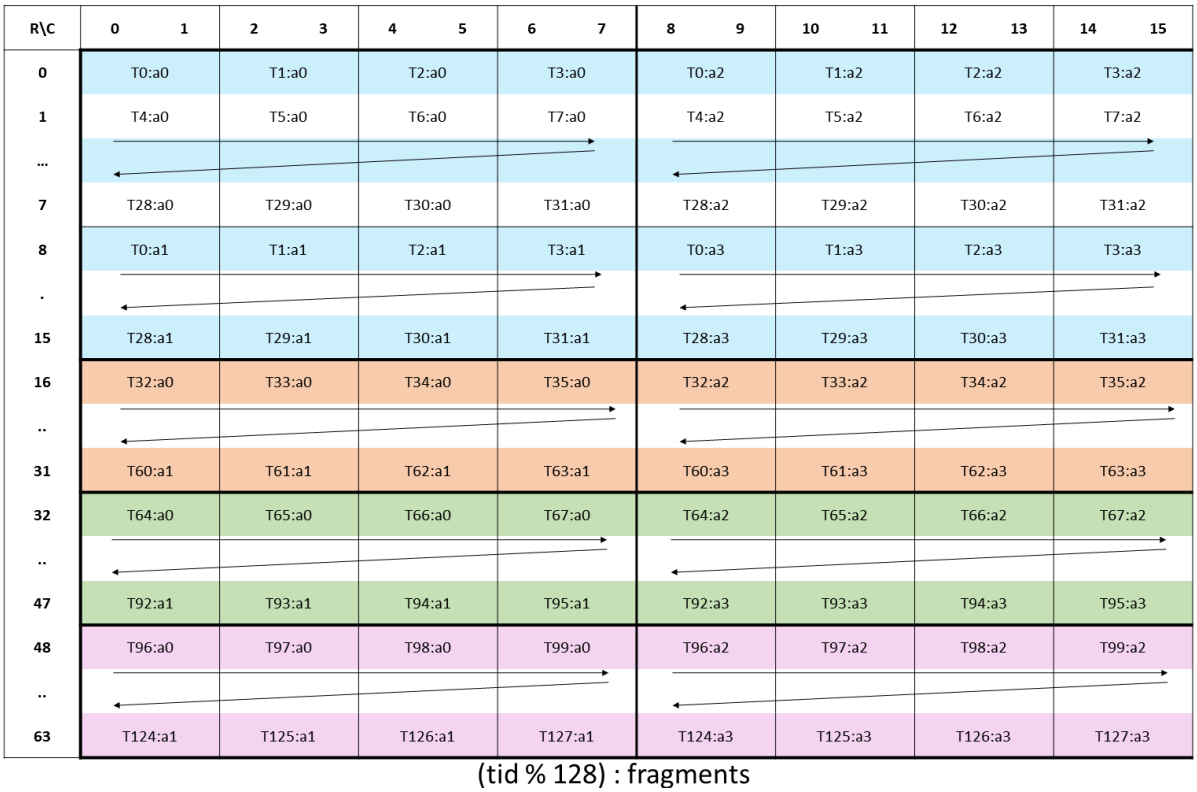

Figure 177: Sparse WGMMA .m64nNk16 fragment layout for matrix A with `.tf32` type.

- Accumulator D:

  Matrix fragments for accumulator D are the same as in case of *Matrix Fragments for wgmma.mma_async.m64nNk8* for the same `.dtype` format.

- Multiplicand B:

  Shared memory layout for Matrix B is documented in *Shared Memory Matrix Layout*.

- Metadata operand is a `.b32` register containing eight 4-bit vectors each storing the index of a non-zero element of a 2-wide chunk of matrix A.

  Figure 178 shows the mapping of the metadata bits to the elements of matrix A for a warp. In this figure, variable `i` represents the value of the sparsity selector operand.

9.7.15.6.2.3 Matrix Fragments for sparse `wgmma.mma_async.m64nNk64`

A warpgroup executing sparse `wgmma.mma_async.m64nNk64` will compute an MMA operation of shape `.m64nNk64` where N is a valid n dimension as listed in *Matrix Shape*.

Elements of the matrix are distributed across the threads in a warpgroup so each thread of the warpgroup holds a fragment of the matrix.

- Multiplicand A, from shared memory is documented in *Matrix Fragments for sparse wgmma.mma_async.m64nNk64*.

- Multiplicand A, from registers:

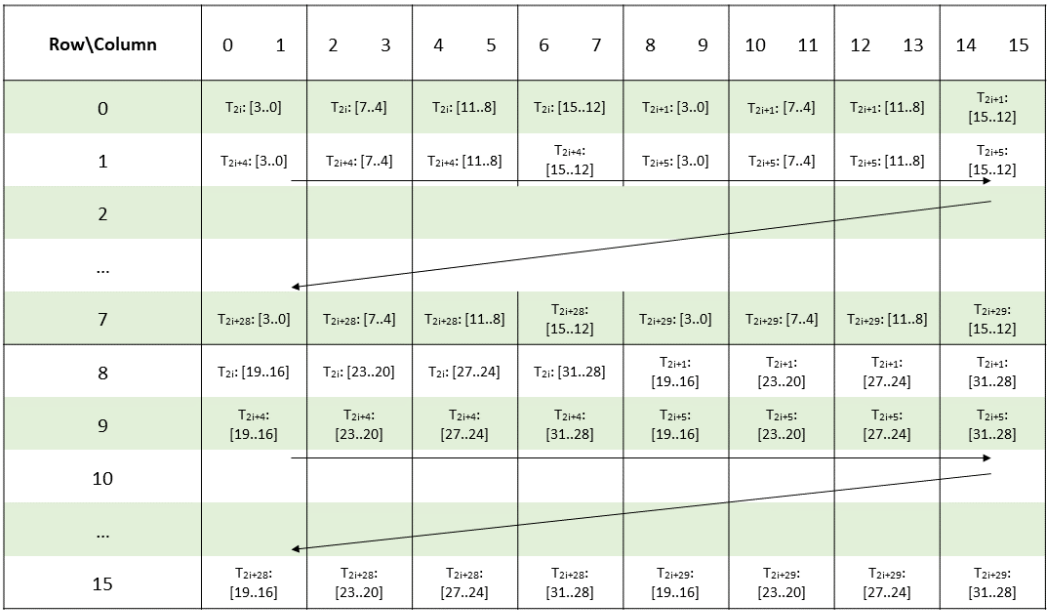

Figure 178: Sparse WGMMA .m64nNk16 metadata layout for `.tf32` type.

.atype	Fragments	Elements
`.e4m3` / `.e5m2`	A vector expression containing four `.b32` registers, with each register containing four non-zero `.e4m3` / `.e5m2` elements out of eight consecutive elements from matrix A.	Non-zero elements: a0, a1, a2, ... , a15 Mapping of the non-zero elements is as described in *Sparse matrix storage*
`.s8` / `.u8`	A vector expression containing four `.b32` registers, with each register containing four non-zero `.s8` / `.u8` elements out of eight consecutive elements from matrix A.	

The layout of the fragments held by different threads is shown in Figure 179.

- Accumulator D:

  Matrix fragments for accumulator D are the same as in case of *Matrix Fragments for wgmma.mma_async.m64nNk32* for the same `.dtype` format.

- Multiplicand B:

  Shared memory layout for Matrix B is documented in *Matrix Fragments for sparse wgmma.mma_async.m64nNk64*.

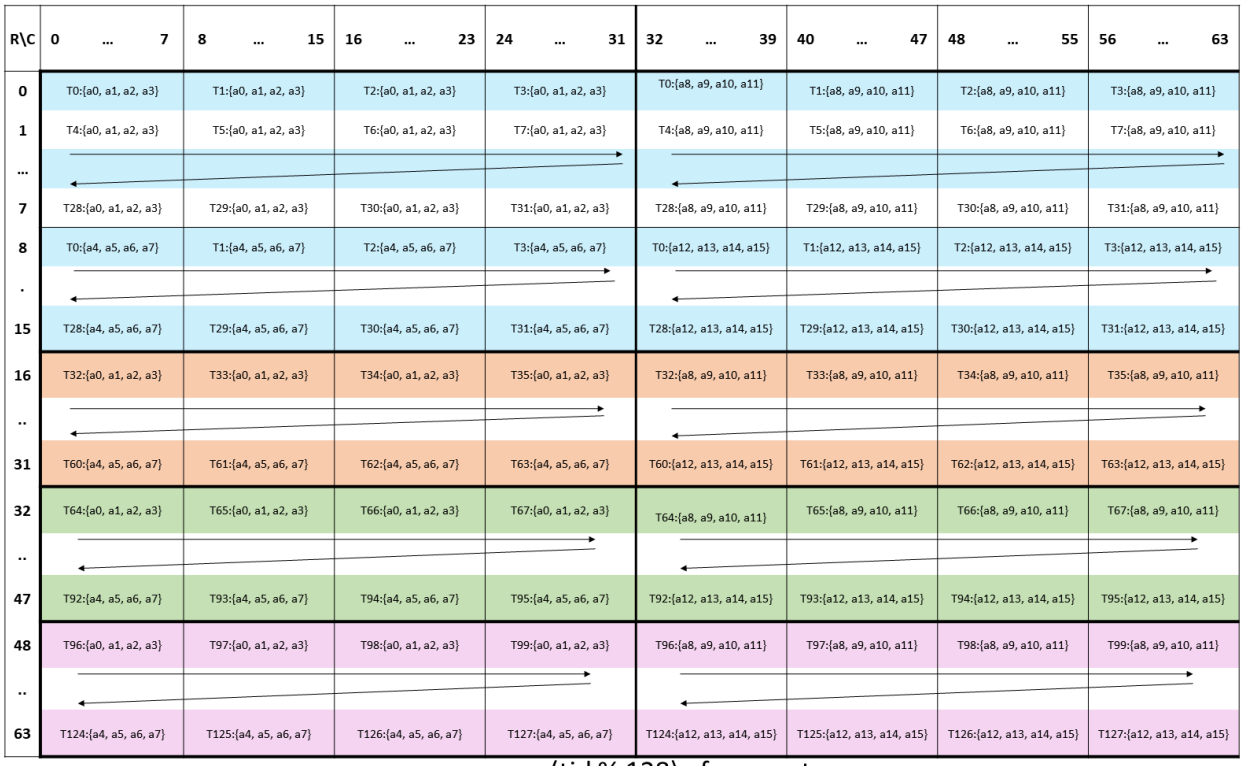

Figure 179: Sparse WGMMA .m64nNk64 fragment layout for matrix A with `.e4m3`/ `.e5m2`/ `.s8`/ `.u8` type.

- Metadata operand is a `.b32` register containing 16 4-bit vectors each storing the indices of two non-zero elements of a 4-wide chunk of matrix A.

  Figure 180 shows the mapping of the metadata bits to the elements of columns 0–31 of matrix A.

Row\Column	0..3	4..7	8..11	12..15	16..19	20..23	24..27	28..31
0	T_0: [3..0]	T_0: [7..4]	T_0: [11..8]	T_0: [15..12]	T_0: [19..16]	T_0: [23..20]	T_0: [27..24]	T_0: [31..28]
1	T_4: [3..0]	T_4: [7..4]	T_4: [11..8]	T_4: [15..12]	T_4: [19..16]	T_4: [23..20]	T_4: [27..24]	T_4: [31..28]
2								
...								
7	T_{28}: [3..0]	T_{28}: [7..4]	T_{28}: [11..8]	T_{28}: [15..12]	T_{28}: [19..16]	T_{28}: [23..20]	T_{28}: [27..24]	T_{28}: [31..28]
8	T_1: [3..0]	T_1: [7..4]	T_1: [11..8]	T_1: [15..12]	T_1: [19..16]	T_1: [23..20]	T_1: [27..24]	T_1: [31..28]
9	T_5: [3..0]	T_5: [7..4]	T_5: [11..8]	T_5: [15..12]	T_5: [19..16]	T_5: [23..20]	T_5: [27..24]	T_5: [31..28]
10								
...								
15	T_{29}: [3..0]	T_{29}: [7..4]	T_{29}: [11..8]	T_{29}: [15..12]	T_{29}: [19..16]	T_{29}: [23..20]	T_{29}: [27..24]	T_{29}: [31..28]

Figure 180: Sparse WGMMA .m64nNk64 metadata layout for `.e4m3`/ `.e5m2`/ `.s8`/ `.u8` type for columns 0–31

Figure 181 shows the mapping of the metadata bits to the elements of columns 32–63 of matrix A.

9.7.15.6.3 Asynchronous Multiply-and-Accumulate Instruction: `wgmma.mma_async.sp`

`wgmma.mma_async.sp`

Perform matrix multiply-and-accumulate operation with sparse matrix A across warpgroup

Row\Column	35..32	39..36	43..40	47..44	51..48	55..52	59..56	63..60
0	T_2: [3..0]	T_2: [7..4]	T_2: [11..8]	T_2: [15..12]	T_2: [19..16]	T_2: [23..20]	T_2: [27..24]	T_2: [31..28]
1	T_6: [3..0]	T_6: [7..4]	T_6: [11..8]	T_6: [15..12]	T_6: [19..16]	T_6: [23..20]	T_6: [27..24]	T_6: [31..28]
2								
...								
7	T_{30}: [3..0]	T_{30}: [7..4]	T_{30}: [11..8]	T_{30}: [15..12]	T_{30}: [19..16]	T_{30}: [23..20]	T_{30}: [27..24]	T_{30}: [31..28]
8	T_3: [3..0]	T_3: [7..4]	T_3: [11..8]	T_3: [15..12]	T_3: [19..16]	T_3: [23..20]	T_3: [27..24]	T_3: [31..28]
9	T_7: [3..0]	T_7: [7..4]	T_7: [11..8]	T_7: [15..12]	T_7: [19..16]	T_7: [23..20]	T_7: [27..24]	T_7: [31..28]
10								
...								
15	T_{31}: [3..0]	T_{31}: [7..4]	T_{31}: [11..8]	T_{31}: [15..12]	T_{31}: [19..16]	T_{31}: [23..20]	T_{31}: [27..24]	T_{31}: [31..28]

Figure 181: Sparse WGMMA .m64nNk64 metadata layout for `.e4m3`/ `.e5m2`/ `.s8`/ `.u8` type for columns 32–63

Syntax

Half precision floating point type:

```
wgmma.mma_async.sp.sync.aligned.shape.dtype.f16.f16  d, a-desc, b-desc, sp-meta, sp-
↪sel, scale-d, imm-scale-a, imm-scale-b, imm-trans-a, imm-trans-b;

wgmma.mma_async.sp.sync.aligned.shape.dtype.f16.f16  d, a, b-desc, sp-meta, sp-sel,
↪scale-d, imm-scale-a, imm-scale-b, imm-trans-b;

.shape   = {.m64n8k32, .m64n16k32, .m64n24k32, .m64n32k32,
            .m64n40k32, .m64n48k32, .m64n56k32, .m64n64k32,
            .m64n72k32, .m64n80k32, .m64n88k32, .m64n96k32,
            .m64n104k32, .m64n112k32, .m64n120k32, .m64n128k32,
            .m64n136k32, .m64n144k32, .m64n152k32, .m64n160k32,
            .m64n168k32, .m648176k32, .m64n184k32, .m64n192k32,
            .m64n200k32, .m64n208k32, .m64n216k32, .m64n224k32,
            .m64n232k32, .m64n240k32, .m64n248k32, .m64n256k32};
.dtype   = {.f16, .f32};
```

Alternate floating point type :

```
.bf16 floating point type:

wgmma.mma_async.sp.sync.aligned.shape.dtype.bf16.bf16  d, a-desc, b-desc, sp-meta, sp-
↪sel, scale-d, imm-scale-a, imm-scale-b, imm-trans-a, imm-trans-b;

wgmma.mma_async.sp.sync.aligned.shape.dtype.bf16.bf16  d, a, b-desc, sp-meta, sp-sel,
↪scale-d, imm-scale-a, imm-scale-b, imm-trans-b;
```

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```
.shape   = {.m64n8k32, .m64n16k32, .m64n24k32, .m64n32k32,
            .m64n40k32, .m64n48k32, .m64n56k32, .m64n64k32,
            .m64n72k32, .m64n80k32, .m64n88k32, .m64n96k32,
            .m64n104k32, .m64n112k32, .m64n120k32, .m64n128k32,
            .m64n136k32, .m64n144k32, .m64n152k32, .m64n160k32,
            .m64n168k32, .m648176k32, .m64n184k32, .m64n192k32,
            .m64n200k32, .m64n208k32, .m64n216k32, .m64n224k32,
            .m64n232k32, .m64n240k32, .m64n248k32, .m64n256k32};
.dtype  = {.f32};

.tf32 floating point type:

wgmma.mma_async.sp.sync.aligned.shape.dtype.tf32.tf32  d, a-desc, b-desc, sp-meta, sp-
↪sel, scale-d, imm-scale-a, imm-scale-b;

wgmma.mma_async.sp.sync.aligned.shape.dtype.tf32.tf32  d, a, b-desc, sp-meta, sp-sel,
↪scale-d, imm-scale-a, imm-scale-b;

.shape   = {.m64n8k16, .m64n16k16, .m64n24k16, .m64n32k16,
            .m64n40k16, .m64n48k16, .m64n56k16, .m64n64k16,
            .m64n72k16, .m64n80k16, .m64n88k16, .m64n96k16,
            .m64n104k16, .m64n112k16, .m64n120k16, .m64n128k16,
            .m64n136k16, .m64n144k16, .m64n152k16, .m64n160k16,
            .m64n168k16, .m648176k16, .m64n184k16, .m64n192k16,
            .m64n200k16, .m64n208k16, .m64n216k16, .m64n224k16,
            .m64n232k16, .m64n240k16, .m64n248k16, .m64n256k16};
.dtype  = {.f32};

FP8 floating point type

wgmma.mma_async.sp.sync.aligned.shape.dtype.atype.btype  d, a-desc, b-desc, sp-meta,
↪sp-sel, scale-d, imm-scale-a, imm-scale-b;

wgmma.mma_async.sp.sync.aligned.shape.dtype.atype.btype  d, a, b-desc, sp-meta, sp-
↪sel, scale-d, imm-scale-a, imm-scale-b;

.shape   = {.m64n8k64, .m64n16k64, .m64n24k64, .m64n32k64,
            .m64n40k64, .m64n48k64, .m64n56k64, .m64n64k64,
            .m64n72k64, .m64n80k64, .m64n88k64, .m64n96k64,
            .m64n104k64, .m64n112k64, .m64n120k64, .m64n128k64,
            .m64n136k64, .m64n144k64, .m64n152k64, .m64n160k64,
            .m64n168k64, .m648176k64, .m64n184k64, .m64n192k64,
            .m64n200k64, .m64n208k64, .m64n216k64, .m64n224k64,
            .m64n232k64, .m64n240k64, .m64n248k64, .m64n256k64};
.atype  = {.e4m3, .e5m2};
.btype  = {.e4m3, .e5m2};
.dtype  = {.f16, .f32};
```

Integer type:

```
wgmma.mma_async.sp.sync.aligned.shape{.satfinite}.s32.atype.btype  d, a-desc, b-desc,
↪sp-meta, sp-sel, scale-d;

wgmma.mma_async.sp.sync.aligned.shape{.satfinite}.s32.atype.btype  d, a, b-desc, sp-
↪meta, sp-sel, scale-d;
```

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```
.shape   = {.m64n8k64, .m64n16k64, .m64n24k64, .m64n32k64,
            .m64n48k64, .m64n64k64, .m64n80k64, .m64n96k64,
            .m64n112k64, .m64n128k64, .m64n144k64, .m64n160k64,
            .m648176k64, .m64n192k64, .m64n208k64, .m64n224k64,
            .m64n240k64, .m64n256k64};
.atype  = {.s8, .u8};
.btype  = {.s8, .u8};
```

Description

Instruction `wgmma.mma_async` issues a MxNxK matrix multiply and accumulate operation, `D = A*B+D`, where the A matrix is MxK, the B matrix is KxN, and the D matrix is MxN.

The matrix A is stored in the packed format Mx(K/2) as described in *Sparse matrix storage*.

The operation of the form `D = A*B` is issued when the input predicate argument `scale-d` is false.

`wgmma.fence` instruction must be used to fence the register accesses of `wgmma.mma_async` instruction from their prior accesses. Otherwise, the behavior is undefined.

`wgmma.commit_group` and `wgmma.wait_group` operations must be used to wait for the completion of the asynchronous matrix multiply and accumulate operations before the results are accessed.

Register operand `d` represents the accumulator matrix as well as the destination matrix, distributed across the participating threads. Register operand `a` represents the multiplicand matrix A in register distributed across the participating threads. The 64-bit register operands `a-desc` and `b-desc` are the matrix descriptors which represent the multiplicand matrices A and B in shared memory respectively. The contents of a matrix descriptor must be same across all the warps in the warpgroup. The format of the matrix descriptor is described in *Matrix Descriptor Format*. Matrix A is structured sparse as described in *Sparse matrix storage*. Operands `sp-meta` and `sp-sel` represent sparsity metadata and sparsity selector respectively. Operand `sp-meta` is a 32-bit integer and operand `sp-sel` is a 32-bit integer constant with values in the range 0..3.

The valid values of `sp-meta` and `sp-sel` for each shape is specified in *Sparse matrix storage* and are summarized here :

Matrix shape	`.atype`	Valid values of `sp-meta`	Valid values of `sp-sel`
`.m64nNk16`	`.tf32`	0b1110 , 0b0100	0 (threads T0, T1) or 1 (threads T2, T3)
`.m64nNk32`	`.f16/ .bf16`	0b00, 0b01, 0b10, 0b11	0 (threads T0, T1) or 1 (threads T2, T3)
`.m64nNk64`	`.e4m3 / .e5m2 / .s8 / .u8`	0b00, 0b01, 0b10, 0b11	0 (all threads contribute)

Matrices A and B are stored in row-major and column-major format respectively. For certain floating point variants, the input matrices A and B can be transposed by specifying the value 1 for the immediate integer arguments `imm-trans-a` and `imm-trans-b` respectively. A value of 0 can be used to avoid the transpose operation. The valid values of `imm-trans-a` and `imm-trans-b` are 0 and 1. The transpose operation is only supported for the `wgmma.mma_async` variants with `.f16/ .bf16` types on matrices accessed from shared memory using matrix descriptors.

For the floating point variants of the `wgmma.mma_async` operation, each element of the input matrices A and B can be negated by specifying the value -1 for operands `imm-scale-a` and `imm-scale-b`

respectively. A value of 1 can be used to avoid the negate operation. The valid values of `imm-scale-a` and `imm-scale-b` are -1 and 1.

The qualifiers `.dtype`, `.atype` and `.btype` indicate the data type of the elements in matrices D, A and B respectively. `.atype` and `.btype` must be the same for all floating point `wgmma.mma_async` variants except for the FP8 floating point variants. The sizes of individual data elements of matrices A and B in alternate floating point variants of the `wgmma.mma_async` operation are as follows:

- Matrices A and B have 8-bit data elements when `.atype/ .btype` is `.e4m3/.e5m2`.
- Matrices A and B have 16-bit data elements when `.atype/ .btype` is `.bf16`.
- Matrices A and B have 32-bit data elements when `.atype/ .btype` is `.tf32`.

Precision and rounding:

- Floating point operations:

  Element-wise multiplication of matrix A and B is performed with at least single precision. When `.dtype` is `.f32`, accumulation of the intermediate values is performed with at least single precision. When `.dtype` is `.f16`, the accumulation is performed with at least half precision.

  The accumulation order, rounding and handling of subnormal inputs are unspecified.

- `.bf16` and `.tf32` floating point operations:

  Element-wise multiplication of matrix A and B is performed with specified precision. `wgmma.mma_async` operation involving type `.tf32` will truncate lower 13 bits of the 32-bit input data before multiplication is issued. Accumulation of the intermediate values is performed with at least single precision.

  The accumulation order, rounding, and handling of subnormal inputs are unspecified.

- Integer operations:

  The integer `wgmma.mma_async` operation is performed with `.s32` accumulators. The `.satfinite` qualifier indicates that on overflow, the accumulated value is limited to the range *MIN_INT32*.. *MAX_INT32* (where the bounds are defined as the minimum negative signed 32-bit integer and the maximum positive signed 32-bit integer respectively).

  If `.satfinite` is not specified, the accumulated value is wrapped instead.

The mandatory `.sync` qualifier indicates that `wgmma.mma_async` instruction causes the executing thread to wait until all threads in the warp execute the same `wgmma.mma_async` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `wgmma.mma_async` instruction. In conditionally executed code, a `wgmma.mma_async` instruction should only be used if it is known that all threads in the warpgroup evaluate the condition identically, otherwise behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.2.

Support for `.u8.s8` and `.s8.u8` as .atype.btype introduced in PTX ISA version 8.4.

Target ISA Notes

Requires sm_90a.

Examples of integer type

```
wgmma.fence.sync.aligned;
wgmma.mma_async.sp.sync.aligned.m64n8k64.s32.u8.u8  {s32d0, s32d1, s32d2, s32d3},
                                                    descA, descB, spMeta, 0, scaleD;
wgmma.mma_async.sp.sync.aligned.m64n8k64.s32.s8.u8  {s32d0, s32d1, s32d2, s32d3},
                                                    descA, descB, spMeta, 0, scaleD;
wgmma.commit_group.sync.aligned;
wgmma.wait_group.sync.aligned 0;
```

9.7.15.7 Asynchronous wgmma Proxy Operations

This section describes warpgroup level wgmma.fence, wgmma.commit_group and wgmma.wait_group instructions.

9.7.15.7.1 Asynchronous Multiply-and-Accumulate Instruction: wgmma.fence

wgmma.fence

Enforce an ordering of register accesses between wgmma.mma_async and other operations.

Syntax

```
wgmma.fence.sync.aligned;
```

Description

wgmma.fence instruction establishes an ordering between prior accesses to any warpgroup registers and subsequent accesses to the same registers by a wgmma.mma_async instruction. Only the accumulator register and the input registers containing the fragments of matrix A require this ordering.

The wgmma.fence instruction must be issued by all warps of the warpgroup at the following locations:

- Before the first wgmma.mma_async operation in a warpgroup.
- Between a register access by a thread in the warpgroup and any wgmma.mma_async instruction that accesses the same registers, either as accumulator or input register containing fragments of matrix A, except when these are accumulator register accesses across multiple wgmma.mma_async instructions of the same shape. In the latter case, an ordering guarantee is provided by default.

Otherwise, the behavior is undefined.

An async proxy fence must be used to establish an ordering between prior writes to shared memory matrices and subsequent reads of the same matrices in a wgmma.mma_async instruction.

The mandatory `.sync` qualifier indicates that `wgmma.fence` instruction causes the executing thread to wait until all threads in the warp execute the same `wgmma.fence` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `wgmma.fence` instruction. In conditionally executed code, an `wgmma.fence` instruction should only be used if it is known that all threads in the warpgroup evaluate the condition identically, otherwise the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90a`.

Examples

```
// Example 1, first use example:
wgmma.fence.sync.aligned;    // Establishes an ordering w.r.t. prior accesses to the
↪registers s32d<0-3>
wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.u8  {s32d0, s32d1, s32d2, s32d3},
                                                  descA, descB, scaleD;
wgmma.commit_group.sync.aligned;
wgmma.wait_group.sync.aligned 0;

// Example 2, use-case with the input value updated in between:
wgmma.fence.sync.aligned;
wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.u8  {s32d0, s32d1, s32d2, s32d3},
                                                  descA, descB, scaleD;
...
mov.b32 s32d0, new_val;
wgmma.fence.sync.aligned;
wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.u8  {s32d4, s32d5, s32d6, s32d7},
                                                 {s32d0, s32d1, s32d2, s32d3},
                                                  descB, scaleD;
wgmma.commit_group.sync.aligned;
wgmma.wait_group.sync.aligned 0;
```

9.7.15.7.2 Asynchronous Multiply-and-Accumulate Instruction: `wgmma.commit_group`

`wgmma.commit_group`

Commits all prior uncommitted `wgmma.mma_async` operations into a *wgmma-group*.

Syntax

```
wgmma.commit_group.sync.aligned;
```

Description

`wgmma.commit_group` instruction creates a new wgmma-group per warpgroup and batches all prior `wgmma.mma_async` instructions initiated by the executing warp but not committed to any wgmma-group into the new wgmma-group. If there are no uncommitted `wgmma.mma_async` instructions then `wgmma.commit_group` results in an empty wgmma-group.

An executing thread can wait for the completion of all `wgmma.mma_async` operations in a wgmma-group by using `wgmma.wait_group`.

The mandatory `.sync` qualifier indicates that `wgmma.commit_group` instruction causes the executing thread to wait until all threads in the warp execute the same `wgmma.commit_group` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `wgmma.commit_group` instruction. In conditionally executed code, an `wgmma.commit_group` instruction should only be used if it is known that all threads in the warpgroup evaluate the condition identically, otherwise the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90a`.

Examples

```
wgmma.commit_group.sync.aligned;
```

9.7.15.7.3 Asynchronous Multiply-and-Accumulate Instruction: `wgmma.wait_group`

`wgmma.wait_group`

Signal the completion of a preceding warpgroup operation.

Syntax

```
wgmma.wait_group.sync.aligned N;
```

Description

`wgmma.wait_group` instruction will cause the executing thread to wait until only N or fewer of the most recent wgmma-groups are pending and all the prior wgmma-groups committed by the executing threads are complete. For example, when N is 0, the executing thread waits on all the prior wgmma-groups to complete. Operand N is an integer constant.

Accessing the accumulator register or the input register containing the fragments of matrix A of a `wgmma.mma_async` instruction without first performing a `wgmma.wait_group` instruction that waits on a *wgmma-group* including that `wgmma.mma_async` instruction is undefined behavior.

The mandatory `.sync` qualifier indicates that `wgmma.wait_group` instruction causes the executing thread to wait until all threads in the warp execute the same `wgmma.wait_group` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `wgmma.wait_group` instruction. In conditionally executed code, an `wgmma.wait_group` instruction should only be used if it is known that all threads in the warpgroup evaluate the condition identically, otherwise the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_90a`.

Examples

```
wgmma.fence.sync.aligned;

wgmma.mma_async.sync.aligned.m64n8k32.s32.u8.u8  {s32d0, s32d1, s32d2, s32d3},
                                                  descA, descB, scaleD;
wgmma.commit_group.sync.aligned;

wgmma.mma_async.sync.aligned.m64n8k16.f32.f16.f16 {f32d0, f32d1, f32d2, f32d3},
                                                  {f16a0, f16a1, f16a2, f16a3},
                                                   descB, 1, -1, -1, 1;
wgmma.commit_group.sync.aligned;

wgmma.wait_group.sync.aligned 0;
```

9.7.16. TensorCore 5th Generation Family Instructions

9.7.16.1 Tensor Memory

The 5th generation TensorCore has dedicated on-chip memory that is specialized for use by TensorCore operations. This Tensor Memory is organized as a two-dimensional matrix where the horizontal rows are called lanes and the vertical columns are called columns.

On architecture `sm_100a/sm_100f`, the 5th generation TensorCore's Tensor Memory has a two-dimensional structure of 512 columns and 128 rows per CTA, with each cell being 32-bits in size.

Restrictions on threads accessing the Tensor Memory via the load and store operations are specified in *Access restrictions*.

9.7.16.1.1 Tensor Memory Addressing

Tensor Memory addresses are 32-bit wide and specify two components.

1. Lane index
2. Column index

The layout is as follows:

31 16	15 0
Lane index	Column index

Figure 182 shows the view of the Tensor Memory Layout within CTA.

9.7.16.1.2 Tensor Memory Allocation

The Tensor Memory is dynamically allocated. The Tensor Memory must be allocated by a single warp in a CTA using the *Tensor Memory Allocation and Management Instructions*.

The allocation and deallocation of *Tensor Memory* is performed in terms of columns. The unit of allocation is 32 columns and the number of columns being allocated must be a power of 2. When a column is allocated, all 128 lanes of the column are allocated.

9.7.16.2 Matrix and Data Movement Shape

There are two kinds of shapes involved.

1. Shapes in the data movement operations
2. Shapes in the MMA operations

Figure 182: Tensor Memory Layout and Addressing

9.7.16.2.1 Matrix Shape

The matrix multiply and accumulate operations support a limited set of shapes for the operand matrices A, B and D. The shapes of all three matrix operands are collectively described by the tuple *MxNxK* where A is *MxK* matrix, B is a *KxN* matrix, and D is a *MxN* matrix.

Table 42 shows matrix shapes that are supported for the specified types for the `tcgen05.mma` operation.

Table 42: Various combinations of .kind and shapes

Various Combinations						**Shapes Supported**		
.kind::*	**Has .ws**	**CTA Group**	**Sparsity**	**dtype**	**atype/btype**			
`kind::f16`	No `.ws`	1	Dense	`.f16`	`.f16`	64xN[1]xK 128xN[2]xK	N[1] = {8, 16, 24, ... 256} steps of 8 N[2] = {16, 32, ... 256} steps of 16	K = 16
				`.f32`	`.f16, .bf16`			
			Sparse	`.f16`	`.f16`			K = 32
				`.f32`	`.f16, .bf16`			
		2	Dense	`.f16`	`.f16`	128xNxK 256xNxK	N = {32, 64, ... 256} steps of 32	K = 16

continues on next page

Table 42 – continued from previous page

Various Combinations						Shapes Supported		
.kind::*	Has .ws	CTA Group	Sparsity	dtype	atype/btype			
				.f32	.f16, .bf16			
			Sparse	.f16	.f16			K = 32
				.f32	.f16, .bf16			
	.ws	1	Dense	.f16	.f16	32xNxK 64xNxK 128xNxK	N = {64, 128, 256}	K = 16
				.f32	.f16, .bf16			
			Sparse	.f16	.f16		N = {64, 128}	K = 32
				.f32	.f16, .bf16			
		2	Either	.f16	.f16	Invalid		
				.f32	.f16, .bf16			
.kind::tf32	No .ws	1	Dense	.f32	.tf32	64xN[1]xK 128xN[2]xK	N[1] = {8, 16, 24, ... 256} steps of 8 N[2] = {16, 32, ... 256} steps of 16	K = 8
			Sparse					K = 16
		2	Dense			128xNxK 256xNxK	N = {32, 64, ... 256} steps of 32	K = 8
			Sparse					K = 16
	.ws	1	Dense			32xNxK 64xNxK 128xNxK	N= {64, 128, 256}	K = 8
			Sparse				N= {64, 128}	K = 16
		2	Dense			Invalid		
			Sparse					
.kind::f8f6f4	No .ws	1	Dense	.f32 .f16	.e4m3, .e5m2, .e2m3, .e3m2, .e2m1	64xN[1]xK 128xN[2]xK	N[1] = {8, 16, ... 256} steps of 8 N[2] = {16, 32, ... 256} steps of 16	K = 32
			Sparse					K = 64

continues on next page

Table 42 – continued from previous page

Various Combinations						Shapes Supported		
.kind::*	Has .ws	CTA Group	Sparsity	dtype	atype/btype			
		2	Dense			128xNxK 256xNxK	N = {32, 64, ... 256} steps of 32	K = 32
			Sparse					K = 64
	.ws	1	Dense			32xNxK 64xNxK 128xNxK	N= {64, 128, 256}	K = 32
			Sparse				N= {64, 128}	K = 64
		2	Dense			Invalid		
			Sparse					
.kind::mxf8f6f4	No .ws	1	Dense	.f32	.e4m3, .e5m2, .e2m3, .e3m2, .e2m1 X (Scale) .ue8m0	128xNxK	N = {8, 16, ... 256} steps of 8	K = 32
			Sparse					K = 64
		2	Dense			128xNxK 256xNxK	N = {16, 32, ... 256} steps of 16	K = 32
			Sparse			256xNxK		K = 64
	.ws	1	Dense			Invalid		
			Sparse					
		2	Dense					
			Sparse					
.kind::i8	No .ws	1	Dense	.s32	.s8, .u8	64xNxK 128xNxK	N = {8, 16, 24, 32, 48, ... 256} steps of 16 after N > 32	K = 32
			Sparse					K = 64
		2	Dense			128xNxK 256xNxK	N = {32, 64, ... 256} steps of 32	K = 32
			Sparse					K = 64
	.ws	1	Dense			32xNxK 64xNxK 128xNxK	N= {64, 128, 256}	K = 32
			Sparse				N= {64, 128}	K = 64
		2	Dense			Invalid		

continues on next page

Table 42 – continued from previous page

Various Combinations						Shapes Supported		
.kind::*	Has .ws	CTA Group	Spar-sity	dtype	atype/btype			
			Sparse					
.kind::mxf4	No .ws	1	Dense	.f32	.e2m1 X (Scale) .ue8m0	128xNxK	N = {8, 16, ... 256} steps of 8	K = 64
			Sparse					K = 128
		2	Dense			128xNxK 256xNxK 256xNxK[1]	N = {16, 32, ... 256} steps of 16	K = 64 K[1] = 96
			Sparse			256xNxK		K = 128
	.ws	1 / 2	Either			Invalid		
.kind::mxf4nvf4	No .ws	1	Dense	.f32	.e2m1 X (Scale) .ue8m0, .ue4m3	128xNxK	N = {8, 16, ... 256} steps of 8	K = 64
			Sparse					K = 128
		2	Dense			128xNxK 256xNxK 256xNxK[1]	N = {16, 32, ... 256} steps of 16	K = 64 K[1] = 96
			Sparse			256xNxK		K = 128
	.ws	1 / 2	Either			Invalid		

9.7.16.2.1.1 Target ISA Note

- K = 96 is only supported for target architecture `sm_103a`.

9.7.16.2.2 Specifying Matrix Shape

M and *N* can be specified in the *Instruction descriptor*.

K cannot be explicitly specified but is implicitly determined by the MMA-kind and the sparsity, as shown in the Table 42.

9.7.16.2.3 Data Movement Shape

The data movement shape indicates the dimension of the data to be moved to or from the *Tensor Memory*. These shapes are described as a tuple `lane x size` where:

- `lane` indicates the number of rows in the *Tensor Memory*; and
- `size` indicates the amount of data, in units of bits (b), across the columns in the *Tensor Memory*.

The following shapes are supported by various tcgen05 operations:

Shape	tcgen05.<op>
`.16x64b`, `.16x128b`, `.16x256b`, `.16x32bx2`, `.32x32b`	`.ld` / `.st`
`.4x256b`, `.32x128b`, `.64x128b`, `.128x256b`, `.128x128b`	`.cp`
`.31x256b` (implicit)	`.shift`

9.7.16.2.3.1 Memory Layout

The following shows the layout of the matrix fragments across threads of the warp.

9.7.16.2.3.2 Matrix fragments for shape .32x32b

A `tcgen05{.ld, .st}.32x32b` instruction has the following data vector register.

Fragment	Elements (low to high)
A vector expression containing `.num` number of `.b32` registers as mentioned in the Table 50.	r0, r1, ...

A warp executing `tcgen05{.ld, .st}.32x32b` will access 32 lanes of the Tensor Memory. It loads from or stores to each of the lane (32 * .num)-bits of data as shown in Figure 183.

9.7.16.2.3.3 Matrix fragments for shape .16x64b

A `tcgen05{.ld, .st}.16x64b` instruction has the following data vector register.

Fragment	Elements (low to high)
A vector expression containing `.num` number of `.b32` registers as mentioned in the Table 50.	r0, r1, ...

A warp executing `tcgen05{.ld, .st}.16x64b` will access 16 lanes of the Tensor Memory. It loads from or stores to each of the lane (64 * .num)-bits of data as shown in Figure 184.

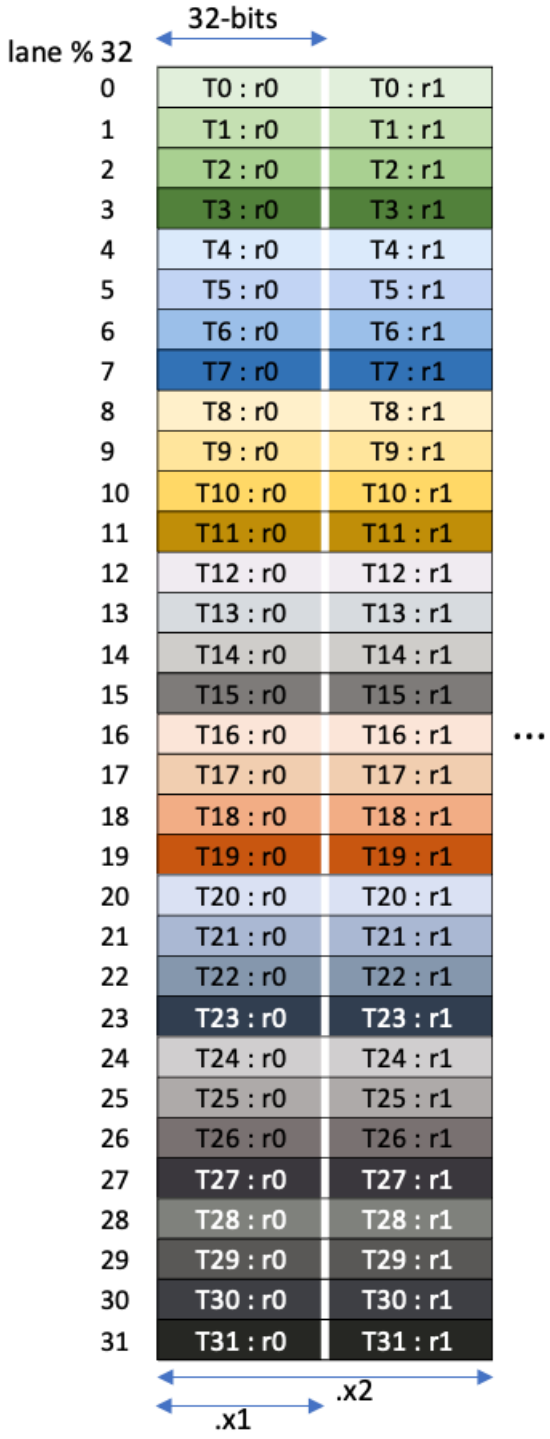


Figure 183: Matrix Fragment for shape .32x32b

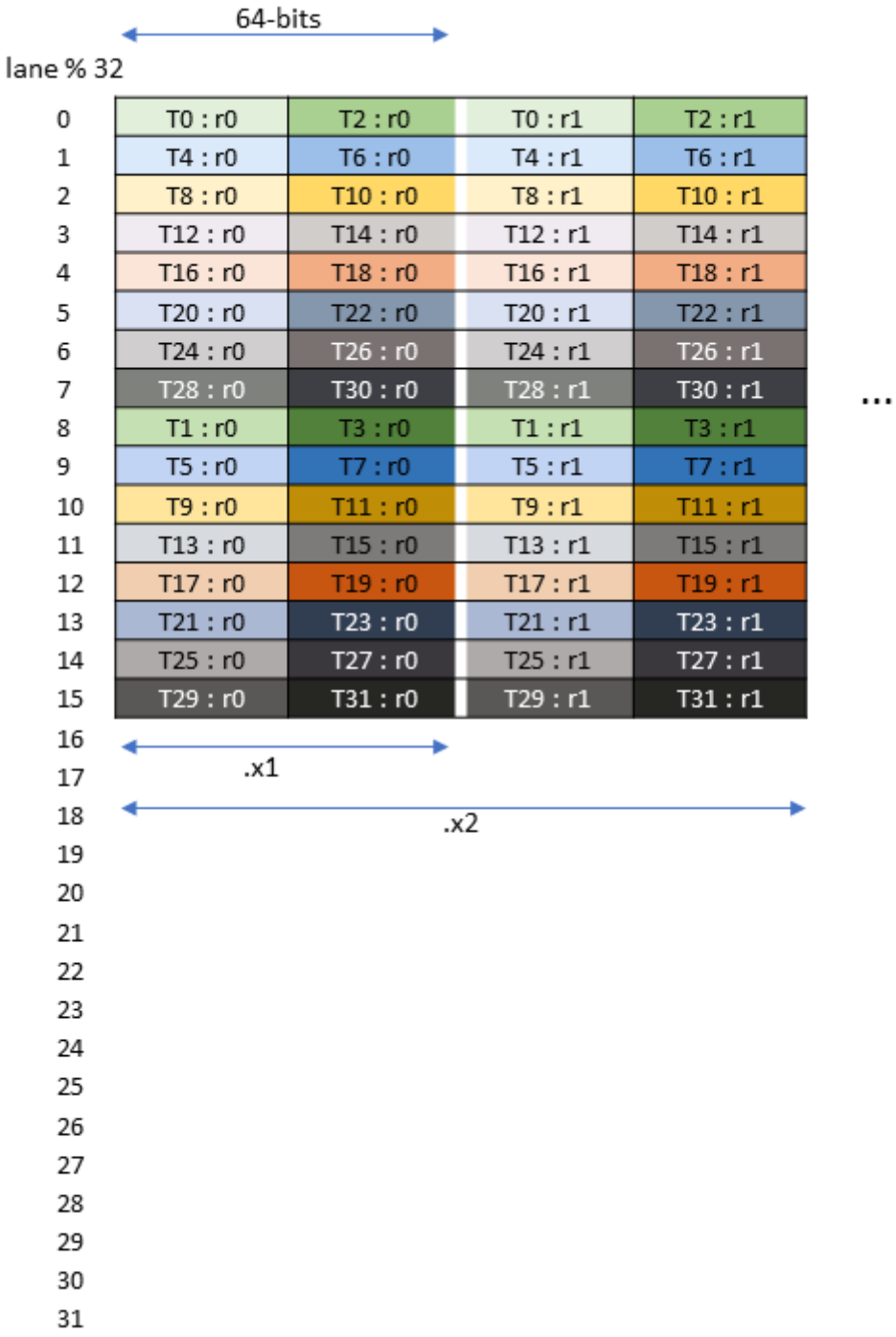


Figure 184: Matrix Fragment for shape .16x64b

9.7.16.2.3.4 Matrix fragments for shape .16x128b

A `tcgen05{.ld,.st}.16x128b` instruction has the following data vector register.

Fragment	Elements (low to high)
A vector expression containing `.num` number of `.b32` registers as mentioned in the Table 50.	r0, r1, ...

A warp executing `tcgen05{.ld,.st}.16x128b` will access 16 lanes of the Tensor Memory. It loads from or stores to each of the lane (128 * .num)-bits of data as shown in Figure 185.

9.7.16.2.3.5 Matrix fragments for shape .16x256b

A `tcgen05{.ld,.st}.16x256b` instruction has the following data vector register.

Fragment	Elements (low to high)
A vector expression containing `.num` number of `.b32` registers as mentioned in the Table 50.	r0, r1, r2, r3, ...

A warp executing `tcgen05{.ld,.st}.16x256b` will access 16 lanes of the Tensor Memory. It loads from or stores to each of the lane (256 * .num)-bits of data as shown in Figure 186.

9.7.16.2.3.6 Matrix fragments for shape .16x32bx2

A `tcgen05{.ld,.st}.16x32bx2` instruction has the following data vector register.

Fragment	Elements (low to high)
A vector expression containing `.num` number of `.b32` registers as mentioned in the Table 50.	r0, r1, ...

A warp executing `tcgen05{.ld,.st}.16x32bx2` will access 16 lanes of the Tensor Memory. It loads from or stores to each of the lane (32 * .num)-bits of data as shown in Figure 187.

9.7.16.3 Major-ness supported by Strides

There are two strides involved while accessing a matrix from shared memory:

1. Leading dimension stride (byte offset or absolute address)
2. Stride dimension byte offset

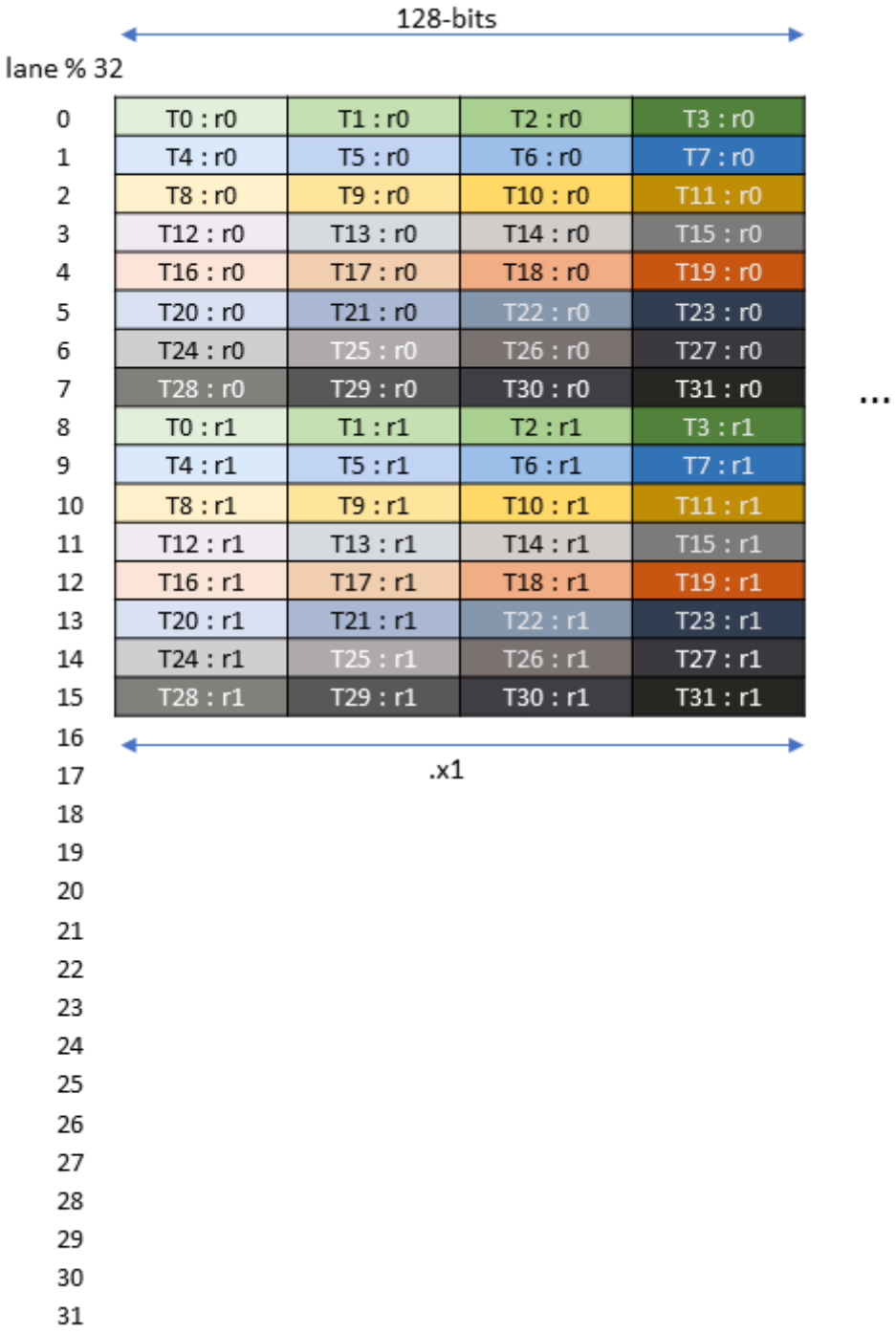


Figure 185: Matrix Fragment for shape .16x128b

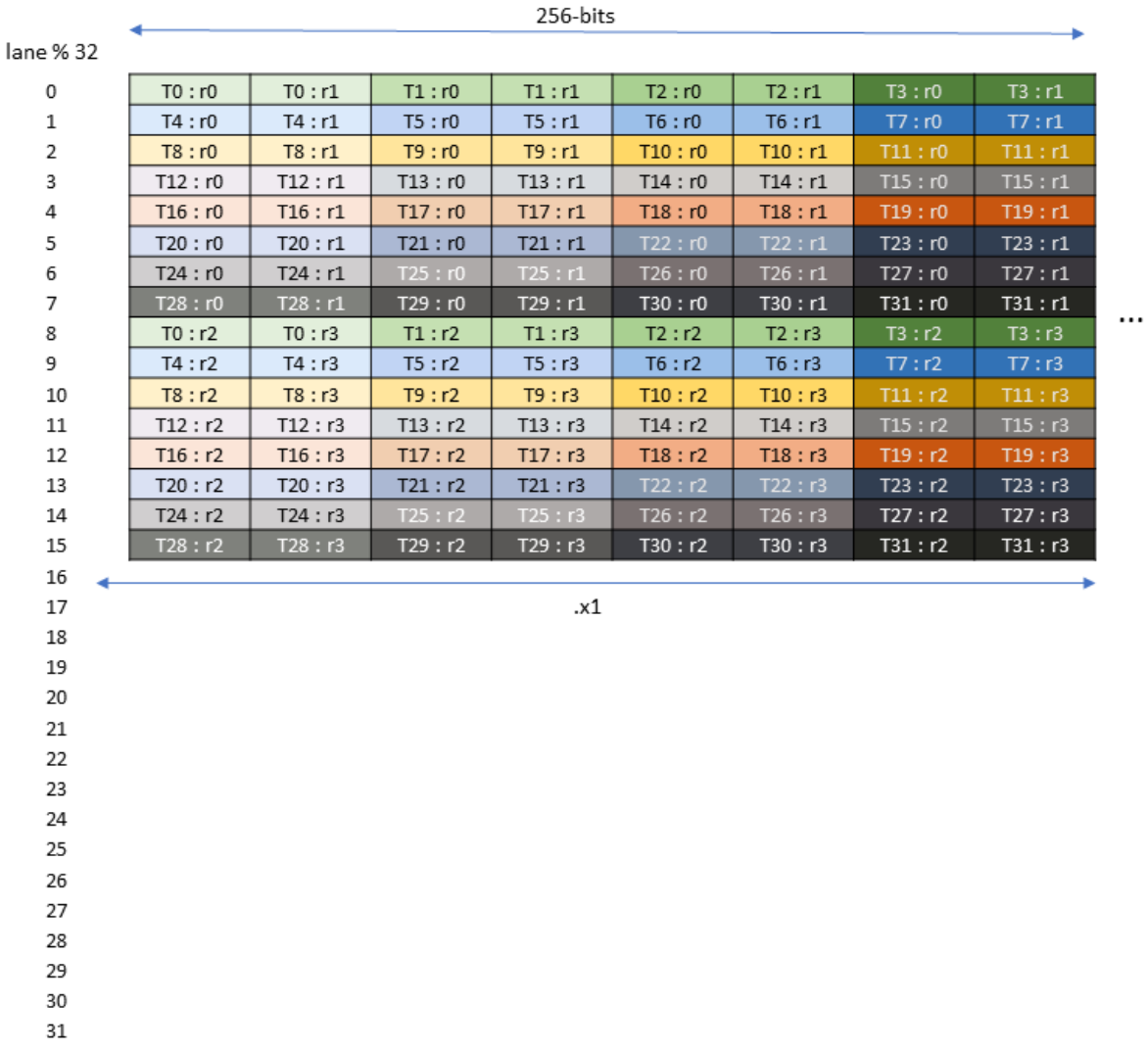


Figure 186: Matrix Fragment for shape .16x256b

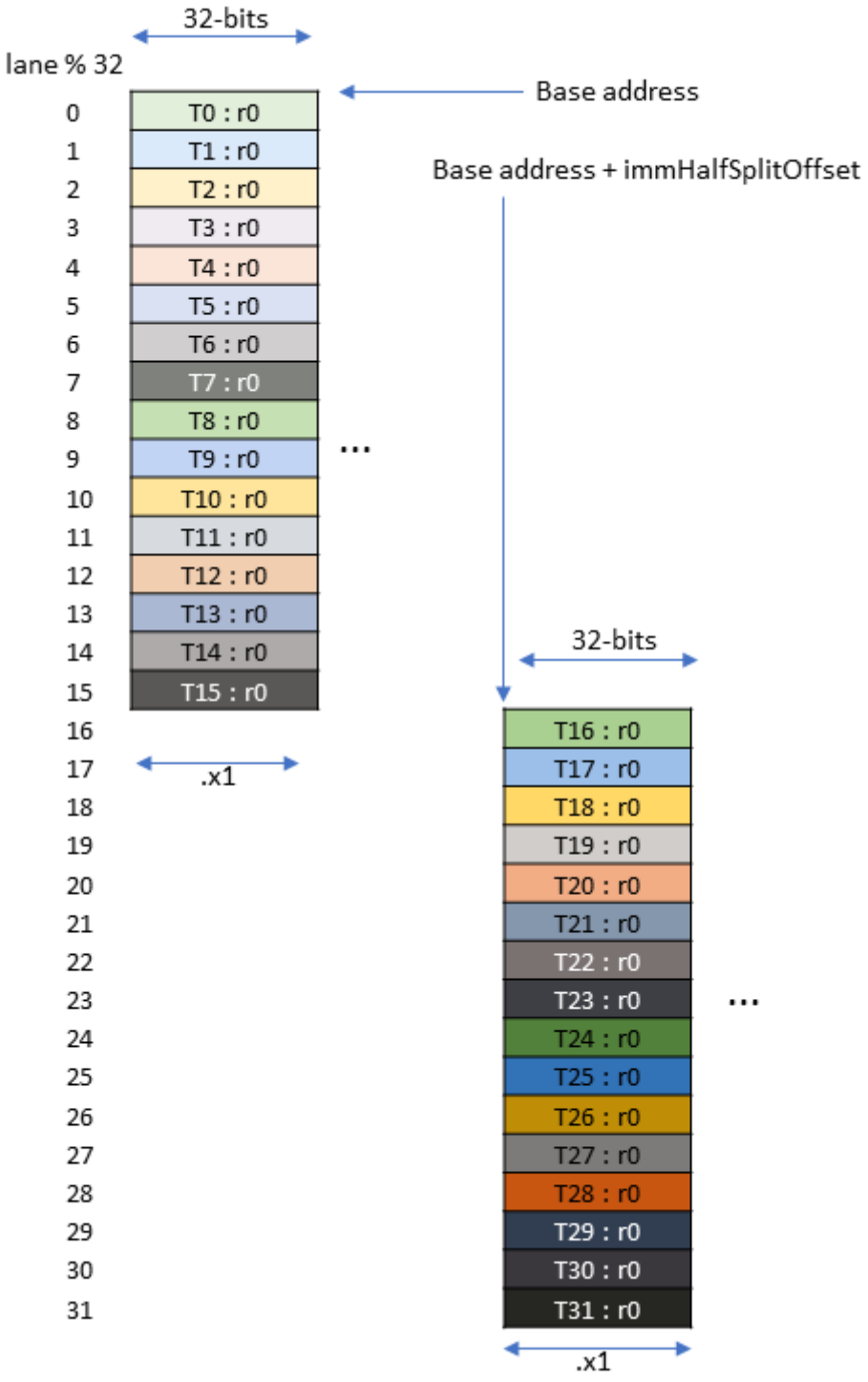


Figure 187: Matrix Fragment for shape .16x32bx2

9.7.16.3.1 Leading Dimension Stride: relative offset or absolute address

There are two modes of Leading Dimension Strides as described below. Bit #52 is the *Shared memory descriptor* is used to distinguish between two modes.

9.7.16.3.1.1 Relative offset mode

In this mode, the leading dimension stride is specified as a relative byte offset between the columns as explained in the below table. The leading dimension stride can either be specified as a relative offset between the columns or as an absolute byte address of next buffer. The leading dimension stride is defined differently for transposed and non-transposed matrices. The leading dimension stride is defined as follows for matrices whose element types are normalized to 128-bits:

Major-ness	Definition
K-Major	▶ No-Swizzling: the stride from the first column to the second column of the 8x2 tile in the 128-bit element type normalized matrix. ▶ Swizzled layouts: not used, assumed to be 1.
MN-Major	▶ Interleave: stride from the first 8 columns to the next 8 columns. ▶ Swizzled layouts: stride from the first (swizzle-byte-size/16) rows to the next (swizzle-byte-size/16) rows.

9.7.16.3.1.2 Absolute address mode for K dimension being 48B

The `tcgen05.mma` instruction with *K-dimension* of 48B would overflow the 128B shared memory boundary if the data is packed contiguously.

In this case, the absolute address mode can be used to break up the data in the shared memory into two chunks such that both these chunks are laid out within the aligned 128-byte address boundary. The leading dimension absolute address can point to the second data chunk in the shared memory.

9.7.16.3.1.3 Restrictions on the Leading Dimension Absolute Address Stride

Following are the restrictions on the absolute address stride mode:

1. Only 128B swizzle (with 16B atomicity) is supported.
2. Only K-Major mode is supported. That is, the transpose bits(bits #15 and #16) in *Instruction descriptor* must be 0.
3. The matrix base offset must be 0.

9.7.16.3.2 Stride Dimension Byte Offset

The stride dimension byte offset is defined differently for transposed and non-transposed matrices. The stride dimension byte offset is defined as follows for matrices whose element types are normalized to 128-bits:

Major-ness	Definition
K-Major	The offset from the first 8 rows to the next 8 rows.
MN-Major	▶ Interleave: offset from the first row to the next row. ▶ Swizzled layout: offset from the first 8 columns to the next 8 columns

9.7.16.3.3 Canonical Layouts

In terms of CuTe layouts the canonical layout can be expressed as follows:

Major-ness	Swizzling mode	Canonical Layout without swizzling	Swizzling on the previous column
MN- major	No-swizzling or Interleaved	((T,1,m),(8,k)):((1,T,SBO),(1T,LBO))	Swizzle<0, 4, 3>
	32B Swizzling	((T,2,m),(8,k)):((1,T,LBO),(2T,SBO))	Swizzle<1, 4, 3>
	64B Swizzling	((T,4,m),(8,k)):((1,T,LBO),(4T,SBO))	Swizzle<2, 4, 3>
	128B Swizzling	((T,8,m),(8,k)):((1,T,LBO),(8T,SBO))	Swizzle<3, 4, 3>
K- major	No-swizzling or Interleaved	((8,m),(T,2k)):((1T,SBO),(1,LBO))	Swizzle<0, 4, 3>
	32B Swizzling	((8,m),(T,2k)):((2T,SBO),(1,T))	Swizzle<1, 4, 3>
	64B Swizzling	((8,m),(T,2k)):((4T,SBO),(1,T))	Swizzle<2, 4, 3>
	128B Swizzling	((8,m),(T,2k)):((8T,SBO),(1,T))	Swizzle<3, 4, 3>

where

- T = 128 / sizeof-elements-in-bits T represents scale factor which normalizes matrix element types to 128-bits.
- m represents the number of repeating patterns across rows.
- k represents the number of repeating patterns across columns.

Examples

- K-Major, no-swizzling and tf32 type: Figure 188

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	64	65	66	67	128	129	130	131	192	193	194	195
1	4	5	6	7	68	69	70	71	132	133	134	135	196	197	198	199
2	8	9	10	11	72	73	74	75	136	137	138	139	200	201	202	203
3	12	13	14	15	76	77	78	79	140	141	142	143	204	205	206	207
4	16	17	18	19	80	81	82	83	144	145	146	147	208	209	210	211
5	20	21	22	23	84	85	86	87	148	149	150	151	212	213	214	215
6	24	25	26	27	88	89	90	91	152	153	154	155	216	217	218	219
7	28	29	30	31	92	93	94	95	156	157	158	159	220	221	222	223
8	32	33	34	35	96	97	98	99	160	161	162	163	224	225	226	227
9	36	37	38	39	100	101	102	103	164	165	166	167	228	229	230	231
10	40	41	42	43	104	105	106	107	168	169	170	171	232	233	234	235
11	44	45	46	47	108	109	110	111	172	173	174	175	236	237	238	239
12	48	49	50	51	112	113	114	115	176	177	178	179	240	241	242	243
13	52	53	54	55	116	117	118	119	180	181	182	183	244	245	246	247
14	56	57	58	59	120	121	122	123	184	185	186	187	248	249	250	251
15	60	61	62	63	124	125	126	127	188	189	190	191	252	253	254	255

Figure 188: K major, no-swizzling and tf32 type

the strides and related details are as follows:

Exact layout : Swizzle<0,4,3> o ((8,2),(4,4)):((4,32),(1,64))

Canonical Layout :Swizzle<0,4,3> o ((8,m),(T,2k)):((1T,SBO),(1,LBO))

Parameters	Value
T	4
m	2
k	2
LBO (relative offset)	32*sizeof(tf32)
SBO	64*sizeof(tf32)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 8

- K-Major, 32B swizzling and tf32 type: Figure 189

  the strides and related details are as follows:

  Exact layout : Swizzle<1,4,3> o ((8,2),(4,4)):((8,64),(1,4))

  Canonical Layout :Swizzle<1,4,3> o ((8,m),(T,2k)):((2T,SBO),(1,T))

Parameters	Value
T	4
m	2
k	2
LBO (relative offset)	NA
SBO	64*sizeof(tf32)
Encoding of LBO in descriptor	1 (assumed)
Encoding of SBO in descriptor	(SBO) >> 4 = 16

- MN-Major, no-swizzling and bf16 type: Figure 190

  the strides and related details are as follows:

  Exact layout : Swizzle<0,4,3> o ((8,1,2),(8,2)):((1,8,64),(8,128))

  Canonical Layout :Swizzle<0,4,3> o ((T,1,m),(8,k)):((1,T,SBO),(1T,LBO))

Parameters	Value
T	8
m	2
k	2
LBO (relative offset)	128*sizeof(bf16)
SBO	64*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 8

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	1	2	3	4	5	6	7	128	129	130	131	132	133	134	135
1	8	9	10	11	12	13	14	15	136	137	138	139	140	141	142	143
2	16	17	18	19	20	21	22	23	144	145	146	147	148	149	150	151
3	24	25	26	27	28	29	30	31	152	153	154	155	156	157	158	159
4	36	37	38	39	32	33	34	35	164	165	166	167	160	161	162	163
5	44	45	46	47	40	41	42	43	172	173	174	175	168	169	170	171
6	52	53	54	55	48	49	50	51	180	181	182	183	176	177	178	179
7	60	61	62	63	56	57	58	59	188	189	190	191	184	185	186	187
8	64	65	66	67	68	69	70	71	192	193	194	195	196	197	198	199
9	72	73	74	75	76	77	78	79	200	201	202	203	204	205	206	207
10	80	81	82	83	84	85	86	87	208	209	210	211	212	213	214	215
11	88	89	90	91	92	93	94	95	216	217	218	219	220	221	222	223
12	100	101	102	103	96	97	98	99	228	229	230	231	224	225	226	227
13	108	109	110	111	104	105	106	107	236	237	238	239	232	233	234	235
14	116	117	118	119	112	113	114	115	244	245	246	247	240	241	242	243
15	124	125	126	127	120	121	122	123	252	253	254	255	248	249	250	251

Figure 189: K major, 32B swizzling and tf32 type

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	8	16	24	32	40	48	56	128	136	144	152	160	168	176	184
1	1	9	17	25	33	41	49	57	129	137	145	153	161	169	177	185
2	2	10	18	26	34	42	50	58	130	138	146	154	162	170	178	186
3	3	11	19	27	35	43	51	59	131	139	147	155	163	171	179	187
4	4	12	20	28	36	44	52	60	132	140	148	156	164	172	180	188
5	5	13	21	29	37	45	53	61	133	141	149	157	165	173	181	189
6	6	14	22	30	38	46	54	62	134	142	150	158	166	174	182	190
7	7	15	23	31	39	47	55	63	135	143	151	159	167	175	183	191
8	64	72	80	88	96	104	112	120	192	200	208	216	224	232	240	248
9	65	73	81	89	97	105	113	121	193	201	209	217	225	233	241	249
10	66	74	82	90	98	106	114	122	194	202	210	218	226	234	242	250
11	67	75	83	91	99	107	115	123	195	203	211	219	227	235	243	251
12	68	76	84	92	100	108	116	124	196	204	212	220	228	236	244	252
13	69	77	85	93	101	109	117	125	197	205	213	221	229	237	245	253
14	70	78	86	94	102	110	118	126	198	206	214	222	230	238	246	254
15	71	79	87	95	103	111	119	127	199	207	215	223	231	239	247	255

Figure 190: MN major, no-swizzling and bf16 type

- MN-Major, 32B swizzling and bf16 type: Figure 191

  the strides and related details are as follows:

  Exact layout : Swizzle<1,4,3> o ((8,2,2),(8,2)):((1,8,128),(16,256))

  Canonical Layout :Swizzle<1,4,3> o ((T,2,m),(8,k)):((1,T,LBO),(2T,SBO))

Parameters	Value
T	8
m	2
k	2
LBO (relative offset)	128*sizeof(bf16)
SBO	256*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 16
Encoding of SBO in descriptor	(SBO) >> 4 = 32

- MN-Major, 64B swizzling and bf16 type: Figure 192

  the strides and related details are as follows:

  Exact layout : Swizzle<2,4,3> o ((8,4,2),(8,2)):((1,8,256),(32,512))

  Canonical Layout :Swizzle<2,4,3> o ((T,4,m),(8,k)):((1,T,LBO),(4T,SBO))

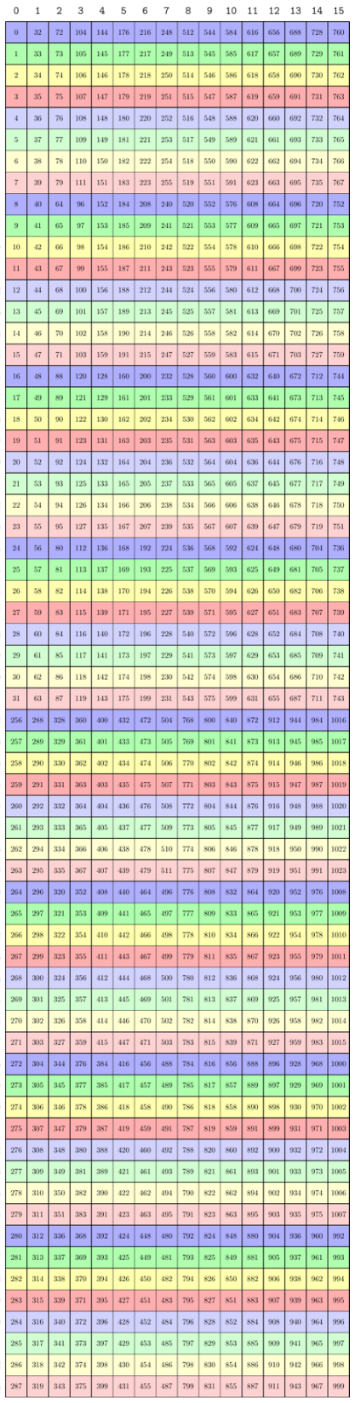
Parameters	Value
T	8
m	2
k	2
LBO (relative offset)	256*sizeof(bf16)
SBO	512*sizeof(bf16)
Encoding of LBO in descriptor	(LBO) >> 4 = 32
Encoding of SBO in descriptor	(SBO) >> 4 = 64

9.7.16.4 Matrix Descriptors

There are three kinds of matrix descriptors used by the `tcgen05` family of instructions.

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	16	32	48	72	88	104	120	256	272	288	304	328	344	360	376
1	1	17	33	49	73	89	105	121	257	273	289	305	329	345	361	377
2	2	18	34	50	74	90	106	122	258	274	290	306	330	346	362	378
3	3	19	35	51	75	91	107	123	259	275	291	307	331	347	363	379
4	4	20	36	52	76	92	108	124	260	276	292	308	332	348	364	380
5	5	21	37	53	77	93	109	125	261	277	293	309	333	349	365	381
6	6	22	38	54	78	94	110	126	262	278	294	310	334	350	366	382
7	7	23	39	55	79	95	111	127	263	279	295	311	335	351	367	383
8	8	24	40	56	64	80	96	112	264	280	296	312	320	336	352	368
9	9	25	41	57	65	81	97	113	265	281	297	313	321	337	353	369
10	10	26	42	58	66	82	98	114	266	282	298	314	322	338	354	370
11	11	27	43	59	67	83	99	115	267	283	299	315	323	339	355	371
12	12	28	44	60	68	84	100	116	268	284	300	316	324	340	356	372
13	13	29	45	61	69	85	101	117	269	285	301	317	325	341	357	373
14	14	30	46	62	70	86	102	118	270	286	302	318	326	342	358	374
15	15	31	47	63	71	87	103	119	271	287	303	319	327	343	359	375
16	128	144	160	176	200	216	232	248	384	400	416	432	456	472	488	504
17	129	145	161	177	201	217	233	249	385	401	417	433	457	473	489	505
18	130	146	162	178	202	218	234	250	386	402	418	434	458	474	490	506
19	131	147	163	179	203	219	235	251	387	403	419	435	459	475	491	507
20	132	148	164	180	204	220	236	252	388	404	420	436	460	476	492	508
21	133	149	165	181	205	221	237	253	389	405	421	437	461	477	493	509
22	134	150	166	182	206	222	238	254	390	406	422	438	462	478	494	510
23	135	151	167	183	207	223	239	255	391	407	423	439	463	479	495	511
24	136	152	168	184	192	208	224	240	392	408	424	440	448	464	480	496
25	137	153	169	185	193	209	225	241	393	409	425	441	449	465	481	497
26	138	154	170	186	194	210	226	242	394	410	426	442	450	466	482	498
27	139	155	171	187	195	211	227	243	395	411	427	443	451	467	483	499
28	140	156	172	188	196	212	228	244	396	412	428	444	452	468	484	500
29	141	157	173	189	197	213	229	245	397	413	429	445	453	469	485	501
30	142	158	174	190	198	214	230	246	398	414	430	446	454	470	486	502
31	143	159	175	191	199	215	231	247	399	415	431	447	455	471	487	503

Figure 191: MN major, 32B swizzling and bf16 type



	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0	0	32	72	104	144	176	216	248	512	544	584	616	656	688	728	760
1	1	33	73	105	145	177	217	249	513	545	585	617	657	689	729	761
2	2	34	74	106	146	178	218	250	514	546	586	618	658	690	730	762
3	3	35	75	107	147	179	219	251	515	547	587	619	659	691	731	763
4	4	36	76	108	148	180	220	252	516	548	588	620	660	692	732	764
5	5	37	77	109	149	181	221	253	517	549	589	621	661	693	733	765
6	6	38	78	110	150	182	222	254	518	550	590	622	662	694	734	766
7	7	39	79	111	151	183	223	255	519	551	591	623	663	695	735	767
8	8	40	64	96	152	184	208	240	520	552	576	608	664	696	720	752
9	9	41	65	97	153	185	209	241	521	553	577	609	665	697	721	753
10	10	42	66	98	154	186	210	242	522	554	578	610	666	698	722	754
11	11	43	67	99	155	187	211	243	523	555	579	611	667	699	723	755
12	12	44	68	100	156	188	212	244	524	556	580	612	668	700	724	756
13	13	45	69	101	157	189	213	245	525	557	581	613	669	701	725	757
14	14	46	70	102	158	190	214	246	526	558	582	614	670	702	726	758
15	15	47	71	103	159	191	215	247	527	559	583	615	671	703	727	759
16	16	48	88	120	128	160	200	232	528	560	600	632	640	672	712	744
17	17	49	89	121	129	161	201	233	529	561	601	633	641	673	713	745
18	18	50	90	122	130	162	202	234	530	562	602	634	642	674	714	746
19	19	51	91	123	131	163	203	235	531	563	603	635	643	675	715	747
20	20	52	92	124	132	164	204	236	532	564	604	636	644	676	716	748
21	21	53	93	125	133	165	205	237	533	565	605	637	645	677	717	749
22	22	54	94	126	134	166	206	238	534	566	606	638	646	678	718	750
23	23	55	95	127	135	167	207	239	535	567	607	639	647	679	719	751
24	24	56	80	112	136	168	192	224	536	568	592	624	648	680	704	736
25	25	57	81	113	137	169	193	225	537	569	593	625	649	681	705	737
26	26	58	82	114	138	170	194	226	538	570	594	626	650	682	706	738
27	27	59	83	115	139	171	195	227	539	571	595	627	651	683	707	739
28	28	60	84	116	140	172	196	228	540	572	596	628	652	684	708	740
29	29	61	85	117	141	173	197	229	541	573	597	629	653	685	709	741
30	30	62	86	118	142	174	198	230	542	574	598	630	654	686	710	742
31	31	63	87	119	143	175	199	231	543	575	599	631	655	687	711	743
32	256	288	328	360	400	432	472	504	768	800	840	872	912	944	984	1016
33	257	289	329	361	401	433	473	505	769	801	841	873	913	945	985	1017
34	258	290	330	362	402	434	474	506	770	802	842	874	914	946	986	1018
35	259	291	331	363	403	435	475	507	771	803	843	875	915	947	987	1019
36	260	292	332	364	404	436	476	508	772	804	844	876	916	948	988	1020
37	261	293	333	365	405	437	477	509	773	805	845	877	917	949	989	1021
38	262	294	334	366	406	438	478	510	774	806	846	878	918	950	990	1022
39	263	295	335	367	407	439	479	511	775	807	847	879	919	951	991	1023
40	264	296	320	352	408	440	464	496	776	808	832	864	920	952	976	1008
41	265	297	321	353	409	441	465	497	777	809	833	865	921	953	977	1009
42	266	298	322	354	410	442	466	498	778	810	834	866	922	954	978	1010
43	267	299	323	355	411	443	467	499	779	811	835	867	923	955	979	1011
44	268	300	324	356	412	444	468	500	780	812	836	868	924	956	980	1012
45	269	301	325	357	413	445	469	501	781	813	837	869	925	957	981	1013
46	270	302	326	358	414	446	470	502	782	814	838	870	926	958	982	1014
47	271	303	327	359	415	447	471	503	783	815	839	871	927	959	983	1015
48	272	304	344	376	384	416	456	488	784	816	856	888	896	928	968	1000
49	273	305	345	377	385	417	457	489	785	817	857	889	897	929	969	1001
50	274	306	346	378	386	418	458	490	786	818	858	890	898	930	970	1002
51	275	307	347	379	387	419	459	491	787	819	859	891	899	931	971	1003
52	276	308	348	380	388	420	460	492	788	820	860	892	900	932	972	1004
53	277	309	349	381	389	421	461	493	789	821	861	893	901	933	973	1005
54	278	310	350	382	390	422	462	494	790	822	862	894	902	934	974	1006
55	279	311	351	383	391	423	463	495	791	823	863	895	903	935	975	1007
56	280	312	336	368	392	424	448	480	792	824	848	880	904	936	960	992
57	281	313	337	369	393	425	449	481	793	825	849	881	905	937	961	993
58	282	314	338	370	394	426	450	482	794	826	850	882	906	938	962	994
59	283	315	339	371	395	427	451	483	795	827	851	883	907	939	963	995
60	284	316	340	372	396	428	452	484	796	828	852	884	908	940	964	996
61	285	317	341	373	397	429	453	485	797	829	853	885	909	941	965	997
62	286	318	342	374	398	430	454	486	798	830	854	886	910	942	966	998
63	287	319	343	375	399	431	455	487	799	831	855	887	911	943	967	999

Figure 192: MN major, 64B swizzling and bf16 type

9.7.16.4.1 Shared memory descriptor

The shared memory descriptor describes the properties of multiplicand matrix in shared memory including its location in the shared memory of the current *CTA*. It is a 64-bit value contained in a register with the following layout:

Table 43: Shared memory descriptor layout

Bit-field	Size in bits	Description
0-13	14	matrix-descriptor-encode (Matrix start address)
16-29	14	matrix-descriptor-encode (*Leading dimension byte offset relative*) OR matrix-descriptor-encode (*Leading dimension byte address absolute*)
32-45	14	matrix-descriptor-encode (*Stride dimension byte offset*)
46-48	3	Fixed constant value of 0b001
49-51	3	Matrix base offset
52	1	Leading dimension stride mode: - 0: byte offset relative - 1: byte address absolute
53-60	8	Fixed constant value of 0xb00000000
61-63	3	Specifies the swizzling mode to be used: 0. No swizzling 1. 128-Byte with 32B atomic swizzling 2. 128-Byte swizzling 4. 64-Byte swizzling 6. 32-Byte swizzling Note: Values 3, 5 and 7 are invalid

where matrix-descriptor-encode(x) = (x & 0x3FFFF) >> 4

The value of base offset is 0 when the repeating pattern of the specified swizzling mode starts as per shown in Table 44.

Table 44: Starting address of repeating pattern for various swizzling modes

Swizzling mode	Starting address of the repeating pattern
128-Byte swizzle	1024-Byte boundary
64-Byte swizzle	512-Byte boundary
32-Byte swizzle	256-Byte boundary

Otherwise, the base offset must be a non-zero value, computed using the following formula: `base offset = (pattern start addr >> 0x7) & 0x7`

The following must be 16-byte aligned:

1. Matrix start address
2. Leading dimension byte offset
3. Stride dimension byte offset

9.7.16.4.1.1 Target ISA Note

- The byte address mode for the leading dimension stride is supported on `sm_103a`.

9.7.16.4.2 Instruction descriptor

The instruction descriptor describes the shapes, types and other details of all the matrices and the matrix-multiplication-and-accumulation operation. It is a 32-bit value in registers and the exact layout is dependent on the MMA-Kind:

Table 45: Instruction descriptor format for .kind::tf32, .kind::f16, .kind::f8f6f4 and .kind::i8

Bits	Size (bits)	Description	Values			
			.kind::tf32	**.kind::f16**	**.kind::f8f6f4**	**.kind::i8**
0-1	2	*Sparsity selector*, if Sparsity is enabled	0-3			
2	1	Sparsity	Dense = 0 Sparse = 1			
3	1	Saturate for integer types	0 (NA)			No Saturate = 0 Saturate = 1
4-5	2	dtype (Matrix D type)	F32 = 1	F16 = 0 F32 = 1		S32 = 2
6	1	Reserved	0			
7-9	3	atype (Matrix A type)	TF32 = 2	F16 = 0 BF16 = 1	E4M3 = 0 E5M2 = 1 E2M3 = 3 E3M2 = 4 E2M1 = 5	Unsigned 8b = 0 Signed 8b = 1
10-12	3	btype (Matrix B type)				
13	1	Negate A Matrix	No Negate = 0 Negate = 1			No Negate = 0
14	1	Negate B Matrix				
15	1	Transpose A Matrix	No Transpose = 0 Transpose = 1			
16	1	Transpose B Matrix				
17-22	6	N, Dimension of Matrix B (3 LSBs not included)	N >> 3			
23	1	Reserved	0			
24-28	5	M, Dimension of Matrix A (4 LSBs not included)	M >> 4			
29	1	Reserved	0			
30-31	2	Maximum shift while attempting B matrix -reuse in `.ws`	no shift = 0 maximum shift of 8 = 1 maximum shift of 16 = 2 maximum shift of 32 = 3			

Table 46: Instruction descriptor format for .kind::mxf8f6f4

Bits	Size (bits)	Description	Values
			.kind::mxf8f6f4
0-1	2	Reserved	0
2	1	Sparsity	Dense = 0 Sparse = 1
3	1	Reserved	0
4-5	2	*Matrix B Scale Factor Data ID*	0-3
6	1	Reserved	0
7-9	3	atype (Matrix A type)	E4M3 = 0 E5M2 = 1 E2M3 = 3 E3M2 = 4 E2M1 = 5
10-12	3	btype (Matrix B type)	
13	1	Negate A Matrix	No Negate = 0 Negate = 1
14	1	Negate B Matrix	
15	1	Transpose A Matrix	No Transpose = 0 Transpose = 1
16	1	Transpose B Matrix	
17-22	6	N, Dimension of Matrix B (3 LSBs not included)	N >> 3
23	1	Scale Matrix Type, for both scale_A / scale_B	UE8M0 = 1
24-26	3	Reserved	0
27-28	2	M, Dimension of Matrix A (7 LSBs not included)	M >> 7
29-30	2	*Matrix A Scale Factor Data ID*	0-3
31	1	Reserved	0

Table 47: Instruction descriptor format for .kind::mxf4 and .kind::mxf4nvf4

Bits	Size (bits)	Description	Values	
			.kind::mxf4	.kind::mxf4nvf4
0-1	2	Reserved	0	
2	1	Sparsity	Dense = 0 Sparse = 1	
3	1	Reserved	0	
4-5	2	*Matrix B Scale Factor Data ID*	0 or 2	
6	1	Reserved	0	
7-9	3	atype (Matrix A type)	E2M1 = 1	
10-11	2	btype (Matrix B type)		
12	1	Reserved	0	
13	1	Negate A Matrix	No Negate = 0 Negate = 1	
14	1	Negate B Matrix		
15	1	Transpose A Matrix	No Transpose = 0	
16	1	Transpose B Matrix		
17-22	6	N, Dimension of Matrix B (3 LSBs not included)	N >> 3	
23	1	Scale Matrix Type, for both scale_A / scale_B	UE8M0 = 1	UE4M3 = 0
24-26	3	Reserved	0	
27-28	2	M, Dimension of Matrix A (7 LSBs not included)	M >> 7	
29-30	2	*Matrix A Scale Factor Data ID*	0 or 2	
31	1	K Dimension	(Dense K=64 / Sparse K=128) = 0 (Dense K=96) = 1	

9.7.16.4.3 Zero-Column Mask Descriptor

The zero-column mask descriptor is used to generate a mask that specifies which columns of B matrix will have zero value for the MMA operation regardless of the values present in the shared memory. The total size of the generated mask is N-bits.

A 0-bit in the mask specifies that values of the corresponding column in matrix B should be used for the MMA operation. A 1-bit in the mask specifies 0s must be used for the entire column for the MMA operation.

The zero-column mask descriptor is a 64-bit value in registers with the following layout:

Table 48: Zero-Column Mask descriptor layout

Bits	Size (bits)	Field Name	Description
0-7	8	Start Count 0 (sc0)	Specifies the LSBs that must be skipped for sub-mask mask-i
8-15	8	Start Count 1 (sc1)	
16-23	8	Start Count 2 (sc2)	
24-31	8	Start Count 3 (sc3)	
32	1	First Span 0 (fs0)	Specifies the starting value for sub-mask mask-i
33	1	First Span 1 (fs1)	
34	1	First Span 2 (fs2)	
35	1	First Span 3 (fs3)	
36-38	3	Reserved	
39	1	Non-Zero Mask	Value 0 indicates generated mask will have all 0s Value 1 indicates the mask has to be generated
40-47	8	Skip Span	(Count of consecutive columns where B matrix is used) - 1
48-55	8	Use Span	(Count of consecutive columns where 0s ar used) - 1
56-61	6	Column Shift	Shifts column by specified amount. Thus allows MMA on non-0 starting column. Max shift amount = 16 for M=32 Max shift amount = 32 otherwise

The zero-column mask is made up of one or more sub-mask depending on M, as shown in the table:

M	Zero-Column Mask breakup	Sub-masks	First Span used	Start Column used
128	Single sub-mask of size N-bits	mask0	fs0	sc0
64	Two sub-masks, each with size of N/2 bits	mask0, mask1	fs0, fs1	sc0, sc1
32	Four sub-masks, each with size of N/4 bits	mask0, mask1 mask2, mask3	fs0, fs1, fs2, fs3	sc0, sc1, sc2, sc3

The following table shows the coverage of the sub-masks across N-dimension:

Sub-mask	M		
	128	64	32
mask0	Columns [0, N-1]	Columns [0, N/2-1]	Columns [0, N/4-1]
mask1	–	Columns [N/2, N-1]	Columns [N/4, N/2-1]
mask2	–	–	Columns [N/2, (N/4*3)-1]
mask3	–	–	Columns [(N/4*3), N-1]

The following examples shows zero-column mask descriptor and their corresponding mask generated:

1. Example 1: M = 128

   Input zero-column mask descriptor:

Start count	First span	Non-Zero Mask	Skip Span	Use Span	Shift
{0, 0, 0, 0}	{0, 0, 0, 0}	0	4	3	0

   Output zero-column mask: 0x0.

   As Non-Zero Mask field is 0, the mask is 0x0. All the columns of the matrix B will be used for the MMA operation.

2. Example 2: M = 128

   Input zero-column mask descriptor:

Start count	First span	Non-Zero Mask	Skip Span	Use Span	Shift
{-, -, -, 0}	{-, -, -, 0}	1	2	3	0

   Output mask0: 0b ... 111 0000 111 0000 (size = N)

3. Example 3: M = 64

   Input zero-column mask descriptor:

Start count {.., sc1, sc0}	First span {.., fs1, fs0}	Non-Zero Mask	Skip Span	Use Span	Shift
{-, -, 0, 0}	{-, -, 0, 1}	1	2	3	0

   Output mask0: 0b ... 111 0000 111 0000 111

   Output masl1: 0b ... 0000 111 0000 111 0000

4. Example 4: M = 32

   Input zero-column mask descriptor:

Start count {sc3, sc2, sc1, sc0}	First span {fs3, fs2, fs1, fs0}	Non-Zero Mask	Skip Span	Use Span	Shift
{1, 2, 1, 0}	{0, 0, 1, 1}	1	2	3	2

Output mask0: 0b ... 0000 111 0000 111

Output mask1: 0b ... 0000 111 0000 11

Output mask2: 0b ... 111 0000 111 00

Output mask3: 0b ... 111 0000 111 000

If N = 128 then B Matrix with columns from 2 to 129 will be used for the MMA operation, due to the shift of 2.

9.7.16.5 Issue Granularity

Each of the `tcgen05` operation has different requirements for the number of threads/warps that needs to issue them.

The following table lists the execution granularity requirements of each of the `tcgen05` operation:

Table 49: Execution granularity requirements for tcgen05 operations

tcgen05 operation	.cta_group	Issue Granularity
`.mma`, `.cp`, `.shift`, `.commit`	::1	An issue from a single thread in the current CTA would initiate the base operation.
	::2	Issue from a single thread from the *CTA-Pair* would initiate the base operation.
`.alloc`, `.dealloc`, `.relinquish_alloc_permit`	::1	Issue from a single warp in the current CTA would initiate the allocation management instruction.
	::2	Issue from two warps, one in each of the current CTA and its *Peer CTA*, collectively needs to perform the operation.
`.ld`, `.st`, `.wait::{ld, st}`	N/A	Issue from a warp in the current CTA can access only 1/4 of the Tensor Memory of the current CTA. So, a warpgroup is needed to access the entire Tensor Memory of the current CTA.
`.fence::*`	N/A	A thread needs to fence all its accesses to the tensor memory that it wants to order with other accesses to the tensor memory from other threads.

9.7.16.5.1 CTA Pair

Any 2 CTAs within the cluster whose `%cluster_ctarank` differs by the last bit only is said to form a CTA pair.

Within a CTA pair, the CTA whose last bit in the `%cluster_ctarank` is:

- 0 is termed the even numbered CTA within the CTA pair.
- 1 is termed as the odd numbered CTA within the CTA pair.

Most of the `tcgen05` operations can either execute at a single CTA level granularity OR at a CTA pair level granularity. When a `tcgen05` operation is performed at CTA pair granularity, the Tensor Memory of both the CTAs within the CTA pair are accessed. The set of threads that need to issue the `tcgen05` operation is listed in the *Issue Granularity*.

9.7.16.5.2 Peer CTA

The peer CTA of the odd CTA within the CTA pair is the even CTA in the same pair. Similarly, the peer CTA of the even CTA within the CTA pair is the odd CTA in the same pair.

9.7.16.6 Memory Consistency Model for 5th generation of TensorCore operations

Ordering of `tcgen05` instructions is described in terms of two key concepts:

1. Pipelined tcgen05 instructions
2. Specialized tcgen05-specific inter-thread synchronization mechanisms.

These concepts combine to form four canonical synchronization patterns, as described further below.

9.7.16.6.1 Asynchronous Operations

The tcgen05 family of instructions are divided into 2 categories:

1. Asynchronous instructions:

   These `tcgen05` operations are not inherently ordered with respect to other `tcgen05` operations in the same thread (unless pipelined as mentioned below).

2. Synchronous instructions:

   These `tcgen05` operations are inherently ordered with respect to other `tcgen05` operations in the same order.

   The Tensor Memory allocation related instructions that access shared memory maintain same-address ordering with respect to non-`tcgen05` instructions.

The following table lists the category of each of the `tcgen05` instruction:

tcgen05.* operation	Category
.alloc	Synchronous instructions
.dealloc	
.relinquish_alloc_permit	
.fence::*	
.wait::*	
.commit	
.mma	Asynchronous instructions
.cp	
.shift	
.ld	
.st	

9.7.16.6.2 Pipelined tcgen05 Instructions

The asynchronous `tcgen05` operations may execute and complete in a different order than they were issued. However, some specific pairs of the asynchronous `tcgen05` instructions form `tcgen05` pipelines, where in the two asynchronous operations are guaranteed to execute in the same order as the instructions that issued them. The specific pairings are as follows:

1. `tcgen05.mma.cta_group::N` -> `tcgen05.mma.cta_group::N` (same N and accumulator and shape)
2. `tcgen05.copy.cta_group::N` -> `tcgen05.mma.cta_group::N` (same N)
3. `tcgen05.shift.cta_group::N` -> `tcgen05.mma.cta_group::N` (same N)
4. `tcgen05.shift.cta_group::N` -> `tcgen05.cp.4x256b.cta_group::N` (same N)
5. `tcgen05.mma.cta_group::N` -> `tcgen05.shift.cta_group::N` (same N)

9.7.16.6.2.1 Implicitly pipelined tcgen05 Instructions

Instructions `tcgen05.commit` and `tcgen05.wait` are implicitly pipelined with respect to previously issued `tcgen05.{mma,cp,shift}` and `tcgen05.{ld,st}` instructions respectively that they track from the same thread.

9.7.16.6.2.2 mbarrier based completion mechanism

Completion of the following instruction's asynchronous operations is observed through the mbarrier based waiting mechanism:

1. `tcgen05.mma`
2. `tcgen05.cp`
3. `tcgen05.shift`

`tcgen05.commit` is used to track the completion of the above asynchronous instructions.

Following are the implicitly pipelined `tcgen05` instruction pairing that uses mbarrier based completion mechanism:

- `tcgen05.mma.cta_group::N` -> `tcgen05.commit.cta_group::N` (same N)
- `tcgen05.cp.cta_group::N` -> `tcgen05.commit.cta_group::N` (same N)
- `tcgen05.shift.cta_group::N` -> `tcgen05.commit.cta_group::N` (same N)

9.7.16.6.2.3 `tcgen05.wait` instruction based completion mechanism

Completion of the following instruction's asynchronous operations is observed through `tcgen05.wait` based waiting mechanism:

1. `tcgen05.ld`
2. `tcgen05.st`

`tcgen05.wait::ld` and `tcgen05.wait::st` is used to track the completion of the `tcgen05.ld` and `tcgen05.st` asynchronous instructions.

Following are the implicitly pipelined `tcgen05` instruction pairing that uses `tcgen05.wait` based completion mechanism:

- `tcgen05.ld` -> `tcgen05.wait::ld`
- `tcgen05.st` -> `tcgen05.wait::st`

9.7.16.6.3 Specialized Inter-thread Synchronization for tcgen05 instructions

The `tcgen05` instructions support a specialized inter-thread synchronization which are optimized for `tcgen05` family of instructions. The standard memory consistency model synchronization mechanisms also apply to the `tcgen05` family of instructions.

The *TensorCore 5th Generation Specialized Synchronization Operations* section contains the specialized inter-thread synchronization for tcgen05 instructions.

The `tcgen05.fence::before_thread_sync` and `tcgen05.fence::after_thread_sync` composes with execution ordering instructions, like morally strong `ld`/`st`/`atom` instructions, `mbarrier`

instruction, `barrier` instructions and so on, to establish an ordering between the `tcgen05` operations across threads. The asynchronous `tcgen05` instructions that are ordered across threads also form a `tcgen05` pipeline.

An asynchronous `tcgen05` operation prior to a `tcgen05.fence::before_thread_sync` is ordered before all subsequent `tcgen05` and the execution ordering operations.

An asynchronous `tcgen05` operation subsequent to a `tcgen05.fence::after_thread_sync` is ordered after all the prior `tcgen05` and the execution ordering operations.

9.7.16.6.4 Canonical synchronization patterns

Using the above rules, the following are the five canonical synchronization patterns:

9.7.16.6.4.1 Pipelined instructions, same thread

In this pattern, no explicit ordering mechanism is needed and the ordering guarantee is provided by the pipelined instruction pairing.

Example:

```
tcgen05.mma
tcgen05.mma (same shape and accumulator)
```

The two instructions will be executed in program order.

9.7.16.6.4.2 Non-pipelined instructions, same thread

In this pattern, explicit waiting mechanisms are used to wait for the completion of the asynchronous `tcgen05` operations.

Example 1:

```
tcgen05.st
tcgen05.wait::st
tcgen05.ld
```

`tcgen05.wait::st` is used to wait for the completion of the prior asynchronous instruction `tcgen05.st`.

Example 2:

```
tcgen05.mma [d], ...
tcgen05.commit.mbarrier::arrive::one
mbarrier.try_wait.relaxed.cluster (loop until successful)
tcgen05.fence::after_thread_sync
tcgen05.ld [d], ...
```

For the completion of the asynchronous `tcgen05.mma`, `tcgen05.commit` is used.

As `tcgen05.ld` is an asynchronous operation, the instruction `tcgen05.fence::after_thread_sync` is needed.

No explicit `tcgen05.fence::before_thread_sync` is needed as this is implicitly performed by `tcgen05.commit`. The combination of `tcgen05.mma` and `tcgen05.commit` forms a conceptual asynchronous pipeline and establishes execution ordering.

```
tcgen05.mma [d], ...
tcgen05.fence::before_thread_sync
mbarrier::arrive
```

9.7.16.6.4.3 Pipelined instructions, different thread

In this pattern, no explicit waiting mechanism is needed but proper synchronization between threads is needed.

Example:

Thread 0	Thread 1

`tcgen05.cp`
`tcgen05.fence::before_thread_sync`
`mbarrier.arrive.relaxed.cluster`	

	`mbarrier.try_wait.relaxed.cluster //`
	`↪loop till success`
	`tcgen05.fence::after_thread_sync`
	`tcgen05.mma`

9.7.16.6.4.4 Non-pipelined instructions, different thread

In this pattern, the producer threads that issue the asynchronous `tcgen05` instructions must explicitly wait for the instructions' completion before synchronizing with the consumer threads.

Example 1:

Thread 0	Thread 1

`tcgen05.ld`
`tcgen05.wait::ld`
`tcgen05.fence::before_thread_sync`
`mbarrier.arrive.relaxed.cluster`	

	`mbarrier.try_wait.relaxed.cluster //`
	`↪loop till success`
	`tcgen05.fence::after_thread_sync`
	`tcgen05.mma`

Example 1:

Thread 0	Thread 1

`tcgen05.mma`
`tcgen05.commit.mbarrier::arrive::one`
`↪[mbar]`	

	`mbarrier.try_wait.relaxed.cluster [mbar]`
	`↪// loop till success`
	`tcgen05.fence::after_thread_sync`
	`tcgen05.ld`

The synchronization mechanisms can also be composed with each other. For example:

Thread 0	Thread 1

`tcgen05.mma`
`tcgen05.commit.mbarrier::arrive::one`
`↪[bar1]`
`mbarrier.try_wait.relaxed.cluster [bar1]`
`↪// loop`
`...`
`tcgen05.fence::after_thread_sync`
`...// completion is guaranteed`
`tcgen05.fence::before_thread_sync`
`mbarrier.arrive.relaxed.cluster [bar2]`
`↪// loop`
`...`	

	`mbarrier.try_wait.relaxed.cluster [bar2]`
	`↪// loop`
	`...`
	`tcgen05.fence::after_thread_sync`
	`tcgen05.ld`

9.7.16.6.4.5 Register dependencies, same thread

For `tcgen05.ld`, an intra-thread ordering through true register dependency will be respected regardless of the presence or absence of other forms of synchronization. This form of register dependency does not imply any other form of ordering. For example, a register dependency does not imply that a dependee instruction's memory accesses will be performed before a dependent instruction's memory accesses. To enforce such memory orderings and avoiding anti-dependency hazards around `tcgen05.ld`, `tcgen05.wait::ld` must be used.

Example:

```
tcgen05.ld %r1, ...;
tcgen05.mma ..., %r1, ...;
```

9.7.16.6.5 Shared Memory Accesses

The shared memory accesses by `tcgen05.mma` and `tcgen05.cp` operations are performed in the asynchronous proxy (async proxy).

Accessing the same memory location across miltiple proxies needs a cross-proxy fence. For the async proxy, `fence.proxy.async` should be used to synchronize memory between generic proxy and the async proxy.

9.7.16.7 Tensor Memory Allocation and Management Instructions

9.7.16.7.1 Tensorcore 5th Generation Instructions: `tcgen05.alloc`, `tcgen05.dealloc`, `tcgen05.relinquish_alloc_permit`

`tcgen05.alloc`, `tcgen05.dealloc`, `tcgen05.relinquish_alloc_permit`

Dynamic *Tensor Memory* allocation management instructions

Syntax

```
tcgen05.alloc.cta_group.sync.aligned{.shared::cta}.b32  [dst], nCols;

tcgen05.dealloc.cta_group.sync.aligned.b32              taddr, nCols;

tcgen05.relinquish_alloc_permit.cta_group.sync.aligned;

.cta_group = { .cta_group::1, .cta_group::2 }
```

Description

`tcgen05.alloc` is a potentially blocking instruction which dynamically allocates the specified number of columns in the *Tensor Memory* and writes the address of the allocated *Tensor Memory* into shared memory at the location specified by address operand dst. The `tcgen05.alloc` blocks if the requested amount of *Tensor Memory* is not available and unblocks as soon as the requested amount of *Tensor Memory* becomes available for allocation.

Instruction `tcgen05.dealloc` deallocates the *Tensor Memory* specified by the *Tensor Memory* address `taddr`. The operand `taddr` must point to a previous *Tensor Memory* allocation.

The unsigned 32-bit operand `nCols` specify the number of columns to be allocated or de-allocated. The unit of allocation and de-allocation is 32 columns and all of lanes per column. The number of columns must be a power of 2. The operand `nCols` must be within the range [32, 512]. The number of columns allocated should not increase between any two allocations in the execution order within the CTA. Operand `nCols` must be power of 2.

Instruction `tcgen05.relinquish_alloc_permit` specifies that the CTA of the executing thread is relinquishing the right to allocate *Tensor Memory*. So, it is illegal for a CTA to perform `tcgen05.alloc` after any of its constituent threads execute `tcgen05.relinquish_alloc_permit`.

If no state space is specified then *Generic Addressing* is used. If the address specified by `dst` does not fall within the address window of `.shared::cta` state space then the behavior is undefined.

Qualifier `.cta_group` specifies the number of CTAs involved in the allocation and de-allocation operation. When `.cta_group::1` is specified, one warp from the CTA must perform the allocation and de-allocation. When `.cta_group::2` is specified, one warp from each of the *peer CTAs* must collectively perform the allocation and de-allocation. Refer to the *Issue Granularity* section. When `.cta_group::2` is specified, the issuing warp must make sure that peer CTA is launched and is still active.

The mandatory `.sync` qualifier indicates that the instruction causes the executing thread to wait until all threads in the warp execute the same instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same instruction. In conditionally executed code, the instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of the instruction is undefined if all the threads in the warp do not use the same values of `nCols`, or if any thread in the warp has exited.

The store operation in `tcgen05.alloc` is treated as a weak memory operation in the *Memory Consistency Model*.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
// Example 1:

tcgen05.alloc.cta_group::1.sync.aligned.shared::cta.b32 [sMemAddr1], 32;
ld.shared.b32 taddr, [sMemAddr1];
// use taddr ...
// more allocations and its usages ...
tcgen05.dealloc.cta_group::1.sync.aligned.b32  taddr, 32;
// more deallocations ...
tcgen05.relinquish_alloc_permit.cta_group::1.sync.aligned;

// Example 2:

// Following instructions are performed by current warp and the warp in the peer-CTA:
tcgen05.alloc.cta_group::2.sync.aligned.shared::cta.b32 [sMemAddr2], 32;
ld.shared.b32 taddr, [sMemAddr2];
// use taddr ...
```

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```
// more allocations and its usages ...
tcgen05.dealloc.cta_group::2.sync.aligned.b32  taddr, 32;
// more deallocations ...
tcgen05.relinquish_alloc_permit.cta_group::2.sync.aligned;
```

9.7.16.8 Tensor Memory and Register Load/Store Instructions

The threads of the CTA can perform the loads and stores to the *Tensor Memory* of the CTA and move data between registers and Tensor Memory. The loads and stores of data can be performed in certain shapes as specified in the *Matrix and Data Movement Shape* section.

9.7.16.8.1 Access restrictions

Not all threads of the CTA can access the entire Tensor Memory via the `tcgen05.ld` and `tcgen05.st` operations.

The Tensor Memory of a CTA is divided into 4 equal chunks such that each warp of a warpgroup in the CTA can access a chunk of the Tensor Memory. All the columns of the Tensor Memory can be accessed by all the four warps of a warpgroup. A lane of the Tensor Memory can be accessed by a single warp in the warpgroup. The following table describes the access restriction.

ID of the warp within the warpgroup	Accessible Lanes
0	0-31
1	32-63
2	64-95
3	96-127

9.7.16.8.2 Packing and Unpacking

Optionally, the following pack and unpack operations can be performed during the load and store:

1. Packing: two 16-bit chunks can be packed into a single 32-bit chunk in the register in `tcgen05.ld`
2. Unpacking: a single 32-bit chunk in the register can be unpacked into two 16-bit chunks in `tcgen05.st`

as shown in the Figure 193.

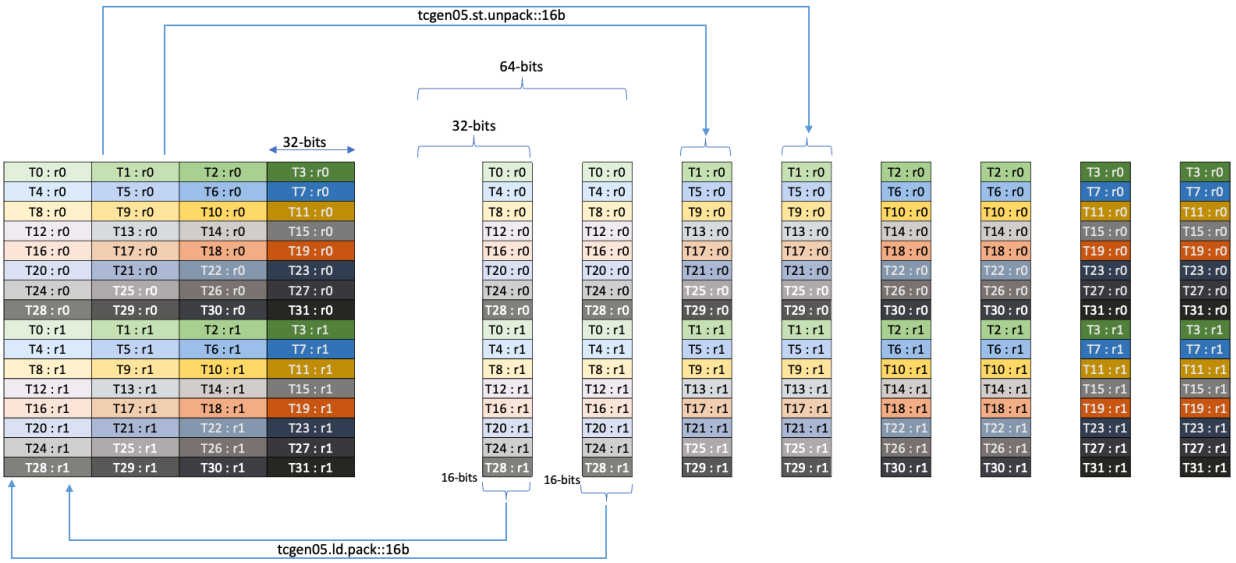

Figure 193: Pack/Unpack operations for tcgen05 ld/st

9.7.16.8.3 Tensorcore 5th Generation Instructions: `tcgen05.ld`

`tcgen05.ld`

Asynchronous collective load from tensor memory into registers.

Syntax

```
// Base load instruction:

tcgen05.ld.sync.aligned.shape1.num{.pack}.b32    r, [taddr];

tcgen05.ld.sync.aligned.shape2.num{.pack}.b32    r, [taddr], immHalfSplitoff;

.shape1 = { .16x64b, .16x128b, .16x256b, .32x32b }
.shape2 = { .16x32bx2 }
.num    = { .x1, .x2, .x4, .x8, .x16, .x32, .x64, .x128 }
.pack   = { .pack::16b }

// Floating point type load along with reduction :

tcgen05.ld.red.sync.aligned.shape3.num.redOp{.abs}{.NaN}.f32 r, redval, [taddr];

tcgen05.ld.red.sync.aligned.shape4.num.redOp{.abs}{.NaN}.f32 r, redval, [taddr],
↪immHalfSplitoff;

// Integer type load along with reduction :
```

(continues on next page)

(continued from previous page)

```
tcgen05.ld.red.sync.aligned.shape3.num.redOp.type r, redval, [taddr];

tcgen05.ld.red.sync.aligned.shape4.num.redOp.type r, redval, [taddr], immHalfSplitoff;

.shape3 = { .32x32b   }
.shape4 = { .16x32bx2 }
.redOp  = { .min, .max }
.type   = { .u32, .s32 }
```

Description

Instruction `tcgen05.ld` asynchronously loads data from the *Tensor Memory* at the location specified by the 32-bit address operand `taddr` into the destination register `r`, collectively across all threads of the warps.

All the threads in the warp must specify the same value of `taddr`, which must be the base address of the collective load operation. Otherwise, the behavior is undefined.

The `.shape` qualifier and the `.num` qualifier together determines the total dimension of the data which is loaded from the *Tensor Memory*. The `.shape` qualifier indicates the base dimension of data to be accessed as described in the *Data Movement Shape*. The `.num` qualifier indicates the repeat factor on the base dimension resulting in the total dimension of the data that is accessed.

The shape `.16x32bx2` performs two accesses into Tensor Memory of the shape `.16x32b`. The base address of the first access is specified by taddr and the base address of the second access is specified by `taddr+immHalfSplitoff`, where `immHalfSplitoff` is an immediate argument.

The destination operand `r` is a brace-enclosed vector expression consisting of one or more 32-bit registers as per the value of `.shape` and `.num`. The size of the vector for various combinations of `.num` and `.shape` is shown in Table 50.

Table 50: Various-combinations of .num and .shape

.num	.shape		
	.16x32bx2 / .16x64b / .32x32b	.16x128b	.16x256b
.x1	1	2	4
.x2	2	4	8
.x4	4	8	16
.x8	8	16	32
.x16	16	32	64
.x32	32	64	128
.x64	64	128	NA
.x128	128	NA	NA

The qualifier `.red` specifies that the reduction operation specified by `.redOp` is performed on the data that is loaded across columns in each lane. The result of the reduction operation is written into the corresponding thread's 32-bit destination register operand `redVal`. When `.red` qualifier is specified, `.num` modifier must be at least `.x2`.

The optional qualifier `.pack::16b` can be used to pack two 16-bit elements from adjacent columns into a single 32-bit element during the load as shown in the section *Packing and Unpacking*.

The mandatory `.sync` qualifier indicates that `tcgen05.ld` causes the executing thread to wait until all threads in the warp execute the same `tcgen05.ld` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `tcgen05.ld` instruction. In conditionally executed code, a `tcgen05.ld` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of `tcgen05.ld` is undefined if all threads do not use the same values of `taddr`, or if any thread in the warp has exited.

The instruction `tcgen05.ld` is performed asynchronously and more details are specified in the section *Memory Consistency Model for 5th generation of TensorCore operations*.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

`tcgen05.ld.red` is introduced in PTX ISA version 8.8.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

`tcgen05.ld.red` is supported on following architectures:

- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_101f` or higher in the same family
  - `sm_103f` or higher in the same family

Examples

```
tcgen05.ld.sync.aligned.32x32b.x2.b32     {r0, r1}, [taddr1];

tcgen05.ld.sync.aligned.16x128b.x4.b32    {r0, r1, r2, r3, r4, r5, r6, r7}, [taddr2];

tcgen05.ld.red.sync.aligned.16x32bx2.x8.u32.max {r0, r1, r2, r3, r4, r5, r6, r7},
                                                 redVal, [taddr3], 16;
```

9.7.16.8.4 Tensorcore 5th Generation Instructions: `tcgen05.st`

`tcgen05.st`

Asynchronous collective store to tensor memory from registers.

Syntax

```
tcgen05.st.sync.aligned.shape1.num{.unpack}.b32    [taddr], r;

tcgen05.st.sync.aligned.shape2.num{.unpack}.b32    [taddr], immHalfSplitoff, r;

.shape1 = { .16x64b, .16x128b, .16x256b, .32x32b }
.shape2 = { .16x32bx2 }
.num    = { .x1, .x2, .x4, .x8, .x16, .x32, .x64, .x128 }
.unpack = { .unpack::16b }
```

Description

Instruction `tcgen05.st` asynchronously stores data from the source register `r` into the *Tensor Memory* at the location specified by the 32-bit address operand `taddr`, collectively across all threads of the warps.

All the threads in the warp must specify the same value of `taddr`, which must be the base address of the collective store operation. Otherwise, the behavior is undefined.

The `.shape` qualifier and the `.num` qualifier together determines the total dimension of the data which is stored to the Tensor Memory. The `.shape` qualifier indicates the base dimension of data to be accessed as described in the *Data Movement Shape*. The `.num` qualifier indicates the repeat factor on the base dimension resulting in the total dimension of the data that is accessed.

The shape `.16x32bx2` performs two accesses into Tensor Memory of the shape `.16x32b`. The base address of the first access is specified by `taddr` and the base address of the second access is specified by `taddr+immHalfSplitoff`, where `immHalfSplitoff` is an immediate argument.

The source operand `r` is a brace-enclosed vector expression consisting of one or more 32-bit registers as per the value of `.shape` and `.num`. The size of the vector for various combinations of `.num` and `.shape` is shown in Table 51.

Table 51: Various-combinations of .num and .shape

.num	.shape		
	.16x32bx2 / .16x64b / .32x32b	.16x128b	.16x256b
.x1	1	2	4
.x2	2	4	8
.x4	4	8	16
.x8	8	16	32
.x16	16	32	64
.x32	32	64	128
.x64	64	128	NA
.x128	128	NA	NA

The optional qualifier `.unpack::16b` can be used to unpack a 32-bit element in the register into two 16-bit elements and store them in adjacent columns as shown in the section *Packing and Unpacking*.

The mandatory `.sync` qualifier indicates that `tcgen05.st` causes the executing thread to wait until all threads in the warp execute the same `tcgen05.st` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `tcgen05.st` instruction. In conditionally executed code, a `tcgen05.st` instruction should only be used if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.

The behavior of `tcgen05.st` is undefined if all threads do not use the same values of `taddr`, or if any thread in the warp has exited.

The instruction `tcgen05.st` is performed asynchronously and more details are specified in the section *Memory Consistency Model for 5th generation of TensorCore operations*.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
tcgen05.st.sync.aligned.16x64b.x4.b32                [taddr0], {r0,  r1,  r2,  r3};

tcgen05.st.sync.aligned.16x128b.x1.unpack::16b.b32  [taddr1], {r0,  r1};
```

9.7.16.8.5 Tensorcore 5th Generation Instructions: `tcgen05.wait`

`tcgen05.wait`

Waits for the completion of all prior asynchronous `tcgen05.ld` / `tcgen05.st` instructions.

Syntax

```
tcgen05.wait_operation.sync.aligned;

.wait_operation = { .wait::ld, .wait::st }
```

Description

Instruction `tcgen05.wait::st` causes the executing thread to block until all prior `tcgen05.st` operations issued by the executing thread have completed.

Instruction `tcgen05.wait::ld` causes the executing thread to block until all prior `tcgen05.ld` operations issued by the executing thread have completed.

The mandatory `.sync` qualifier indicates that `tcgen05.wait_operation` causes the executing thread to wait until all threads in the warp execute the same `tcgen05.wait_operation` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warp must execute the same `tcgen05.wait_operation` instruction.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
Example 1:

tcgen05.ld.sync.aligned.32x32b.x2.b32     {r0, r1}, [taddr0];

// Prevents subsequent tcgen05.mma from racing ahead of the tcgen05.ld

tcgen05.wait::ld.sync.aligned;

tcgen05.mma.cta_group::1.kind::f16   [taddr0],  a-desc,  b-desc, idesc, p;

Example 2:

tcgen05.st.sync.aligned.32x32b.x2.b32     [taddr0], {r0, r1};

// Prevents the write to taddr0 in tcgen05.mma from racing ahead of the tcgen05.st

tcgen05.wait::st.sync.aligned;

tcgen05.mma.cta_group::1.kind::f16   [taddr0],  a-desc,  b-desc, idesc, p;
```

9.7.16.9 Tensor Memory Data Movement Instructions

Data from the shared memory can be copied asynchronously to the *Tensor Memory* using the *Tensor-core 5th Generation Instructions: tcgen05.cp* operation.

9.7.16.9.1 Optional Decompression

Optionally, during the copy, a vector of 4-bit and 6-bit custom floating point types can be decompressed into 8-bit types.

9.7.16.9.1.1 Decompression of 4-bit floating point to 8-bit type

A contiguous set of 16 elements of 4-bits each followed by 8 bytes of padding can be converted into 16 elements of 8-bits each as shown in Figure 194.

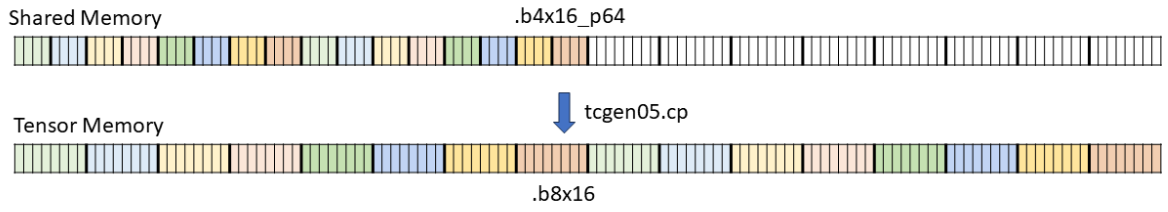

Figure 194: Decompression from 4-bit to 8-bit

The individual 4-bit to 8-bit decompression would look like as shown in Figure 195.

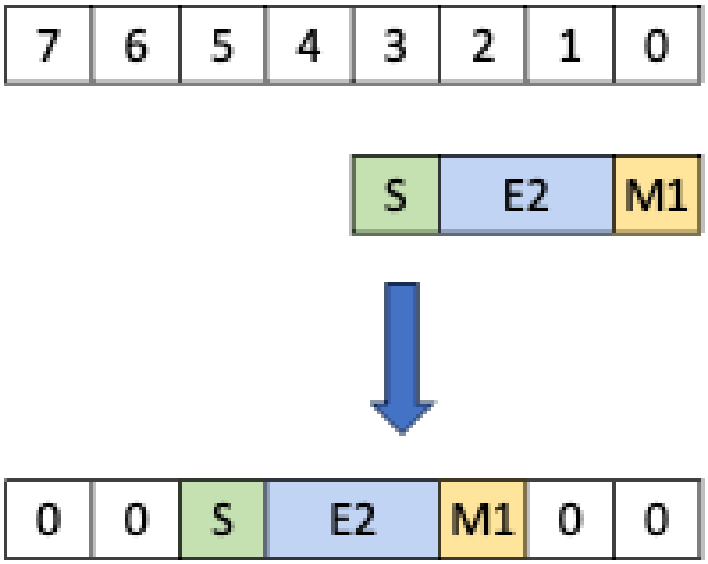

Figure 195: Individual decompression from 4-bit to 8-bit

9.7.16.9.1.2 Decompression of 6-bit floating point to 8-bit type

A contiguous set of 16 elements of 6-bits each followed by 4 bytes of padding is decompressed into 16 elements of 8-bits each as shown in Figure 196.

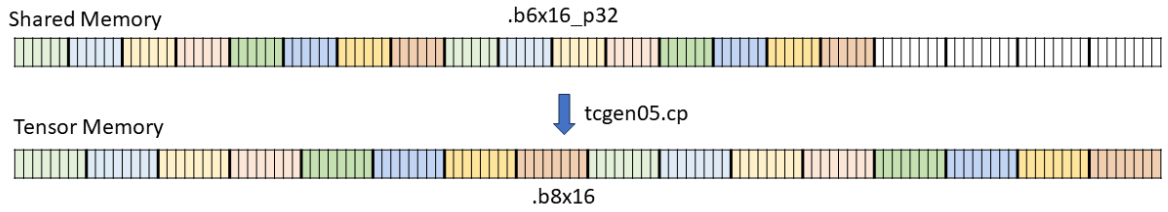

Figure 196: Decompression from 6-bit to 8-bit

The individual 6-bit to 8-bit decompression for types `E3M2` and `E2M3` is shown in Figure 197 and Figure 198 respectively.

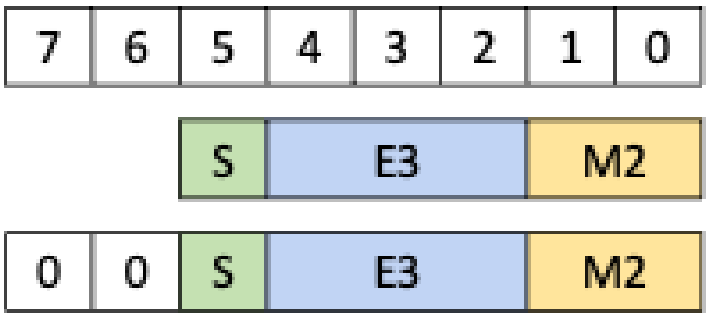

Figure 197: Individual decompression from 6-bit to 8-bit for E3M2 type

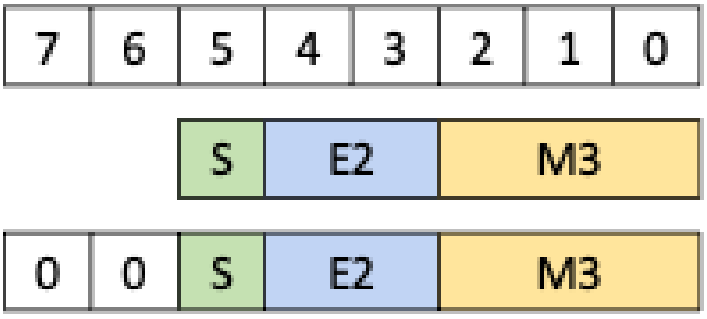

Figure 198: Individual decompression from 6-bit to 8-bit for E2M3 type

9.7.16.9.2 Tensorcore 5th Generation Instructions: `tcgen05.cp`

`tcgen05.cp`

Initiates an asynchronous copy operation from shared memory to the *Tensor Memory*.

Syntax

```
tcgen05.cp.cta_group.shape{.multicast}{.dst_fmt.src_fmt} [taddr], s-desc;

.cta_group = { .cta_group::1, .cta_group::2 }
.src_fmt   = { .b6x16_p32 , .b4x16_p64 }
.dst_fmt   = { .b8x16 }
.shape     = { .128x256b, .4x256b, .128x128b, .64x128b**, .32x128b*** }
.multicast = { .warpx2::02_13** , .warpx2::01_23**, .warpx4*** }
```

Description

Instruction `tcgen05.cp` initiates an asynchronous copy operation from shared memory to the location specified by the address operand `taddr` in the *Tensor Memory*.

The 64-bit register operand `s-desc` is the matrix descriptor which represents the source matrix in the shared memory that needs to be copied. The format of the matrix descriptor is described in *Matrix Descriptors*.

The `.shape` qualifier indicates the dimension of data to be copied as described in the *Data Movement Shape*.

Qualifier `.cta_group` specifies the number of CTAs whose *Tensor Memory* is accessed when a single thread of a single CTA executes the `tcgen05.cp` instruction. When `.cta_group::1` is specified, the data is copied into the *Tensor Memory* of the current CTA. When `.cta_group::2` is specified, the data is copied into the *Tensor Memory* of both the current and the *peer CTAs*.

When the qualifiers `.dst_fmt` and `.src_fmt` are specified, the data is decompressed from the source format `.src_fmt` in the shared memory to the destination format `.dst_fmt` in *Tensor Memory* by the copy operation. The details of source and the destination formats as specified in the section *Optional Decompression*.

Some of the `.shape` qualifiers require certain `.multicast` qualifiers.

1. `.64x128b` requires `.warpx2::02_13` or `.warpx2::01_23`
2. `.32x128b` requires `.warpx4`

When the `.multicast` qualifier is specified as either `.warpx2::02_13` or `.warpx2::01_23` then the data being copied is multicasted into warp pairs and each warp in the warp pair receive half of the data. Warp pairs are formed as follows:

1. `.warpx2::02_13` : warps 0 and 2 form a pair; warps 1 and 3 form a pair.
2. `.warpx2::01_23` : warps 0 and 1 form a pair; warps 2 and 3 form a pair.

When the `.multicast` modifier is specified as `.warpx4` then the data being copied is multicasted into all 4 warps.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
tcgen05.cp.cta_group::1.128x256b                  [taddr0], sdesc0;
tcgen05.cp.cta_group::2.128x128b.b8x16.b6x16_p32 [taddr1], sdesc1;
tcgen05.cp.cta_group::1.64x128b.warpx2::02_13     [taddr2], sdesc2;
```

9.7.16.9.3 Tensorcore 5th Generation Instructions: `tcgen05.shift`

`tcgen05.shift`

Asynchronously shift down the rows of the matrix in the *Tensor Memory* for a warp.

Syntax

```
tcgen05.shift.cta_group.down  [taddr];

.cta_group = { .cta_group::1, .cta_group::2 }
```

Description

Instruction `tcgen05.shift` is an asynchronous instruction which initiates the shifting of 32-byte elements downwards across all the rows, except the last, by one row. The address operand `taddr` specifies the base address of the matrix in the *Tensor Memory* whose rows must be down shifted.

The lane of the address operand `taddr` must be aligned to 32.

Qualifier `.cta_group` specifies the number of CTAs whose *Tensor Memory* is touched when a single thread of a single CTA executes the `tcgen05.shift` instruction. When `.cta_group::1` is specified, the shift operation is performed in the *Tensor Memory* of the current CTA. When `.cta_group::2` is specified, the shift operation is performed in the *Tensor Memory* of both the current and the *peer CTAs*.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- `sm_103a`

Examples

```
tcgen05.shift.down.cta_group::1 [taddr0];
tcgen05.shift.down.cta_group::2 [taddr1];
```

9.7.16.10 TensorCore 5th Generation Matrix Multiply and accumulate Operations

The 5th generation of TensorCore operations of shape *MxNxK* perform matrix multiplication and accumulation of the form:

`D = A*B+D`

where:

- the `A` matrix has shape *MxK*, in either Tensor Memory or Shared Memory
- the `B` matrix has shape *KxN*, in Shared Memory of the current CTA and optionally in peer CTA
- the `D` matrix is of the shape *MxN*, in Tensor Memory

Optionally an input predicate can be used to disable the input from the accumulator matrix and the following operation can be performed as

`D = A*B`

The matrix multiplication and accumulation operations are categorized into various kinds based on input types and the throughput of the multiplication operation. The following shows the different kinds of MMA operations that are supported:

1. `f16` : supports `f16` and `bf16` input types.
2. `tf32` : supports `tf32` input types.
3. `f8f6f4` : supports all input combinations of `f8`, `f6` and `f4` types.
4. `i8` : supports signed and unsigned 8-bit integer input types.
5. `mxf8f6f4/mxf4` : supports mx-floating points input types.
6. `mxf4nvf4` : supports `mxf4` type and a custom NVIDIA floating-point type for inputs where the type of the vector elements is 4 bits and requires a common scaling factor to form the complete floating-point type, similar to other mx-types.

Optionally, the 5th generation of TensorCore MMAs support dense and sparse matrix A. *Sparse Matrices* describes the details of the sparse matrices.

Some of the MMA-kinds requires scaling of input matrices from memory to form the matrix A and matrix B before performing the MMA operation. *Block Scaling* describes the details of the scaling of matrices.

The following table show the various matrices involved in the MMA operations and the memory in which they can reside:

Matrix Type	Memory
A	Tensor Memory OR Shared Memory
B	Shared Memory
D	Tensor Memory
Sparse Meta Data	
A-Scale / B-Scale	

A sequence of MMA instructions may reuse the same A matrix with a sequence of B matrices or may reuse the same B matrix with a sequence of A matrices. In these patterns the TensorCore may be able to laod the unchanged matrix once and reuse it through the sequence without multiple reloads. The A or B matrices are loaded into a TensorCore collector buffer (i.e., special cache).

An MMA instruction has an optional `collector` qualifier to specify when an A or B matrix is new to the sequence and should be loaded, unchanged within the sequence and should be reused, or the last use in the sequence and should be discarded. The `collector` qualifier is used to give the TensorCore permission to reuse a previously loaded A or B matrix; however reuse is opportunistic in that the TensorCore may reload a matrix even when it has permission to reuse that matrix. Thus, the source memory of an A or B matrix must not be modified while the MMA instruction using those matrices has not completed - regardless of `collector` qualifier permissions.

The 5th generation of TensorCore MMAs can be used for general matrix multiplication OR for convolution operations. In case of convolutions, the activations can be stored in either matrix A or matrix B while the weights will be stored in the other matrix.

Activation Matrix	Weights Matrix	Name of the op	Instruction Name	Collector Buffer Applicability
A	B	Activation Stationary	(default `tcgen05.mma`)	Collector buffer is applicable on matrix A
B	A	Weights Stationary	`.ws`	Collector buffer is applicable on matrix B

9.7.16.10.1 Transpose and Negate operations

The matrices A and B can be transposed by specifying the Tranpose A Matrix and Transpose B Matrix bits in the instruction descriptor respectively.

The elements of the matrices A and B can be negated by specifying the Negate A Matrix and Negate B Matrix bits in the instruction descriptor respectively.

The support for Transpose and Negate operation for various MMA-Kind are shown in Table 52.

Table 52: Transpose and Negate operation for various MMA-Kind

MMA-Kind	Is Transpose A/B supported	Is Negate A/B supported
`.kind::tf32`	Yes	Yes
`.kind::f16`	Yes	Yes
`.kind::f8f6f4`	Yes	Yes
`.kind::mxf8f6f4`	Yes	Yes
`.kind::i8`	Yes	No
`.kind::mxf4`	No	Yes
`.kind::mxf4nvf4`	No	Yes

For `.kind::tf32`, the transpose operations on matrices A and B are supported only with 128B swizzling mode with 32B swizzle-atomicity.

For all other MMA-Kinds, the transpose operations on matrices A and B are not supported on 128B swizzling mode with 32B swizzle-atomicity.

9.7.16.10.2 Matrix Layout Organization

Table 53 describes the major-ness used for different matrices.

Table 53: Major-ness for different matrices

Matrix	Residing in Memory	Default Major-ness
D	Tensor Memory	Row-Major
A	Tensor Memory	
	Shared Memory	Depends on swizzling mode. Refer *Shared Memory Layout and Swizzling*
B	Shared Memory	

9.7.16.10.3 Valid Combinations of Type-Size, Major-ness and Swizzling

Table 54: Valid Combinations of Type-Size, Major-ness and Swizzling

Type-Size	Major-ness	Matrix	Supported Swizzle
4-bit, 6-bit, 8-bit, 16-bit, 32-bit	Row	A	All swizzling modes
	Column	B	
8-bit 16-bit	Column (transpose)	A	All except 128B swizzling with 32B atomicity
	Row (transpose)	B	
32-bit	Column (transpose)	A	Only 128B swizzling with 32B atomicity
	Row (transpose)	B	

9.7.16.10.4 Packing formats of elements in Tensor and Shared memory

9.7.16.10.4.1 Packing format for matrix D in Tensor Memory

The sub-word elements of matrix D are expected not to be packed within a 32-bit Tensor Memory word. For example, if the type of elements of the matrix D is 16 bits then a Tensor Memory word would contain a single 16-bit element in its lower 16 bits.

9.7.16.10.4.2 Packing format for matrix A and B

The 6-bit and 4-bit floating point types have different packing format requirements for different MMA kinds in both Tensor memory and Shared memory. The requirements are as follows.

9.7.16.10.4.3 Packing format used for matrix A by `.kind::mxf8f6f4` in Tensor Memory

The individual 4-bit and the 6-bit floating point type elements must be packed in an 8-bit container in Tensor memory as shown below. The 8-bit containers must be contiguously packed in a 32-bit Tensor Memory word. For example, if the type of elements of the matrix A is 6 bits then 4 consecutive A elements should be packed in one 32-bit Tensor Memory word.

- 4-bit packing format as shown in Figure 199
- 6-bit packing format
  - Type E3M2 as shown in Figure 200
  - Type E2M3 as shown in Figure 201

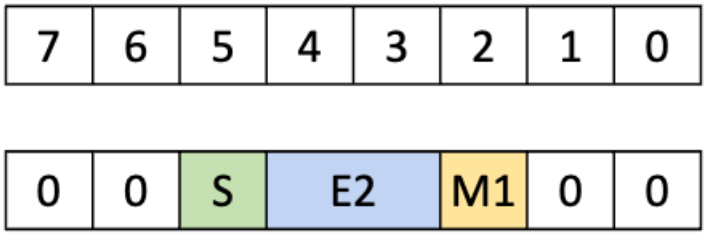

Figure 199: 4-bit packing format with type E2M1

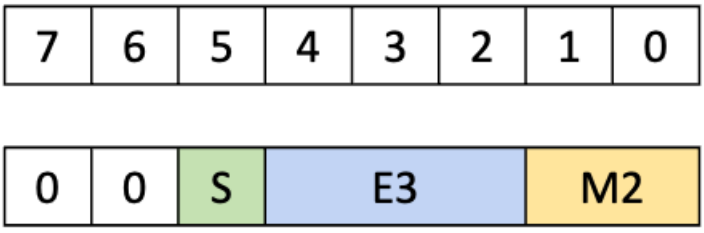

Figure 200: 6-bit packing format with type E3M2

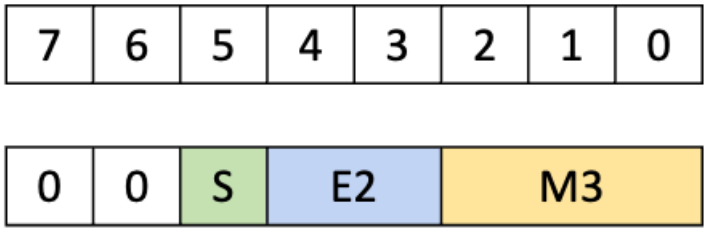

Figure 201: 6-bit packing format with type E2M3

9.7.16.10.4.4 Packing format used for matrix A and B by `.kind::mxf8f6f4` in Shared Memory

The 4-bit and 6-bit floating point elements in shared memory must be contiguously packed along with padding as follows.

- 4-bit packing format as shown in Figure 202

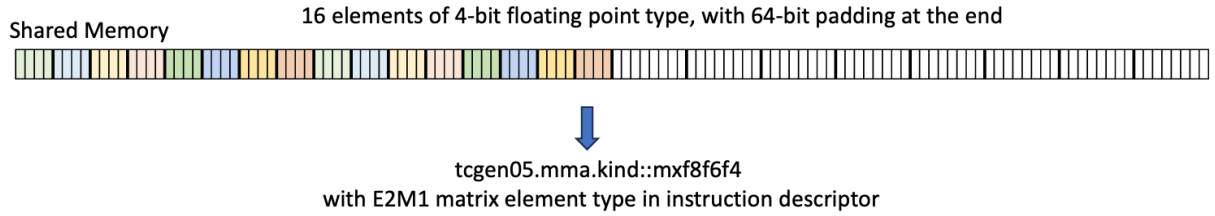

Figure 202: 4-bit packing format

- 6-bit packing format as shown in Figure 203

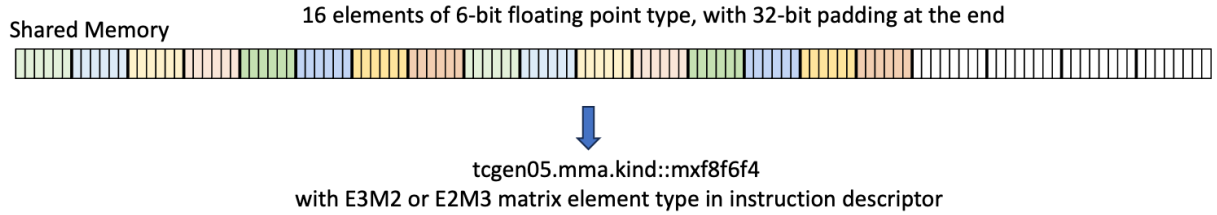

Figure 203: 6-bit packing format

9.7.16.10.4.5 Packing format used for matrix A by `.kind::mxf4` and `.kind::mxf4nvf4` in Tensor Memory

Two 4-bit floating point type elements must be packed in an 8-bit container in Tensor memory as shown in Figure 204 for `mxf4`.

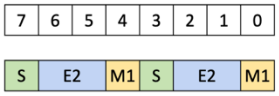

Figure 204: 4-bit packing format with type E2M1

9.7.16.10.4.6 Packing format used for matrix A and B by `.kind::mxf4` and `.kind::mxf4nvf4` in Shared Memory

The packing format for 4-bit floating point elements in shared memory is to pack two 4-bit elements in a 8-bit container, with no padding.

9.7.16.10.5 Data Path Layout Organization

Different MMA variants access the tensor memory with different layout organization. The following table lists the various layouts:

M	cta_group	A-Sparsity	Is .ws mode	Datapath organization	Layout ID	Tensor Memory Datapath Lane Alignment
32	::1	Either	Yes	1x4	*Layout G*	0
64	::1	Either	Yes	2x3	*Layout E*	0
64	::1	Either	No	4x1 (1/2 datapath utilized)	*Layout F*	0 or 16
128	::1	Either	Either	4x1	*Layout D*	0
128	::2	Dense	N/A	2x2	*Layout B*	0
128	::2	Sparse	N/A	4x1 (1/2 datapath utilized)	*Layout C*	0 or 16
256	::2	Either	N/A	4x1	*Layout A*	0

The layouts which utilize only half the datapath lanes, i.e., *Layout F* and *Layout C*, must use the same Tensor Memory lane alignment across matrices A, D and the sparsity metadata matrix.

The following shows the warps that can access the Tensor Memory regions via `tcgen05.ld` / `tcgen05.st` along with the addresses for various Tensor Memory Layouts.

9.7.16.10.5.1 Layout A (M = 256)

Layout organization for M = 256 is shown in Figure 205.

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 206

A Matrix	B Matrix 0 to N-1
M 0-31	warp-rank % 4 == 0 + Even CTA in CTA-Pair
M 32-63	warp-rank % 4 == 1 + Even CTA in CTA-Pair
M 64-95	warp-rank % 4 == 2 + Even CTA in CTA-Pair
M 96-127	warp-rank % 4 == 3 + Even CTA in CTA-Pair
M 128-159	warp-rank % 4 == 0 + Odd CTA in CTA-Pair
M 160-191	warp-rank % 4 == 1 + Odd CTA in CTA-Pair
M 192-223	warp-rank % 4 == 2 + Odd CTA in CTA-Pair
M 224-255	warp-rank % 4 == 3 + Odd CTA in CTA-Pair

Figure 205: Layout organization for M = 256

A Matrix	B Matrix 0 to N-1
M 0-31	0x0000.0XXX
M 32-63	0x0020.0XXX
M 64-95	0x0040.0XXX
M 96-127	0x0060.0XXX
M 128-159	0x0080.0XXX
M 160-191	0x00A0.0XXX
M 192-223	0x00C0.0XXX
M 224-255	0x00E0.0XXX

Figure 206: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.5.2 Layout B (M = 128 + cta-group::2 + Dense A matrix)

Layout organization for M = 128 + .cta_group::2 + Dense A matrix is shown in Figure 207.

		B Matrix 0 to (N/2)-1	B Matrix (N/2) to N-1
A Matrix	M 0-31	warp-rank % 4 == 0 + Even CTA in CTA-Pair	warp-rank % 4 == 2 + Even CTA in CTA-Pair
	M 32-63	warp-rank % 4 == 1 + Even CTA in CTA-Pair	warp-rank % 4 == 3 + Even CTA in CTA-Pair
	M 64-95	warp-rank % 4 == 0 + Odd CTA in CTA-Pair	warp-rank % 4 == 2 + Odd CTA in CTA-Pair
	M 96-127	warp-rank % 4 == 1 + Odd CTA in CTA-Pair	warp-rank % 4 == 3 + Odd CTA in CTA-Pair

Figure 207: Layout organization for M = 128 + .cta_group::2 + Dense A matrix

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 208

		B Matrix 0 to (N/2)-1	B Matrix (N/2) to N-1
A Matrix	M 0-31	0x0000.0XXX	0x0000.0XXX
	M 32-63	0x0020.0XXX	0x0020.0XXX
	M 64-95	0x0040.0XXX	0x0040.0XXX
	M 96-127	0x0060.0XXX	0x0060.0XXX

Figure 208: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.5.3 Layout C (M = 128 + cta-group::2 + Sparse A matrix)

Layout organization for M = 128 + .cta_group::2 + Sparse A matrix is shown in Figure 209.

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 210

9.7.16.10.5.4 Layout D (M = 128 + cta-group::1)

Layout organization for M = 128 + .cta_group::1 is shown in Figure 211.

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 212

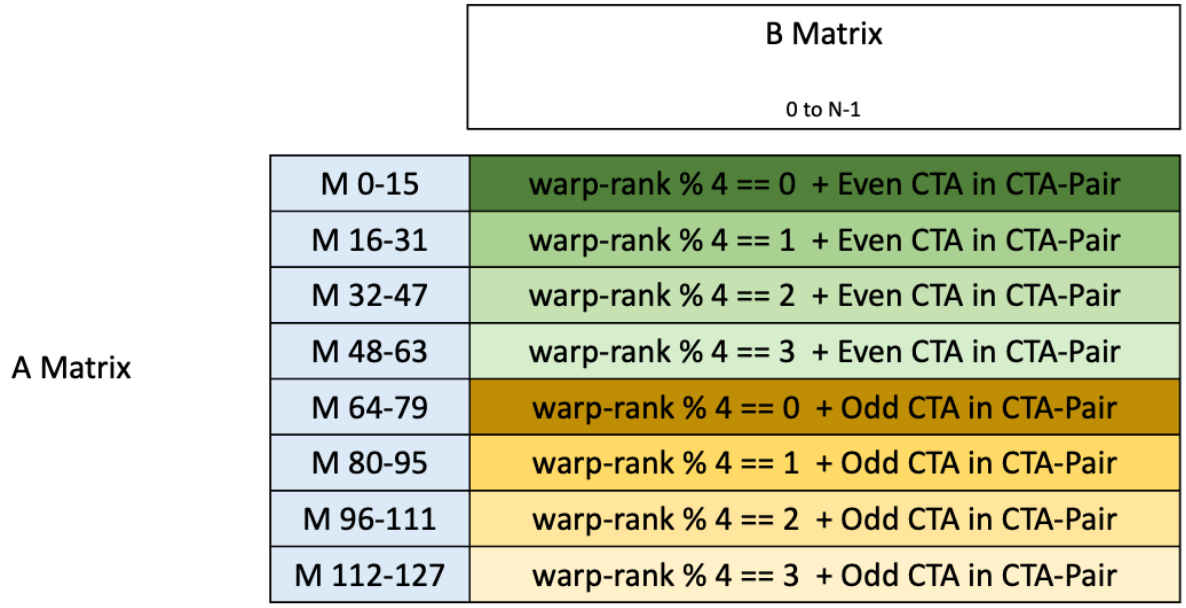

Figure 209: Layout organization for M = 128 + .cta_group::2 + Sparse A matrix

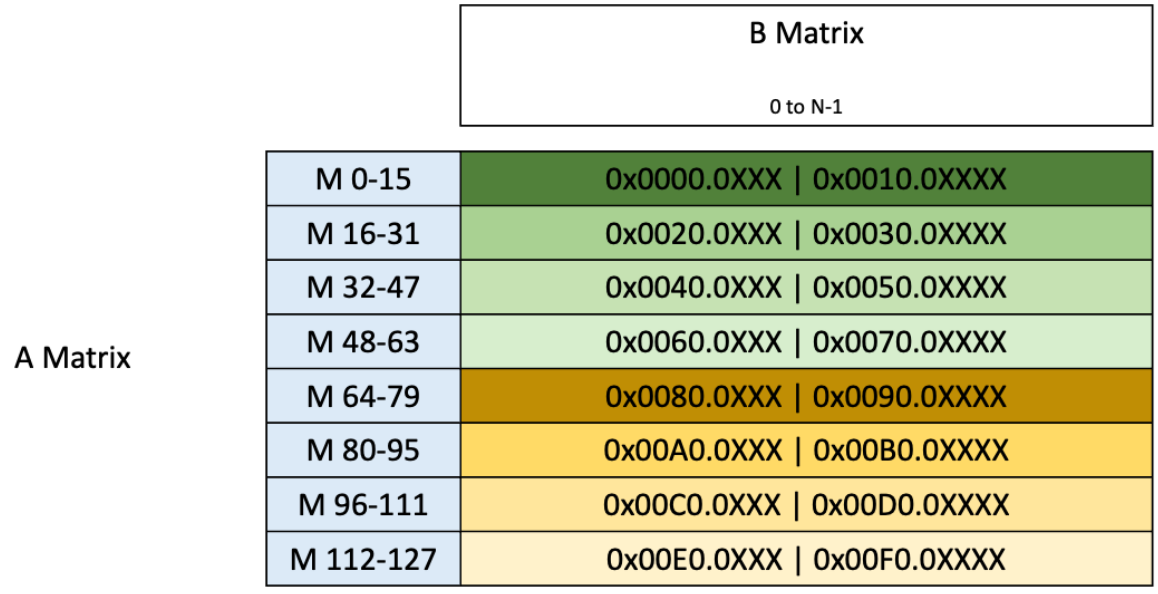

Figure 210: Addresses to use in `tcgen05.ld` / `tcgen05.st`

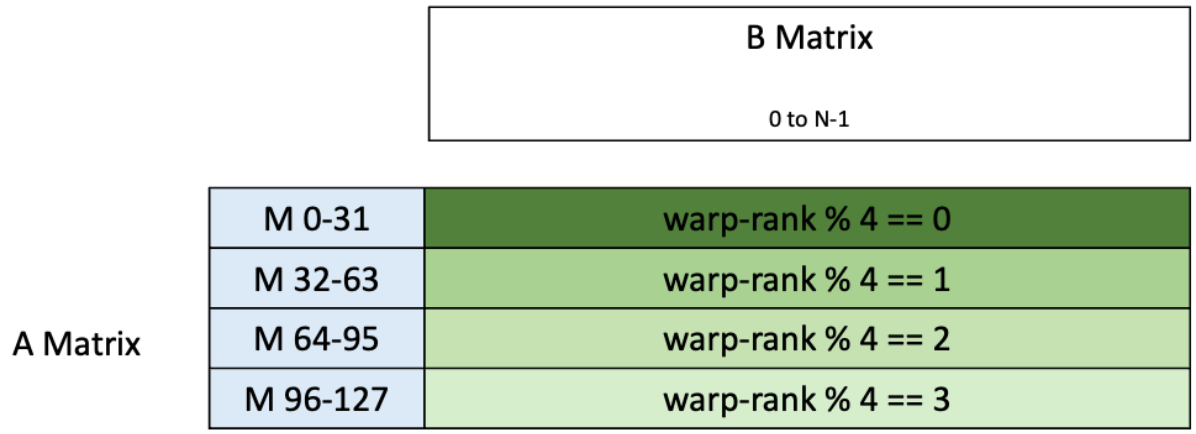

Figure 211: Layout organization for M = 128 + .cta_group::1

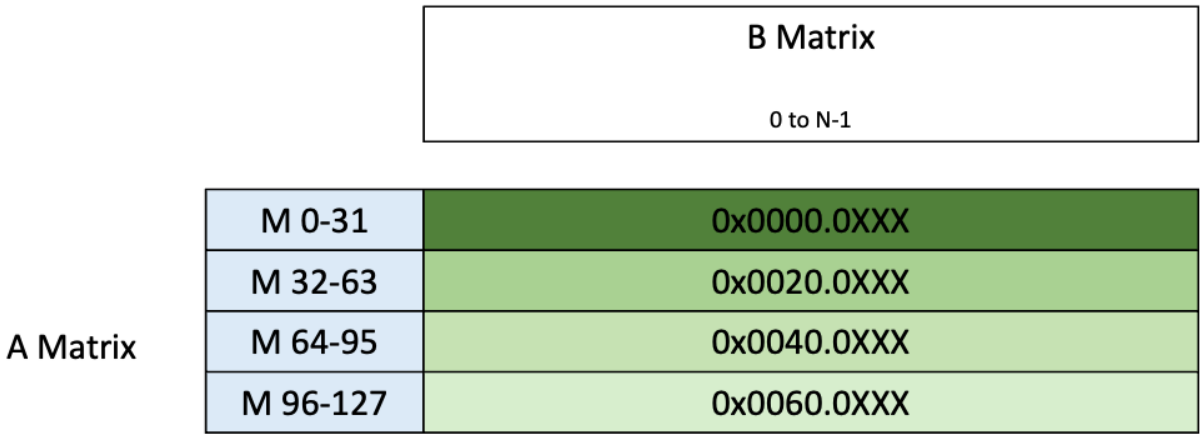

Figure 212: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.5.5 Layout E (M = 64 + .ws mode)

Layout organization for M = 64 + .ws mode is shown in Figure 213.

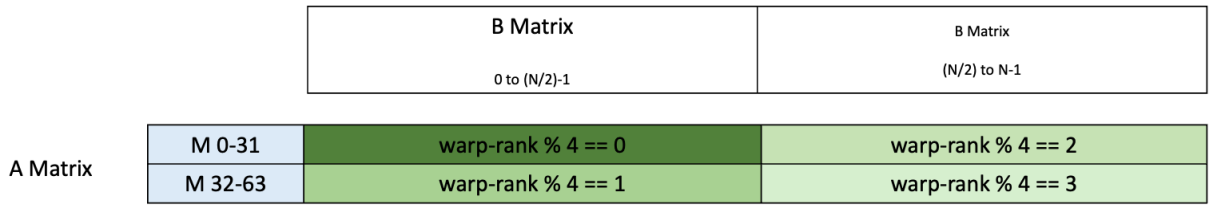

Figure 213: Layout organization for M = 64 + .ws mode

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 214

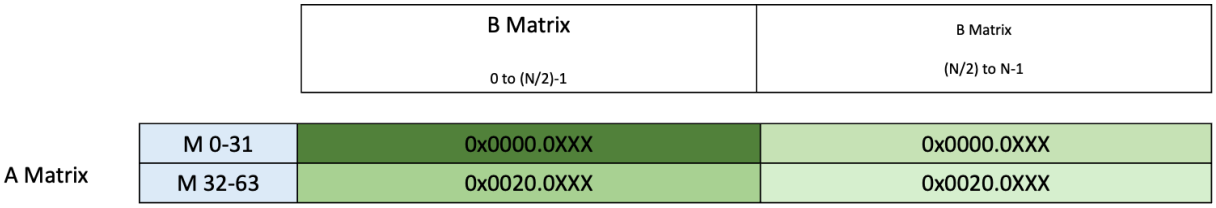

Figure 214: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.5.6 Layout F (M = 64 + non .ws mode)

Layout organization for M = 64 + non .ws mode is shown in Figure 215.

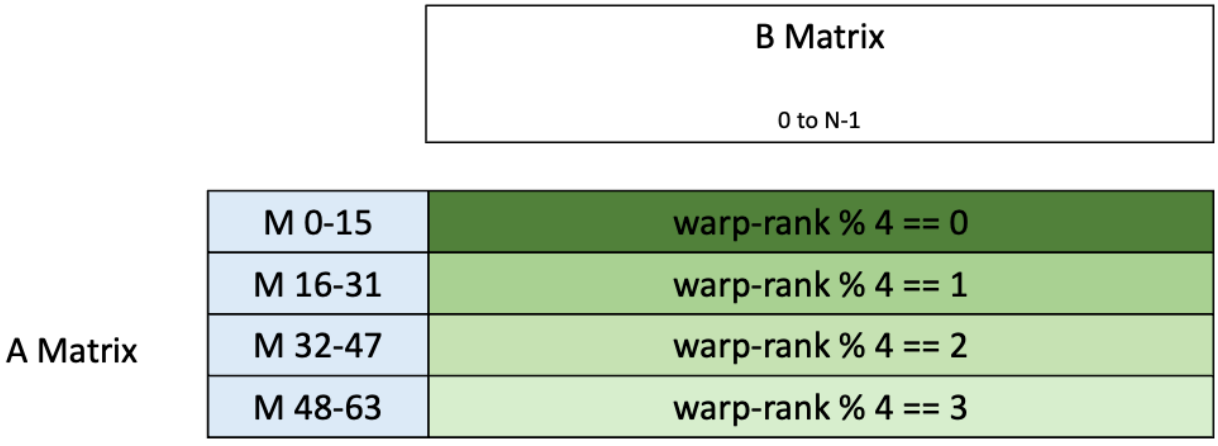

Figure 215: Layout organization for M = 64 + non .ws mode

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 216

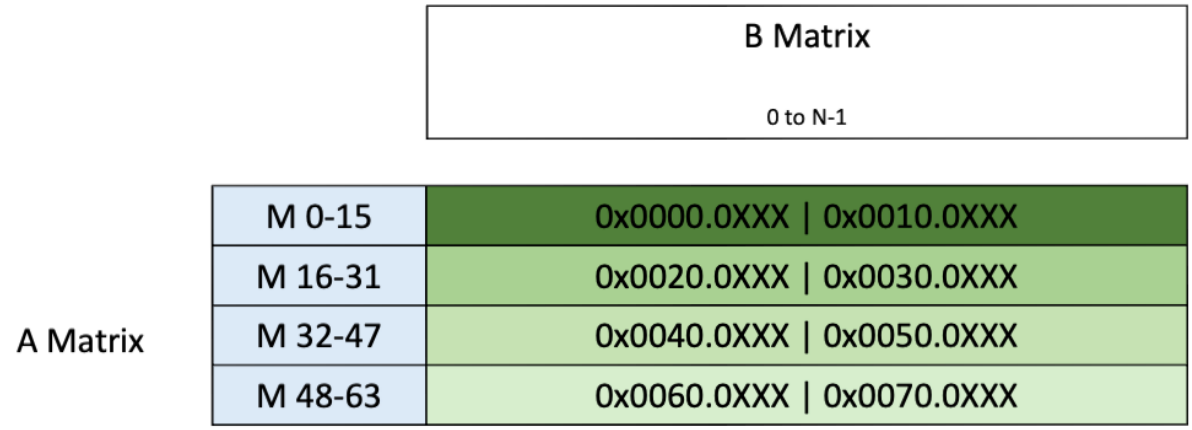

Figure 216: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.5.7 Layout G (M = 32)

Layout organization for M = 32 is shown in Figure 217.

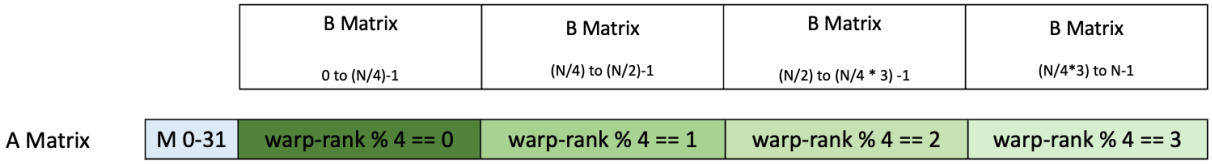

Figure 217: Layout organization for M = 32

Addresses for the above region to be used in `tcgen05.ld` / `tcgen05.st` is shown in Figure 218

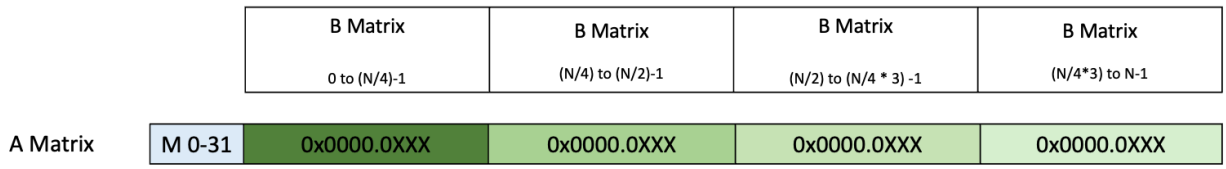

Figure 218: Addresses to use in `tcgen05.ld` / `tcgen05.st`

9.7.16.10.6 Shared Memory Layout and Swizzling

If the bit `Transpose A Matrix` / `Transpose B Matrix` in the *Instruction descriptor* is 0, then *K-major* is used for matrix A / B respectively. If the bit `Transpose A Matrix` in the *Instruction descriptor* is 1 then *M-major* is used for matrix A. If the bit `Transpose B Matrix` in the *Instruction descriptor* is 1, then *N-major* is used for matrix B.

In a column-major default BLAS library such as cuBLAS, the matrices A and B with and without transpose can be classified as either *K-Major* or *M-or-N-Major* as shown in the following table:

	Non-Transposed	**Transposed**
A	K-major	M-major
B	K-major	N-major

To avoid confusion with A, B, `row-major`, `col-major`, `transpose`, and `non-transpose`, we will use *MN-Major* and *K-Major* throughout this section.

The matrices in the shared memory are made up of one or more “swizzle layout atom”. The exact layout of these swizzle atoms depends on the swizzling mode, swizzle-atomicity, and the leading dimension. The layout of the swizzle are shown in Table 55

Table 55: Layout for swizzle atoms

Swizzling mode and Swizzle-Atomicity	**Leading Dimension**	**Swizzle atom layout (128b element)**
128B Swizzling with 32B atomicity	M/N	8x4
	–	–
128B Swizzling with 16B atomicity	M/N	8x8
	K	8x8
64B Swizzling Mode	M/N	4x8
	K	8x4
32B Swizzling Mode	M/N	2x8
	K	8x2
None	M/N	1x8
	K	8x1

The above shapes are for elements of size 128 bits. For smaller element sizes, the same shapes would get multiplied along the leading dimension by a factor of `128 / sizeof_bits(Element)`. For example, 128B MN major swizzle atom would have a shape of (8*(128/32))x8 = 32x8 for tf32 tensor core inputs.

Some example Layouts of *MxK* or *KxN* matrices with various swizzling modes, and are in units of 128b elements as shown by each colored cell as shown in Figure 219, Figure 220, Figure 221, Figure 222, Figure 223, Figure 224, Figure 225, Figure 226, Figure 227.

Following are some of the examples of the 128B swizzling layout for `tf32` element type.

- K-Major: Figure 228

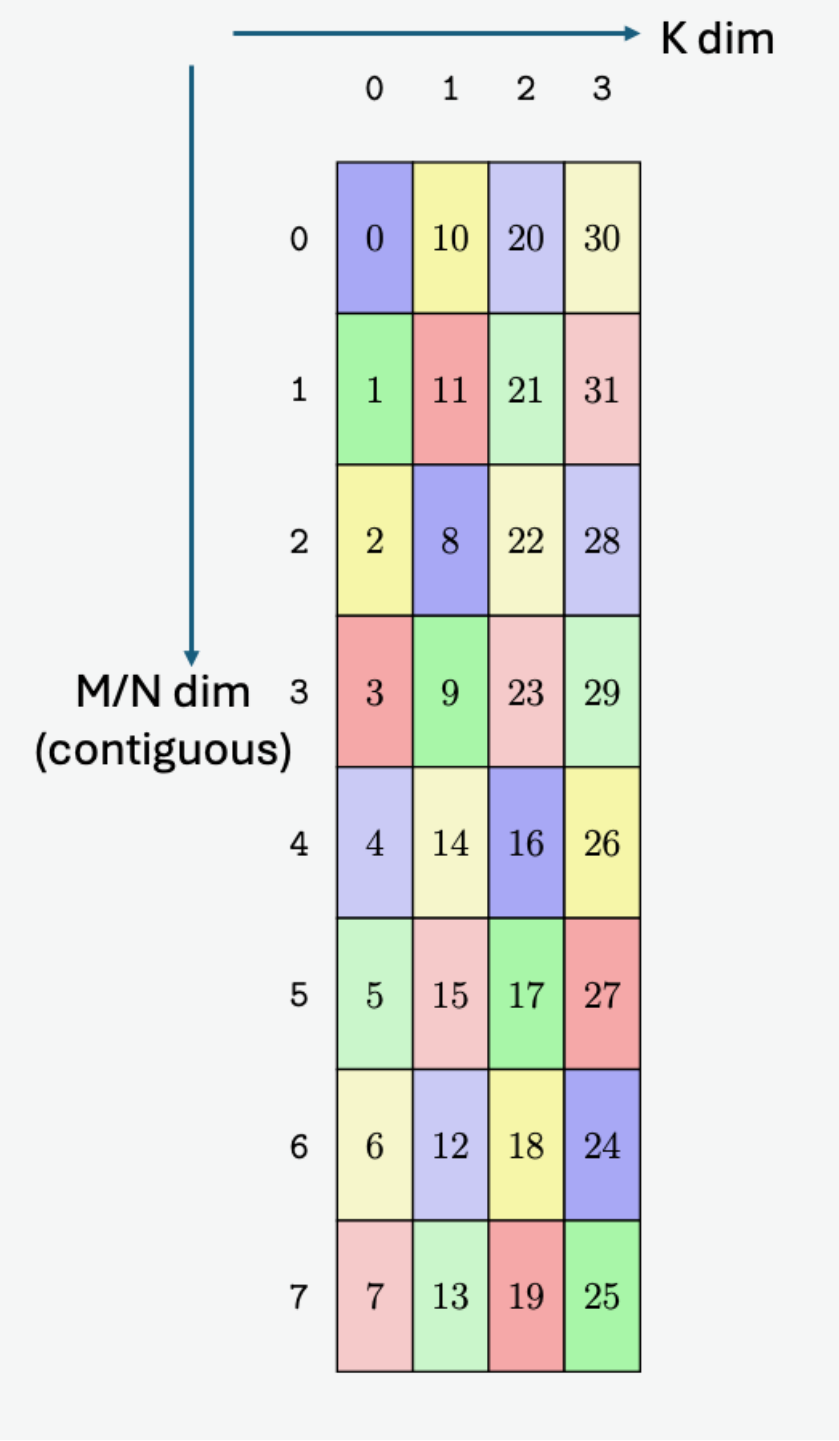

Figure 219: MN major 128B swizzling with 32B atomicity

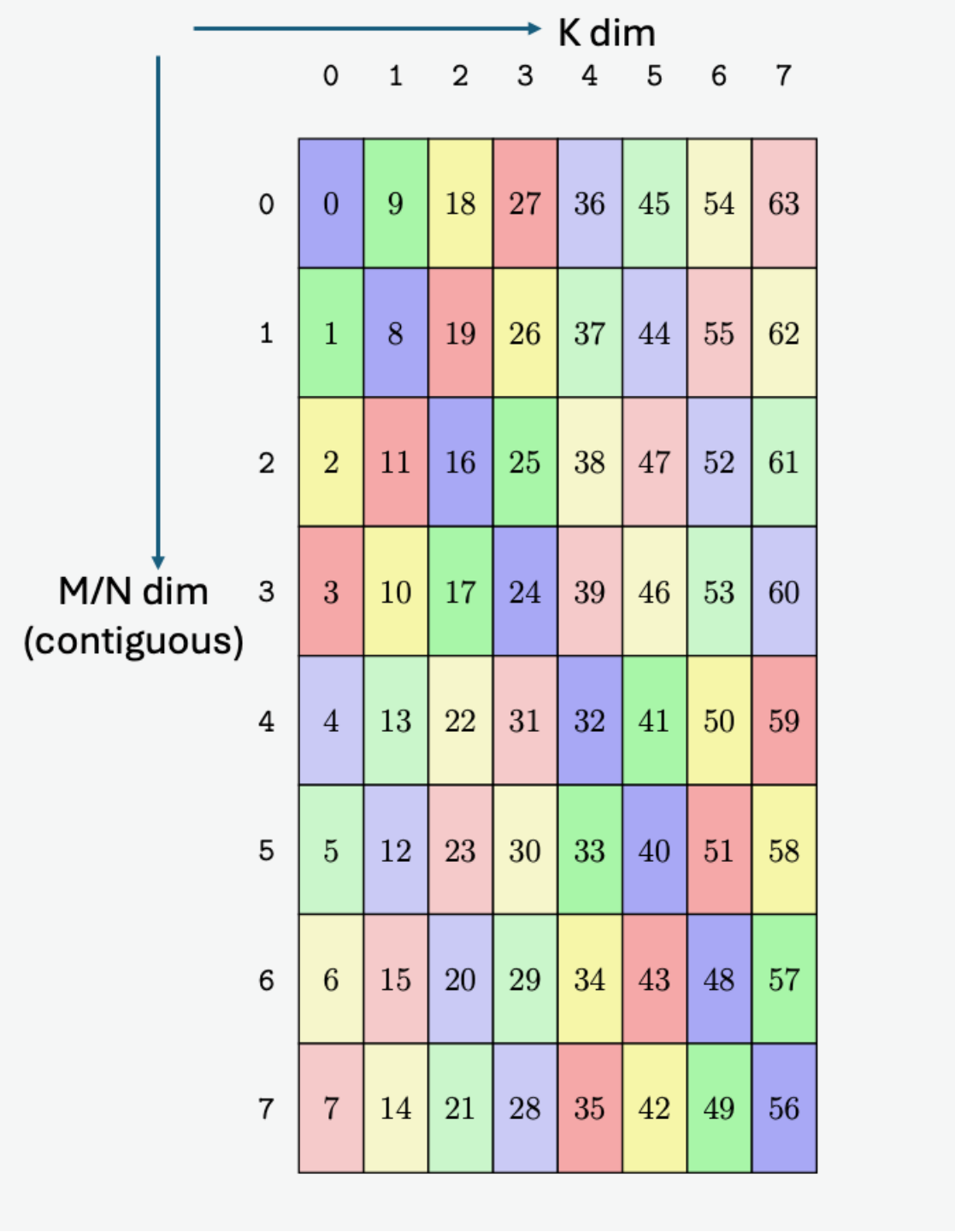

Figure 220: MN major 128B swizzling

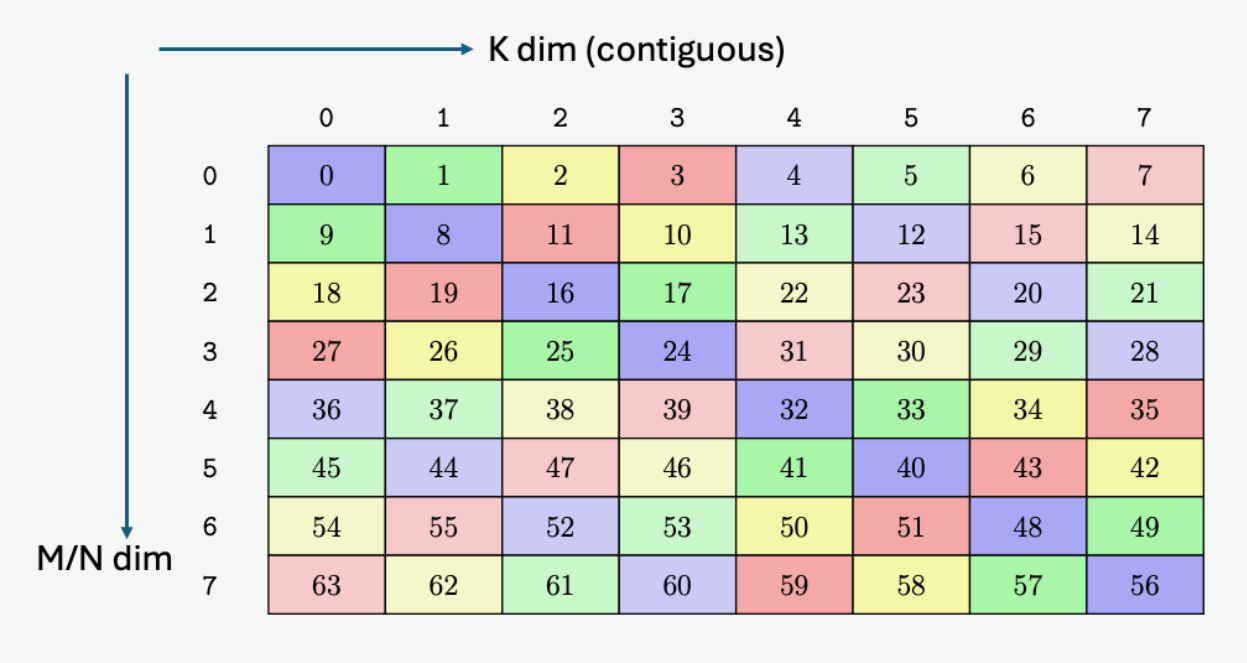

Figure 221: K major 128B swizzling

- MN-Major: Figure 229

9.7.16.10.7 Block Scaling

The `tcgen05.mma` instructions with the following `.kind` qualifier:

- `.kind::mxf8f6f4`
- `.kind::mxf4`
- `.kind::mxf4nvf4`

perform matrix multiplication with block scaling. This operation has the following form:

```
(A * scale_A) * (B * scale_B) + D
```

where `scale_A` and `scale_B` are matrices residing in *Tensor Memory*.

For a `scale_A` matrix of shape *M x SFA_N*, each row of matrix `A` is divided into *SFA_N* number of chunks and each chunk of a row is multiplied with the corresponding element in the *SF_A* of the same row.

Similarly, for a `scale_B` matrix of shape *SFB_M x N*, each column of matrix `B` is divided into the *SFB_M* number of chunks and each chunk of a column is multiplied with the corresponding element in the *SF_B* of the same column.

Figure 230 shows an example of `tcgen05.mma` with block scaling of `scale_vec::2X`.

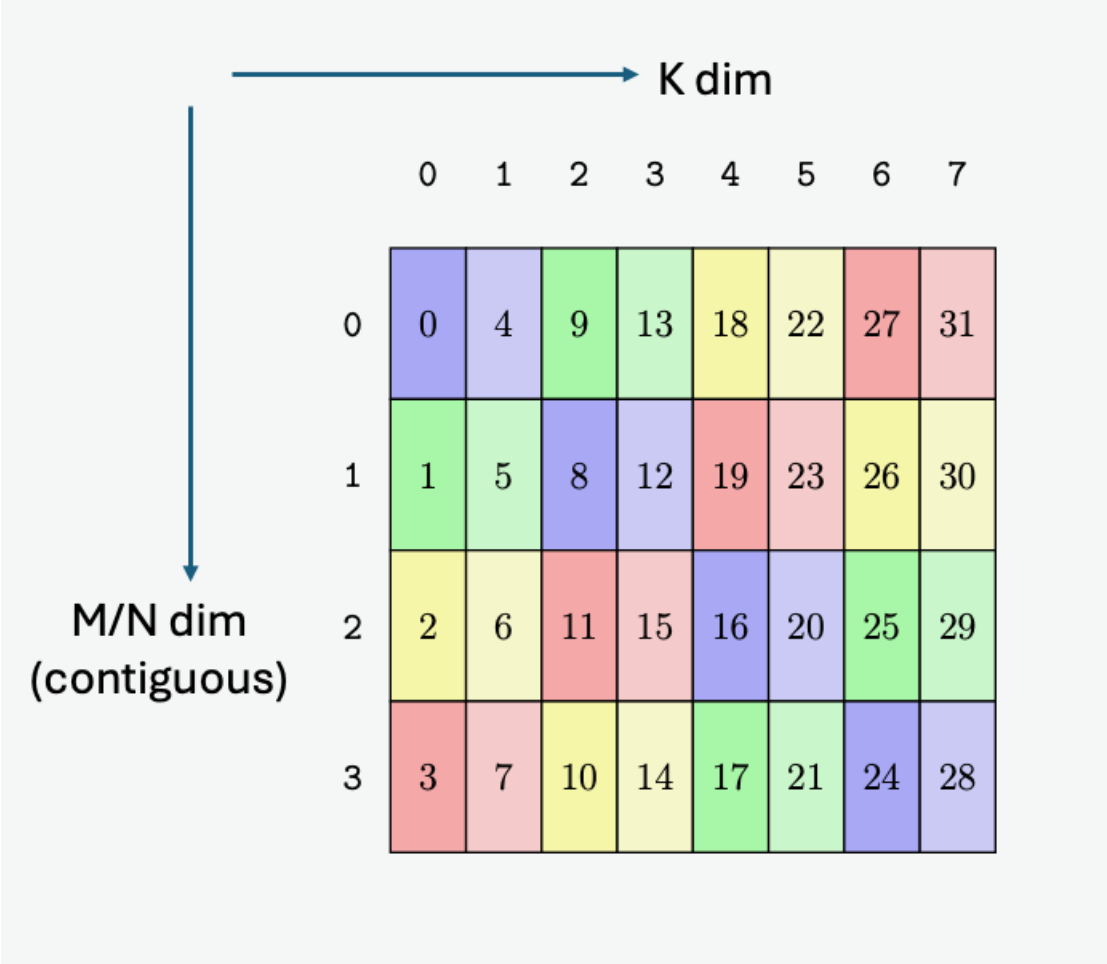

Figure 222: MN major 64B swizzling

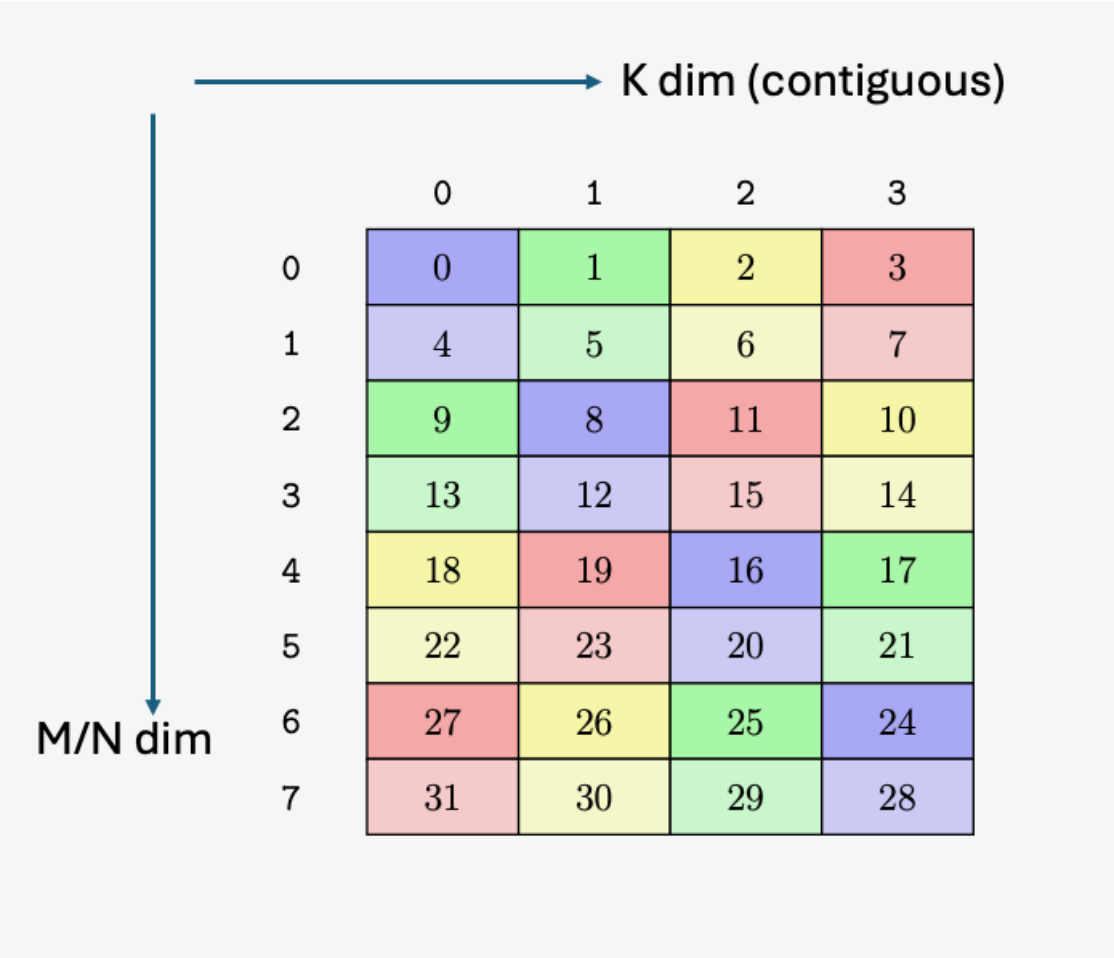

Figure 223: K major 64B swizzling

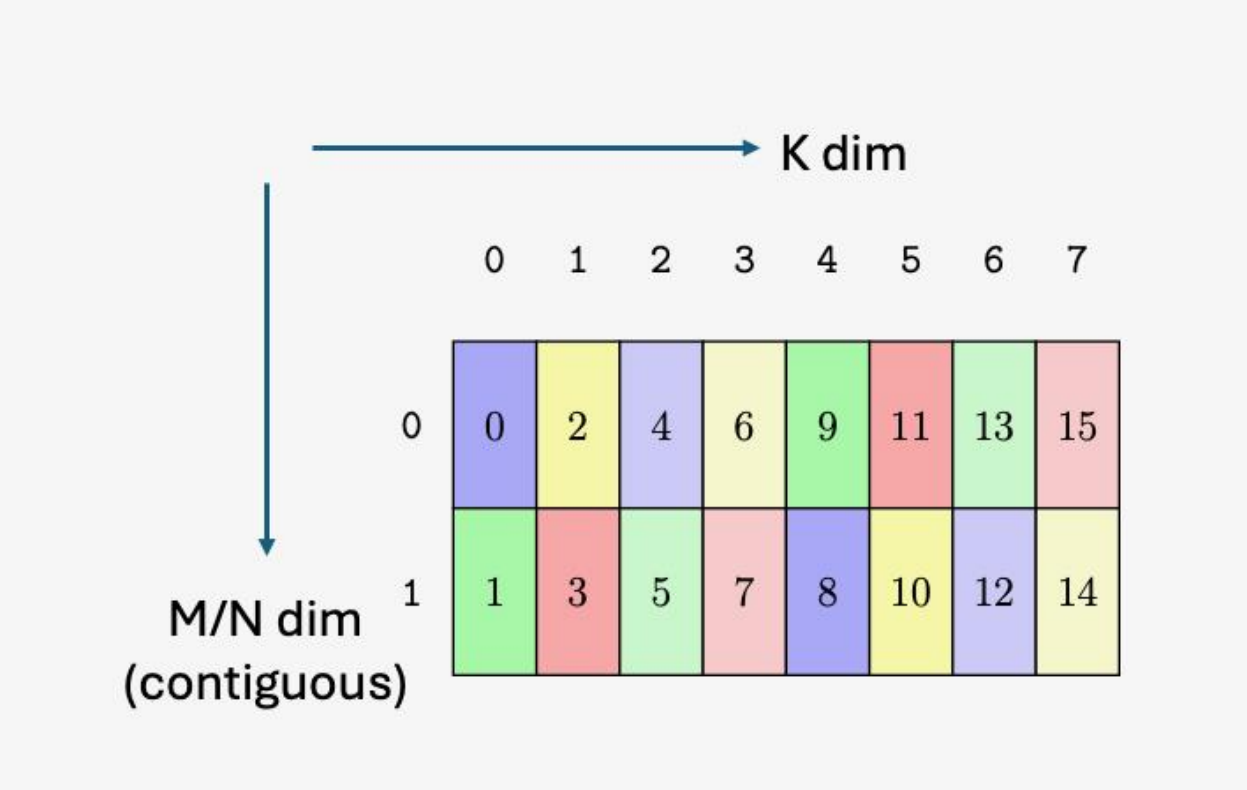

Figure 224: MN major 32B swizzling

9.7.16.10.7.1 Valid combinations of scale_vectorsize with types and MMA-Kind

The shape of *scale_A* and *scale_B* matrices depend on the `.scale_vectorsize` as shown in Table 56.

Table 56: Valid combinations of scale_vectorsize and shapes

.scale_vectorsize	.kind::*	K	Shape of scale_A	Shape of scale_B
.scale_vec::1X	.kind::mxf8f6f4	All supported values of K	M x 1	1 x N
.scale_vec::2X	.kind::mxf4, .kind::mxf4nvf4	All supported values of K	M x 2	2 x N
.scale_vec::4X	.kind::mxf4, .kind::mxf4nvf4	All supported values of K	M x 4	4 x N
.block16	.kind::mxf4nvf4	K = 96	M x 6	6 x N
		All supported values of K except 96	M x 4	4 x N
.block32	.kind::mxf4, .kind::mxf4nvf4	K = 96	M x 3	3 x N
		All supported values of K except 96	M x 2	2 x N
	.kind::mxf8f6f4	All supported values of K	M x 1	1 x N

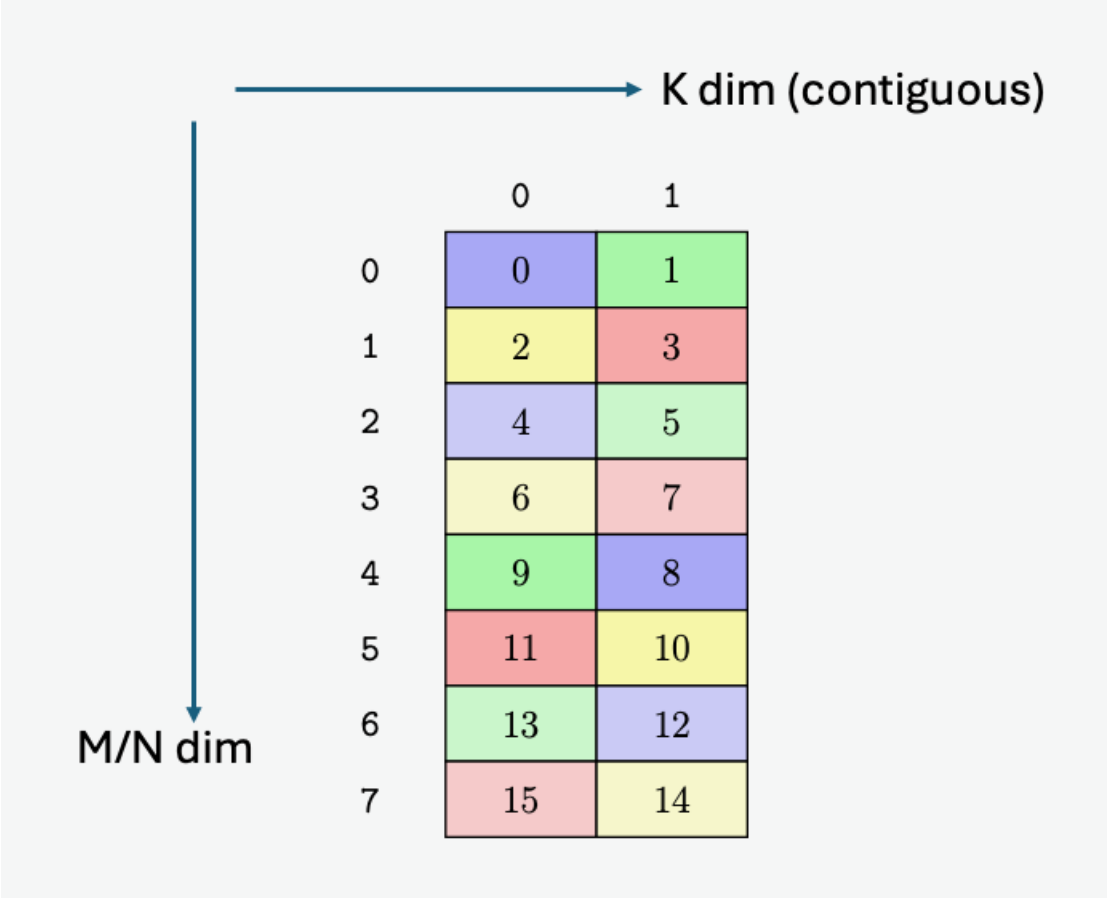

Figure 225: K major 32B swizzling

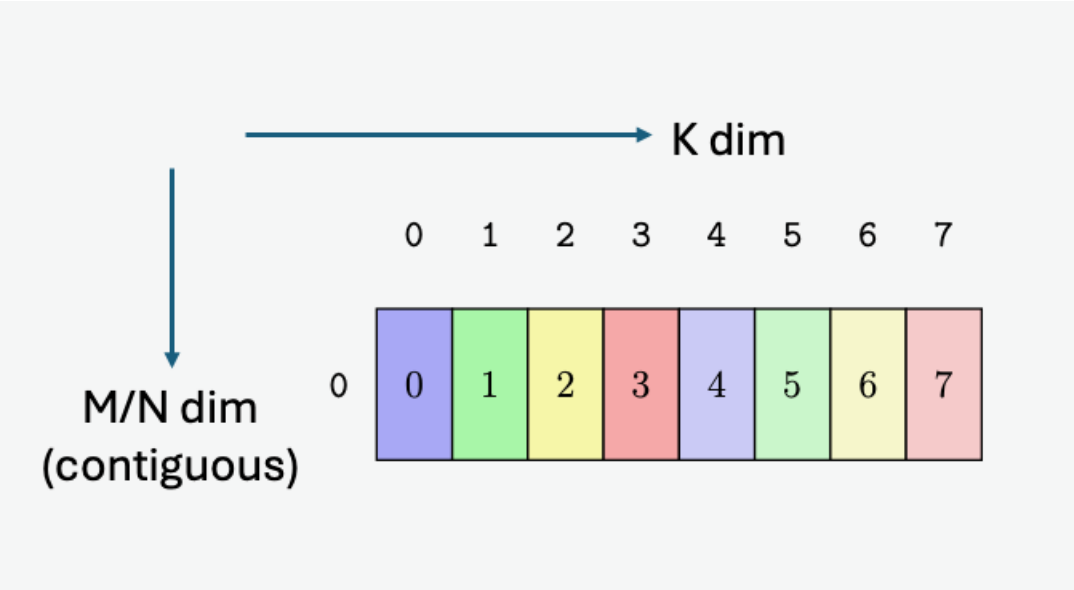

Figure 226: MN major no-swizzling mode

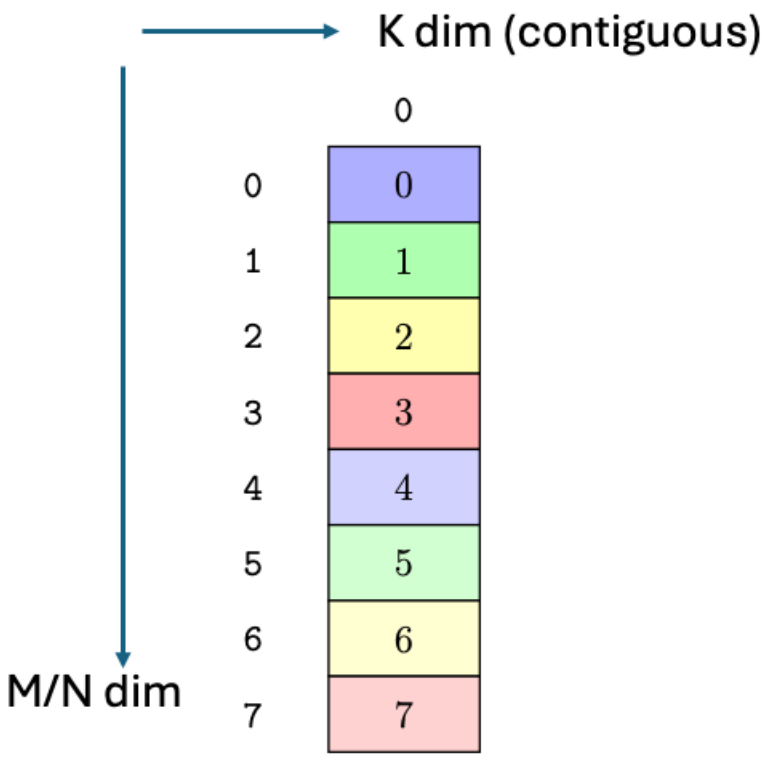

Figure 227: K major no-swizzling mode

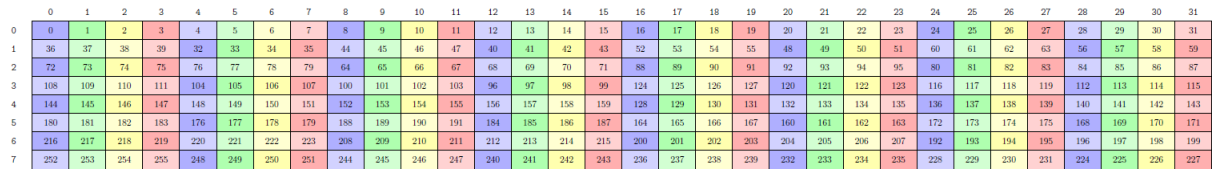

Figure 228: K major

	0	1	2	3	4	5	6	7
0	0	36	72	108	144	180	216	252
1	1	37	73	109	145	181	217	253
2	2	38	74	110	146	182	218	254
3	3	39	75	111	147	183	219	255
4	4	32	76	104	148	176	220	248
5	5	33	77	105	149	177	221	249
6	6	34	78	106	150	178	222	250
7	7	35	79	107	151	179	223	251
8	8	44	64	100	152	188	208	244
9	9	45	65	101	153	189	209	245
10	10	46	66	102	154	190	210	246
11	11	47	67	103	155	191	211	247
12	12	40	68	96	156	184	212	240
13	13	41	69	97	157	185	213	241
14	14	42	70	98	158	186	214	242
15	15	43	71	99	159	187	215	243
16	16	52	88	124	128	164	200	236
17	17	53	89	125	129	165	201	237
18	18	54	90	126	130	166	202	238
19	19	55	91	127	131	167	203	239
20	20	48	92	120	132	160	204	232
21	21	49	93	121	133	161	205	233
22	22	50	94	122	134	162	206	234
23	23	51	95	123	135	163	207	235
24	24	60	80	116	136	172	192	228
25	25	61	81	117	137	173	193	229
26	26	62	82	118	138	174	194	230
27	27	63	83	119	139	175	195	231
28	28	56	84	112	140	168	196	224
29	29	57	85	113	141	169	197	225
30	30	58	86	114	142	170	198	226
31	31	59	87	115	143	171	199	227

Figure 229: MN major

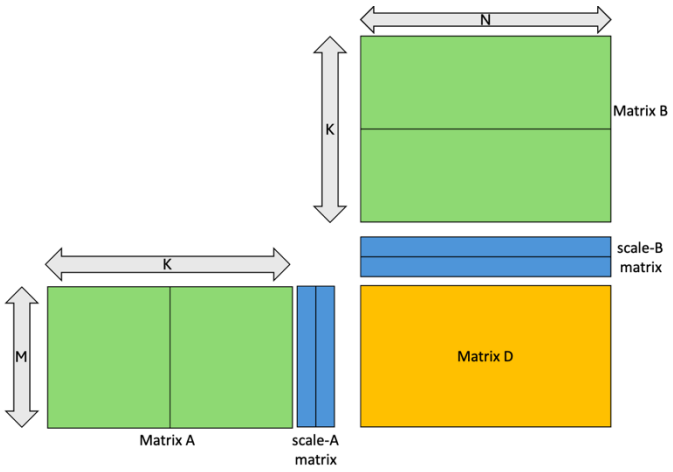

Figure 230: `tcgen05.mma` with block scaling of `scale_vec::2X`

The valid combination of the exact element types and the `.scale_vectorsize` are listed in Table 57.

Table 57: Valid combinations of scale_vectorsize with types and MMA-Kind

.kind::*	Element Data Type	Scale Data Type	.scale_vectorsize
.kind::mxf8f6f4	E4M3, E5M2, E2M3 E3M2, E2M1	UE8M0	.scale_vec::1X / .block32
.kind::mxf4	E2M1 E2M1	UE8M0	.scale_vec::2X / .block32
.kind::mxf4nvf4	E2M1	UE8M0	.scale_vec::2X / .block32, .scale_vec::4X / .block16
	E2M1	UE4M3	.scale_vec::4X / .block16

New `.blockN` qualifiers are aliases for `.scale_vec::NX` qualifiers as:

- `.block32` is alias for `.scale_vec::1X` or `.scale_vec::2X` based on `.kind` and K dimension
- `.block16` is alias for `.scale_vec::4X`

9.7.16.10.7.2 Scale Factor A ID

The value of the scale factor `A ID` selects the sub-columns in the Tensor Memory to form the scale factor A matrix, which is used to scale the matrix A.

The following shows the scale factor matrix layout for various scale vector sizes:

9.7.16.10.7.3 Layout of the Scale Factor A Matrix for scale_vec::1X/block32 with K=32/K=64

There is one scale factor per row of the A matrix with block size as 32 and the scale factor must be provided in 1-byte aligned sub-column of the Tensor Memory. *SFA_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 231 shows which sub-columns get selected for different values of *SFA_ID*.

Lane	Column X [0:7]	Column X [8:15]	Column X [16:23]	Column X [24:31]	Column X+1 [0:7]	Column X+1 [8:15]	Column X+1 [16:23]	Column X+1 [24:31]	Column X+2 [0:7]	Column X+2 [8:15]	Column X+2 [16:23]	Column X+2 [24:31]	Column X+3 [0:7]	Column X+3 [8:15]	Column X+3 [16:23]	Column X+3 [24:31]
0	M0 SF0	M0 SF0	M0 SF0	M0 SF0	M32 SF0	M32 SF0	M32 SF0	M32 SF0	M64 SF0	M64 SF0	M64 SF0	M64 SF0	M96 SF0	M96 SF0	M96 SF0	M96 SF0
1	M1 SF0	M1 SF0	M1 SF0	M1 SF0	M33 SF0	M33 SF0	M33 SF0	M33 SF0	M65 SF0	M65 SF0	M65 SF0	M65 SF0	M97 SF0	M97 SF0	M97 SF0	M97 SF0
2	M2 SF0	M2 SF0	M2 SF0	M2 SF0	M34 SF0	M34 SF0	M34 SF0	M34 SF0	M66 SF0	M66 SF0	M66 SF0	M66 SF0	M98 SF0	M98 SF0	M98 SF0	M98 SF0
3	M3 SF0	M3 SF0	M3 SF0	M3 SF0	M35 SF0	M35 SF0	M35 SF0	M35 SF0	M67 SF0	M67 SF0	M67 SF0	M67 SF0	M99 SF0	M99 SF0	M99 SF0	M99 SF0
4	M4 SF0	M4 SF0	M4 SF0	M4 SF0	M36 SF0	M36 SF0	M36 SF0	M36 SF0	M68 SF0	M68 SF0	M68 SF0	M68 SF0	M100 SF0	M100 SF0	M100 SF0	M100 SF0
5	M5 SF0	M5 SF0	M5 SF0	M5 SF0	M37 SF0	M37 SF0	M37 SF0	M37 SF0	M69 SF0	M69 SF0	M69 SF0	M69 SF0	M101 SF0	M101 SF0	M101 SF0	M101 SF0
6	M6 SF0	M6 SF0	M6 SF0	M6 SF0	M38 SF0	M38 SF0	M38 SF0	M38 SF0	M70 SF0	M70 SF0	M70 SF0	M70 SF0	M102 SF0	M102 SF0	M102 SF0	M102 SF0
7	M7 SF0	M7 SF0	M7 SF0	M7 SF0	M39 SF0	M39 SF0	M39 SF0	M39 SF0	M71 SF0	M71 SF0	M71 SF0	M71 SF0	M103 SF0	M103 SF0	M103 SF0	M103 SF0
8	M8 SF0	M8 SF0	M8 SF0	M8 SF0	M40 SF0	M40 SF0	M40 SF0	M40 SF0	M72 SF0	M72 SF0	M72 SF0	M72 SF0	M104 SF0	M104 SF0	M104 SF0	M104 SF0
9	M9 SF0	M9 SF0	M9 SF0	M9 SF0	M41 SF0	M41 SF0	M41 SF0	M41 SF0	M73 SF0	M73 SF0	M73 SF0	M73 SF0	M105 SF0	M105 SF0	M105 SF0	M105 SF0
10	M10 SF0	M10 SF0	M10 SF0	M10 SF0	M42 SF0	M42 SF0	M42 SF0	M42 SF0	M74 SF0	M74 SF0	M74 SF0	M74 SF0	M106 SF0	M106 SF0	M106 SF0	M106 SF0
11	M11 SF0	M11 SF0	M11 SF0	M11 SF0	M43 SF0	M43 SF0	M43 SF0	M43 SF0	M75 SF0	M75 SF0	M75 SF0	M75 SF0	M107 SF0	M107 SF0	M107 SF0	M107 SF0
12	M12 SF0	M12 SF0	M12 SF0	M12 SF0	M44 SF0	M44 SF0	M44 SF0	M44 SF0	M76 SF0	M76 SF0	M76 SF0	M76 SF0	M108 SF0	M108 SF0	M108 SF0	M108 SF0
13	M13 SF0	M13 SF0	M13 SF0	M13 SF0	M45 SF0	M45 SF0	M45 SF0	M45 SF0	M77 SF0	M77 SF0	M77 SF0	M77 SF0	M109 SF0	M109 SF0	M109 SF0	M109 SF0
14	M14 SF0	M14 SF0	M14 SF0	M14 SF0	M46 SF0	M46 SF0	M46 SF0	M46 SF0	M78 SF0	M78 SF0	M78 SF0	M78 SF0	M110 SF0	M110 SF0	M110 SF0	M110 SF0
15	M15 SF0	M15 SF0	M15 SF0	M15 SF0	M47 SF0	M47 SF0	M47 SF0	M47 SF0	M79 SF0	M79 SF0	M79 SF0	M79 SF0	M111 SF0	M111 SF0	M111 SF0	M111 SF0
16	M16 SF0	M16 SF0	M16 SF0	M16 SF0	M48 SF0	M48 SF0	M48 SF0	M48 SF0	M80 SF0	M80 SF0	M80 SF0	M80 SF0	M112 SF0	M112 SF0	M112 SF0	M112 SF0
17	M17 SF0	M17 SF0	M17 SF0	M17 SF0	M49 SF0	M49 SF0	M49 SF0	M49 SF0	M81 SF0	M81 SF0	M81 SF0	M81 SF0	M113 SF0	M113 SF0	M113 SF0	M113 SF0
18	M18 SF0	M18 SF0	M18 SF0	M18 SF0	M50 SF0	M50 SF0	M50 SF0	M50 SF0	M82 SF0	M82 SF0	M82 SF0	M82 SF0	M114 SF0	M114 SF0	M114 SF0	M114 SF0
19	M19 SF0	M19 SF0	M19 SF0	M19 SF0	M51 SF0	M51 SF0	M51 SF0	M51 SF0	M83 SF0	M83 SF0	M83 SF0	M83 SF0	M115 SF0	M115 SF0	M115 SF0	M115 SF0
20	M20 SF0	M20 SF0	M20 SF0	M20 SF0	M52 SF0	M52 SF0	M52 SF0	M52 SF0	M84 SF0	M84 SF0	M84 SF0	M84 SF0	M116 SF0	M116 SF0	M116 SF0	M116 SF0
21	M21 SF0	M21 SF0	M21 SF0	M21 SF0	M53 SF0	M53 SF0	M53 SF0	M53 SF0	M85 SF0	M85 SF0	M85 SF0	M85 SF0	M117 SF0	M117 SF0	M117 SF0	M117 SF0
22	M22 SF0	M22 SF0	M22 SF0	M22 SF0	M54 SF0	M54 SF0	M54 SF0	M54 SF0	M86 SF0	M86 SF0	M86 SF0	M86 SF0	M118 SF0	M118 SF0	M118 SF0	M118 SF0
23	M23 SF0	M23 SF0	M23 SF0	M23 SF0	M55 SF0	M55 SF0	M55 SF0	M55 SF0	M87 SF0	M87 SF0	M87 SF0	M87 SF0	M119 SF0	M119 SF0	M119 SF0	M119 SF0
24	M24 SF0	M24 SF0	M24 SF0	M24 SF0	M56 SF0	M56 SF0	M56 SF0	M56 SF0	M88 SF0	M88 SF0	M88 SF0	M88 SF0	M120 SF0	M120 SF0	M120 SF0	M120 SF0
25	M25 SF0	M25 SF0	M25 SF0	M25 SF0	M57 SF0	M57 SF0	M57 SF0	M57 SF0	M89 SF0	M89 SF0	M89 SF0	M89 SF0	M121 SF0	M121 SF0	M121 SF0	M121 SF0
26	M26 SF0	M26 SF0	M26 SF0	M26 SF0	M58 SF0	M58 SF0	M58 SF0	M58 SF0	M90 SF0	M90 SF0	M90 SF0	M90 SF0	M122 SF0	M122 SF0	M122 SF0	M122 SF0
27	M27 SF0	M27 SF0	M27 SF0	M27 SF0	M59 SF0	M59 SF0	M59 SF0	M59 SF0	M81 SF0	M81 SF0	M81 SF0	M81 SF0	M123 SF0	M123 SF0	M123 SF0	M123 SF0
28	M28 SF0	M28 SF0	M28 SF0	M28 SF0	M60 SF0	M60 SF0	M60 SF0	M60 SF0	M82 SF0	M82 SF0	M82 SF0	M82 SF0	M124 SF0	M124 SF0	M124 SF0	M124 SF0
29	M29 SF0	M29 SF0	M29 SF0	M29 SF0	M61 SF0	M61 SF0	M61 SF0	M61 SF0	M93 SF0	M93 SF0	M93 SF0	M93 SF0	M125 SF0	M125 SF0	M125 SF0	M125 SF0
30	M30 SF0	M30 SF0	M30 SF0	M30 SF0	M62 SF0	M62 SF0	M62 SF0	M62 SF0	M94 SF0	M94 SF0	M94 SF0	M94 SF0	M126 SF0	M126 SF0	M126 SF0	M126 SF0
31	M31 SF0	M31 SF0	M31 SF0	M31 SF0	M63 SF0	M63 SF0	M63 SF0	M63 SF0	M95 SF0	M95 SF0	M95 SF0	M95 SF0	M127 SF0	M127 SF0	M127 SF0	M127 SF0
	0	1	2	3												

SFA ID = 00 | SFA ID = 01 | SFA ID = 10 | SFA ID = 11

Figure 231: Layout of scale factor A matrix with scale_vec::1X/block32 with K=32/K=64

For example, if *SFA_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, *SFA_ID* values of 1, 2 and 3 would select the blue, yellow, and red columns, respectively.

9.7.16.10.7.4 Layout of the Scale Factor A Matrix for scale_vec::2X/block32 with K=64/K=128

There are two scale factors per row of the A matrix with block size as 32 and the scale factor must be provided in 2-byte aligned sub-column of the Tensor Memory. *SFA_ID* specifies the half word offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 232 shows which sub-columns gets selected for different values of *SFA_ID*.

For example, if *SFA_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, if *SFA_ID* is 2, then all of the blue columns are selected to form the scale factor matrix.

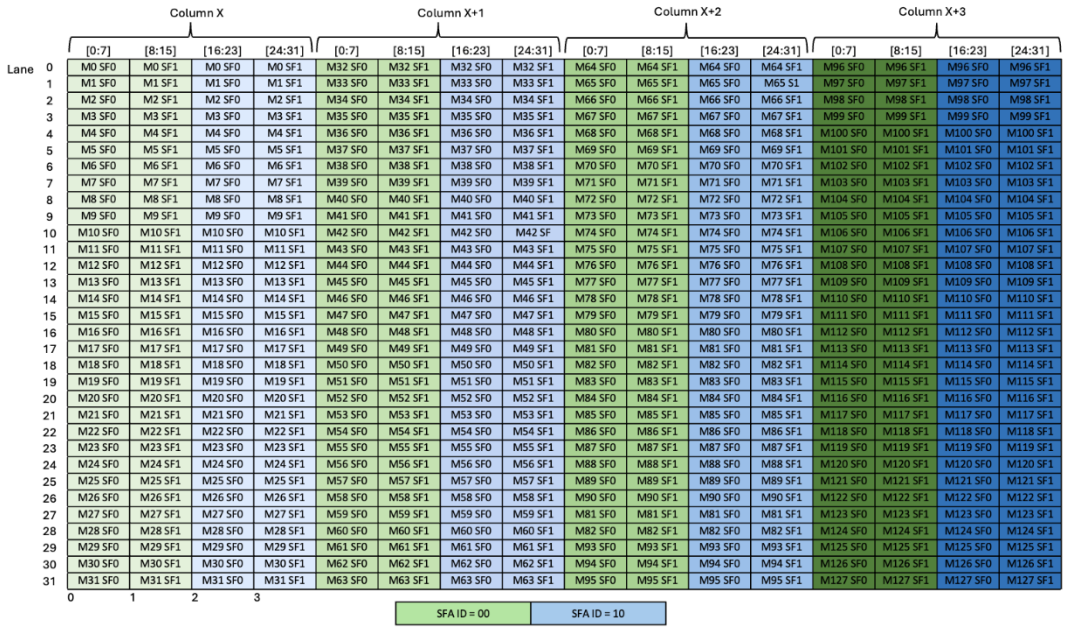

Figure 232: Layout of scale factor A matrix with scale_vec::2X/block32 with K=64/K=128

9.7.16.10.7.5 Layout of the Scale Factor A Matrix for scale_vec::4X/block16 with K=64/K=128

There are four scale factors per row of the A matrix with block size as 16 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. The *SFA_ID* value must be 0 and this specifies that all of the columns (in green) will be used for the scale factor matrix. Figure 233 shows which sub-columns gets selected for different values of *SFA_ID*.

9.7.16.10.7.6 Layout of the Scale Factor A Matrix for block32 with K=96 (Semantically equivalent to scale_vec::3X)

There are three scale factors per row of the A matrix with block size as 32 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. *SFA_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 234, Figure 235, Figure 236 and Figure 237 show which sub-columns get selected for different values of *SFA_ID*.

For example, if *SFA_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, *SFA_ID* values of 1, 2 and 3 would select the blue, yellow, and red columns, respectively.

9.7.16.10.7.7 Layout of the Scale Factor A Matrix for block16 with K=96 (Semantically equivalent to scale_vec::6X)

There are six scale factors per row of the A matrix with block size as 16 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. *SFA_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 238 and Figure 239 show which sub-columns get selected for different values of *SFA_ID*.

For example, if *SFA_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, if *SFA_ID* is 2, then all of the blue columns are selected to form the scale factor matrix.

	Column X				Column X+1				Column X+2				Column X+3			
Lane	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]
0	M0 SF0	M0 SF1	M0 SF2	M0 SF3	M32 SF0	M32 SF1	M32 SF2	M32 SF3	M64 SF0	M64 SF1	M64 SF2	M64 SF3	M96 SF0	M96 SF1	M96 SF2	M96 SF3
1	M1 SF0	M1 SF1	M1 SF2	M1 SF3	M33 SF0	M33 SF1	M33 SF2	M33 SF3	M65 SF0	M65 SF1	M65 SF2	M65 SF3	M97 SF0	M97 SF1	M97 SF2	M97 SF3
2	M2 SF0	M2 SF1	M2 SF2	M2 SF3	M34 SF0	M34 SF1	M34 SF2	M34 SF3	M66 SF0	M66 SF1	M66 SF2	M66 SF3	M98 SF0	M98 SF1	M98 SF2	M98 SF3
3	M3 SF0	M3 SF1	M3 SF2	M3 SF3	M35 SF0	M35 SF1	M35 SF2	M35 SF3	M67 SF0	M67 SF1	M67 SF2	M67 SF3	M99 SF0	M99 SF1	M99 SF2	M99 SF3
4	M4 SF0	M4 SF1	M4 SF2	M4 SF3	M36 SF0	M36 SF1	M36 SF2	M36 SF3	M68 SF0	M68 SF1	M68 SF2	M68 SF3	M100 SF0	M100 SF1	M100 SF2	M100 SF3
5	M5 SF0	M5 SF1	M5 SF2	M5 SF3	M37 SF0	M37 SF1	M37 SF2	M37 SF3	M69 SF0	M69 SF1	M69 SF2	M69 SF3	M101 SF0	M101 SF1	M101 SF2	M101 SF3
6	M6 SF0	M6 SF1	M6 SF2	M6 SF3	M38 SF0	M38 SF1	M38 SF2	M38 SF3	M70 SF0	M70 SF1	M70 SF2	M70 SF3	M102 SF0	M102 SF1	M102 SF2	M102 SF3
7	M7 SF0	M7 SF1	M7 SF2	M7 SF3	M39 SF0	M39 SF1	M39 SF2	M39 SF3	M71 SF0	M71 SF1	M71 SF2	M71 SF3	M103 SF0	M103 SF1	M103 SF2	M103 SF3
8	M8 SF0	M8 SF1	M8 SF2	M8 SF3	M40 SF0	M40 SF1	M40 SF2	M40 SF3	M72 SF0	M72 SF1	M72 SF2	M72 SF3	M104 SF0	M104 SF1	M104 SF2	M104 SF3
9	M9 SF0	M9 SF1	M9 SF2	M9 SF3	M41 SF0	M41 SF1	M41 SF2	M41 SF3	M73 SF0	M73 SF1	M73 SF2	M73 SF3	M105 SF0	M105 SF1	M105 SF2	M105 SF3
10	M10 SF0	M10 SF1	M10 SF2	M10 SF3	M42 SF0	M42 SF1	M42 SF2	M42 SF3	M74 SF0	M74 SF1	M74 SF2	M74 SF3	M106 SF0	M106 SF1	M106 SF2	M106 SF3
11	M11 SF0	M11 SF1	M11 SF2	M11 SF3	M43 SF0	M43 SF1	M43 SF2	M43 SF3	M75 SF0	M75 SF1	M75 SF2	M75 SF3	M107 SF0	M107 SF1	M107 SF2	M107 SF3
12	M12 SF0	M12 SF1	M12 SF2	M12 SF3	M44 SF0	M44 SF1	M44 SF2	M44 SF3	M76 SF0	M76 SF1	M76 SF2	M76 SF3	M108 SF0	M108 SF1	M108 SF2	M108 SF3
13	M13 SF0	M13 SF1	M13 SF2	M13 SF3	M45 SF0	M45 SF1	M45 SF2	M45 SF3	M77 SF0	M77 SF1	M77 SF2	M77 SF3	M109 SF0	M109 SF1	M109 SF2	M109 SF3
14	M14 SF0	M14 SF1	M14 SF2	M14 SF3	M46 SF0	M46 SF1	M46 SF2	M46 SF3	M78 SF0	M78 SF1	M78 SF2	M78 SF3	M110 SF0	M110 SF1	M110 SF2	M110 SF3
15	M15 SF0	M15 SF1	M15 SF2	M15 SF3	M47 SF0	M47 SF1	M47 SF2	M47 SF3	M79 SF0	M79 SF1	M79 SF2	M79 SF3	M111 SF0	M111 SF1	M111 SF2	M111 SF3
16	M16 SF0	M16 SF1	M16 SF2	M16 SF3	M48 SF0	M48 SF1	M48 SF2	M48 SF3	M80 SF0	M80 SF1	M80 SF2	M80 SF3	M112 SF0	M112 SF1	M112 SF2	M112 SF3
17	M17 SF0	M17 SF1	M17 SF2	M17 SF3	M49 SF0	M49 SF1	M49 SF2	M49 SF3	M81 SF0	M81 SF1	M81 SF2	M81 SF3	M113 SF0	M113 SF1	M113 SF2	M113 SF3
18	M18 SF0	M18 SF1	M18 SF2	M18 SF3	M50 SF0	M50 SF1	M50 SF2	M50 SF3	M82 SF0	M82 SF1	M82 SF2	M82 SF3	M114 SF0	M114 SF1	M114 SF2	M114 SF3
19	M19 SF0	M19 SF1	M19 SF2	M19 SF3	M51 SF0	M51 SF1	M51 SF2	M51 SF3	M83 SF0	M83 SF1	M83 SF2	M83 SF3	M115 SF0	M115 SF1	M115 SF2	M115 SF3
20	M20 SF0	M20 SF1	M20 SF2	M20 SF3	M52 SF0	M52 SF1	M52 SF2	M52 SF3	M84 SF0	M84 SF1	M84 SF2	M84 SF3	M116 SF0	M116 SF1	M116 SF2	M116 SF3
21	M21 SF0	M21 SF1	M21 SF2	M21 SF3	M53 SF0	M53 SF1	M53 SF2	M53 SF3	M85 SF0	M85 SF1	M85 SF2	M85 SF3	M117 SF0	M117 SF1	M117 SF2	M117 SF3
22	M22 SF0	M22 SF1	M22 SF2	M22 SF3	M54 SF0	M54 SF1	M54 SF2	M54 SF3	M86 SF0	M86 SF1	M86 SF2	M86 SF3	M118 SF0	M118 SF1	M118 SF2	M118 SF3
23	M23 SF0	M23 SF1	M23 SF2	M23 SF3	M55 SF0	M55 SF1	M55 SF2	M55 SF3	M87 SF0	M87 SF1	M87 SF2	M87 SF3	M119 SF0	M119 SF1	M119 SF2	M119 SF3
24	M24 SF0	M24 SF1	M24 SF2	M24 SF3	M56 SF0	M56 SF1	M56 SF2	M56 SF3	M88 SF0	M88 SF1	M88 SF2	M88 SF3	M120 SF0	M120 SF1	M120 SF2	M120 SF3
25	M25 SF0	M25 SF1	M25 SF2	M25 SF3	M57 SF0	M57 SF1	M57 SF2	M57 SF3	M89 SF0	M89 SF1	M89 SF2	M89 SF3	M121 SF0	M121 SF1	M121 SF2	M121 SF3
26	M26 SF0	M26 SF1	M26 SF2	M26 SF3	M58 SF0	M58 SF1	M58 SF2	M58 SF3	M90 SF0	M90 SF1	M90 SF2	M90 SF3	M122 SF0	M122 SF1	M122 SF2	M122 SF3
27	M27 SF0	M27 SF1	M27 SF2	M27 SF3	M59 SF0	M59 SF1	M59 SF2	M59 SF3	M81 SF0	M81 SF1	M81 SF2	M81 SF3	M123 SF0	M123 SF1	M123 SF2	M123 SF3
28	M28 SF0	M28 SF1	M28 SF2	M28 SF3	M60 SF0	M60 SF1	M60 SF2	M60 SF3	M82 SF0	M82 SF1	M82 SF2	M82 SF3	M124 SF0	M124 SF1	M124 SF2	M124 SF3
29	M29 SF0	M29 SF1	M29 SF2	M29 SF3	M61 SF0	M61 SF1	M61 SF2	M61 SF3	M93 SF0	M93 SF1	M93 SF2	M93 SF3	M125 SF0	M125 SF1	M125 SF2	M125 SF3
30	M30 SF0	M30 SF1	M30 SF2	M30 SF3	M62 SF0	M62 SF1	M62 SF2	M62 SF3	M94 SF0	M94 SF1	M94 SF2	M94 SF3	M126 SF0	M126 SF1	M126 SF2	M126 SF3
31	M31 SF0	M31 SF1	M31 SF2	M31 SF3	M63 SF0	M63 SF1	M63 SF2	M63 SF3	M95 SF0	M95 SF1	M95 SF2	M95 SF3	M127 SF0	M127 SF1	M127 SF2	M127 SF3
	0	1	2	3												

SFA ID = 00

Figure 233: Layout of scale factor A matrix with scale_vec::4X/block16 with K=64/K=128

	Column X				Column X+1				Column X+2				Column X+3			
Lane	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]	[0:7]	[8:15]	[16:23]	[24:31]
0	M0 SF0	M0 SF1	M0 SF2		M32 SF0	M32 SF1	M32 SF2		M64 SF0	M64 SF1	M64 SF2		M96 SF0	M96 SF1	M96 SF2	
1	M1 SF0	M1 SF1	M1 SF2		M33 SF0	M33 SF1	M33 SF2		M65 SF0	M65 SF1	M65 SF2		M97 SF0	M97 SF1	M97 SF2	
2	M2 SF0	M2 SF1	M2 SF2		M34 SF0	M34 SF1	M34 SF2		M66 SF0	M66 SF1	M66 SF2		M98 SF0	M98 SF1	M98 SF2	
3	M3 SF0	M3 SF1	M3 SF2		M35 SF0	M35 SF1	M35 SF2		M67 SF0	M67 SF1	M67 SF2		M99 SF0	M99 SF1	M99 SF2	
4	M4 SF0	M4 SF1	M4 SF2		M36 SF0	M36 SF1	M36 SF2		M68 SF0	M68 SF1	M68 SF2		M100 SF0	M100 SF1	M100 SF2	
5	M5 SF0	M5 SF1	M5 SF2		M37 SF0	M37 SF1	M37 SF2		M69 SF0	M69 SF1	M69 SF2		M101 SF0	M101 SF1	M101 SF2	
6	M6 SF0	M6 SF1	M6 SF2		M38 SF0	M38 SF1	M38 SF2		M70 SF0	M70 SF1	M70 SF2		M102 SF0	M102 SF1	M102 SF2	
7	M7 SF0	M7 SF1	M7 SF2		M39 SF0	M39 SF1	M39 SF2		M71 SF0	M71 SF1	M71 SF2		M103 SF0	M103 SF1	M103 SF2	
8	M8 SF0	M8 SF1	M8 SF2		M40 SF0	M40 SF1	M40 SF2		M72 SF0	M72 SF1	M72 SF2		M104 SF0	M104 SF1	M104 SF2	
9	M9 SF0	M9 SF1	M9 SF2		M41 SF0	M41 SF1	M41 SF2		M73 SF0	M73 SF1	M73 SF2		M105 SF0	M105 SF1	M105 SF2	
10	M10 SF0	M10 SF1	M10 SF2		M42 SF0	M42 SF1	M42 SF2		M74 SF0	M74 SF1	M74 SF2		M106 SF0	M106 SF1	M106 SF2	
11	M11 SF0	M11 SF1	M11 SF2		M43 SF0	M43 SF1	M43 SF2		M75 SF0	M75 SF1	M75 SF2		M107 SF0	M107 SF1	M107 SF2	
12	M12 SF0	M12 SF1	M12 SF2		M44 SF0	M44 SF1	M44 SF2		M76 SF0	M76 SF1	M76 SF2		M108 SF0	M108 SF1	M108 SF2	
13	M13 SF0	M13 SF1	M13 SF2		M45 SF0	M45 SF1	M45 SF2		M77 SF0	M77 SF1	M77 SF2		M109 SF0	M109 SF1	M109 SF2	
14	M14 SF0	M14 SF1	M14 SF2		M46 SF0	M46 SF1	M46 SF2		M78 SF0	M78 SF1	M78 SF2		M110 SF0	M110 SF1	M110 SF2	
15	M15 SF0	M15 SF1	M15 SF2		M47 SF0	M47 SF1	M47 SF2		M79 SF0	M79 SF1	M79 SF2		M111 SF0	M111 SF1	M111 SF2	
16	M16 SF0	M16 SF1	M16 SF2		M48 SF0	M48 SF1	M48 SF2		M80 SF0	M80 SF1	M80 SF2		M112 SF0	M112 SF1	M112 SF2	
17	M17 SF0	M17 SF1	M17 SF2		M49 SF0	M49 SF1	M49 SF2		M81 SF0	M81 SF1	M81 SF2		M113 SF0	M113 SF1	M113 SF2	
18	M18 SF0	M18 SF1	M18 SF2		M50 SF0	M50 SF1	M50 SF2		M82 SF0	M82 SF1	M82 SF2		M114 SF0	M114 SF1	M114 SF2	
19	M19 SF0	M19 SF1	M19 SF2		M51 SF0	M51 SF1	M51 SF2		M83 SF0	M83 SF1	M83 SF2		M115 SF0	M115 SF1	M115 SF2	
20	M20 SF0	M20 SF1	M20 SF2		M52 SF0	M52 SF1	M52 SF2		M84 SF0	M84 SF1	M84 SF2		M116 SF0	M116 SF1	M116 SF2	
21	M21 SF0	M21 SF1	M21 SF2		M53 SF0	M53 SF1	M53 SF2		M85 SF0	M85 SF1	M85 SF2		M117 SF0	M117 SF1	M117 SF2	
22	M22 SF0	M22 SF1	M22 SF2		M54 SF0	M54 SF1	M54 SF2		M86 SF0	M86 SF1	M86 SF2		M118 SF0	M118 SF1	M118 SF2	
23	M23 SF0	M23 SF1	M23 SF2		M55 SF0	M55 SF1	M55 SF2		M87 SF0	M87 SF1	M87 SF2		M119 SF0	M119 SF1	M119 SF2	
24	M24 SF0	M24 SF1	M24 SF2		M56 SF0	M56 SF1	M56 SF2		M88 SF0	M88 SF1	M88 SF2		M120 SF0	M120 SF1	M120 SF2	
25	M25 SF0	M25 SF1	M25 SF2		M57 SF0	M57 SF1	M57 SF2		M89 SF0	M89 SF1	M89 SF2		M121 SF0	M121 SF1	M121 SF2	
26	M26 SF0	M26 SF1	M26 SF2		M58 SF0	M58 SF1	M58 SF2		M90 SF0	M90 SF1	M90 SF2		M122 SF0	M122 SF1	M122 SF2	
27	M27 SF0	M27 SF1	M27 SF2		M59 SF0	M59 SF1	M59 SF2		M81 SF0	M81 SF1	M81 SF2		M123 SF0	M123 SF1	M123 SF2	
28	M28 SF0	M28 SF1	M28 SF2		M60 SF0	M60 SF1	M60 SF2		M82 SF0	M82 SF1	M82 SF2		M124 SF0	M124 SF1	M124 SF2	
29	M29 SF0	M29 SF1	M29 SF2		M61 SF0	M61 SF1	M61 SF2		M93 SF0	M93 SF1	M93 SF2		M125 SF0	M125 SF1	M125 SF2	
30	M30 SF0	M30 SF1	M30 SF2		M62 SF0	M62 SF1	M62 SF2		M94 SF0	M94 SF1	M94 SF2		M126 SF0	M126 SF1	M126 SF2	
31	M31 SF0	M31 SF1	M31 SF2		M63 SF0	M63 SF1	M63 SF2		M95 SF0	M95 SF1	M95 SF2		M127 SF0	M127 SF1	M127 SF2	
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15

per-byte sub-column

SFA ID = 00

Figure 234: Layout of scale factor A matrix with block32 with K=96 with SFA_ID=00

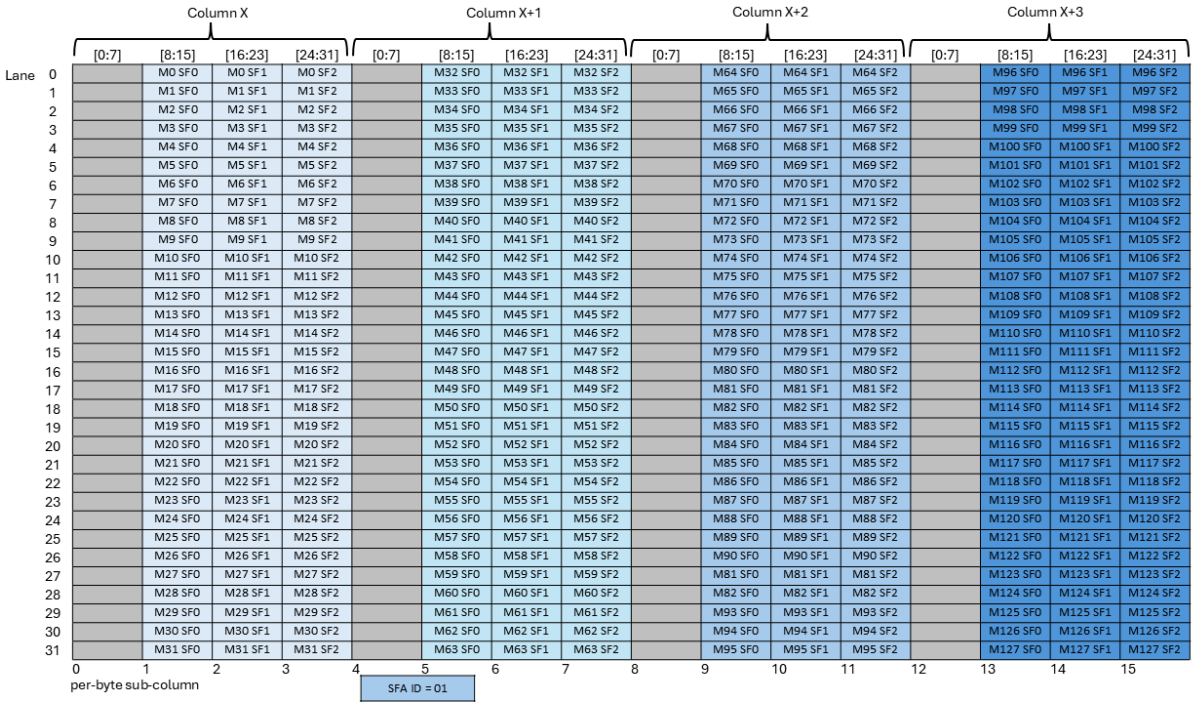

Figure 235: Layout of scale factor A matrix with block32 with K=96 with SFA_ID=01

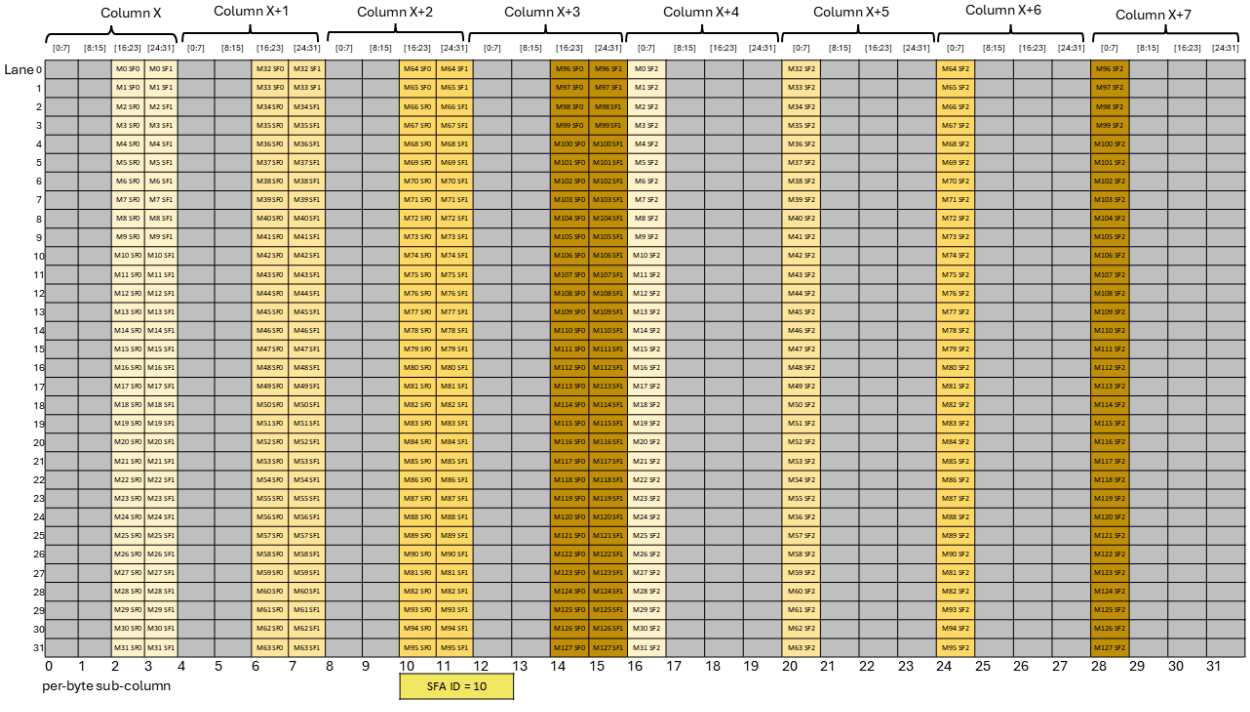

Figure 236: Layout of scale factor A matrix with block32 with K=96 with SFA_ID=10

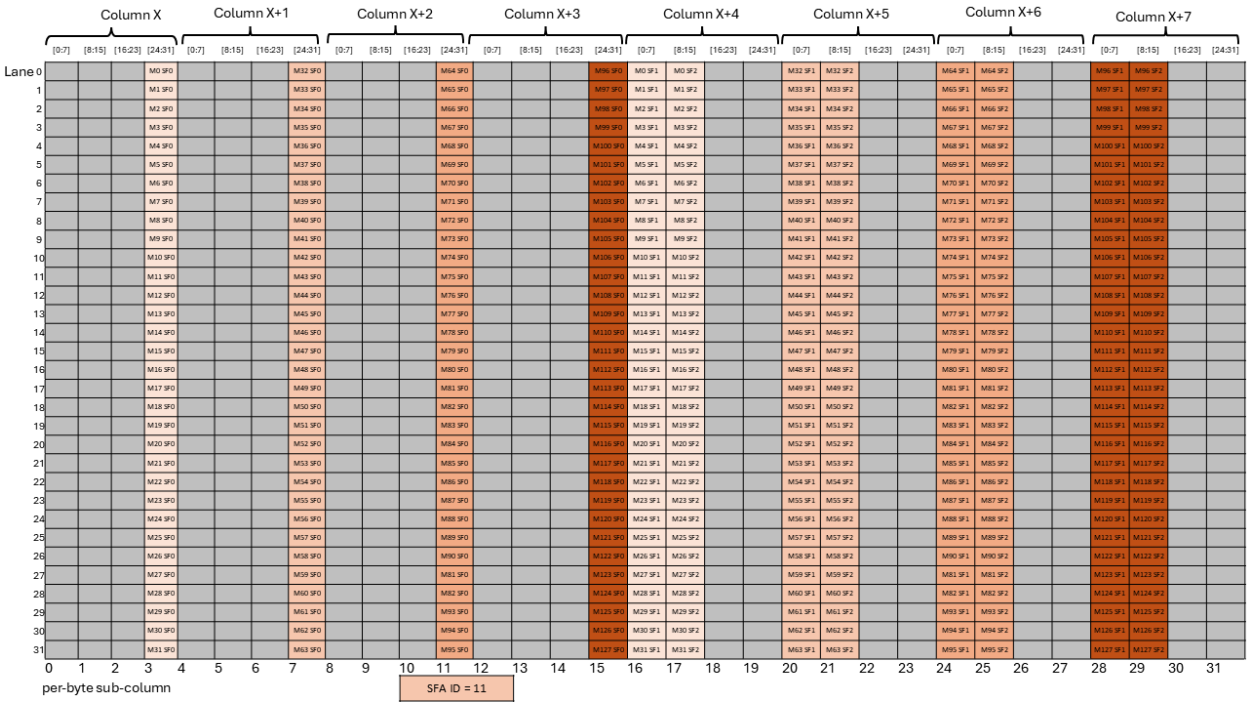

Figure 237: Layout of scale factor A matrix with block32 with K=96 with SFA_ID=11

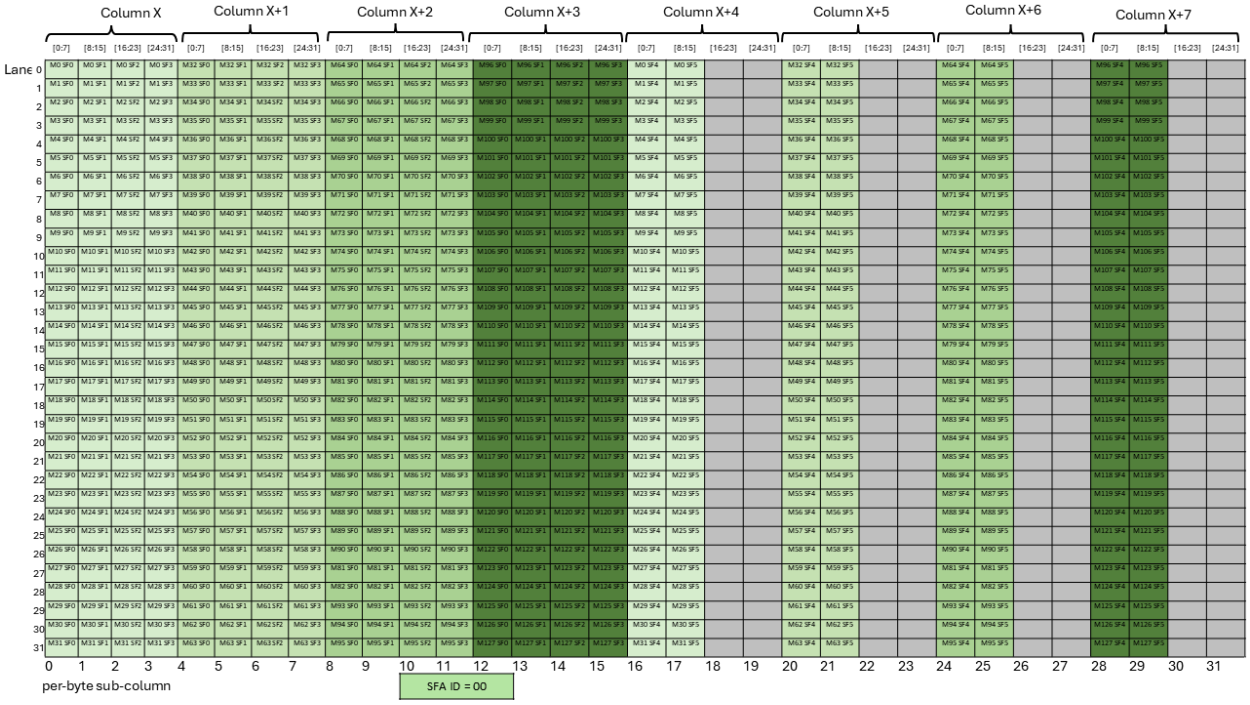

Figure 238: Layout of scale factor A matrix with block16 with K=96 with SFA_ID=00

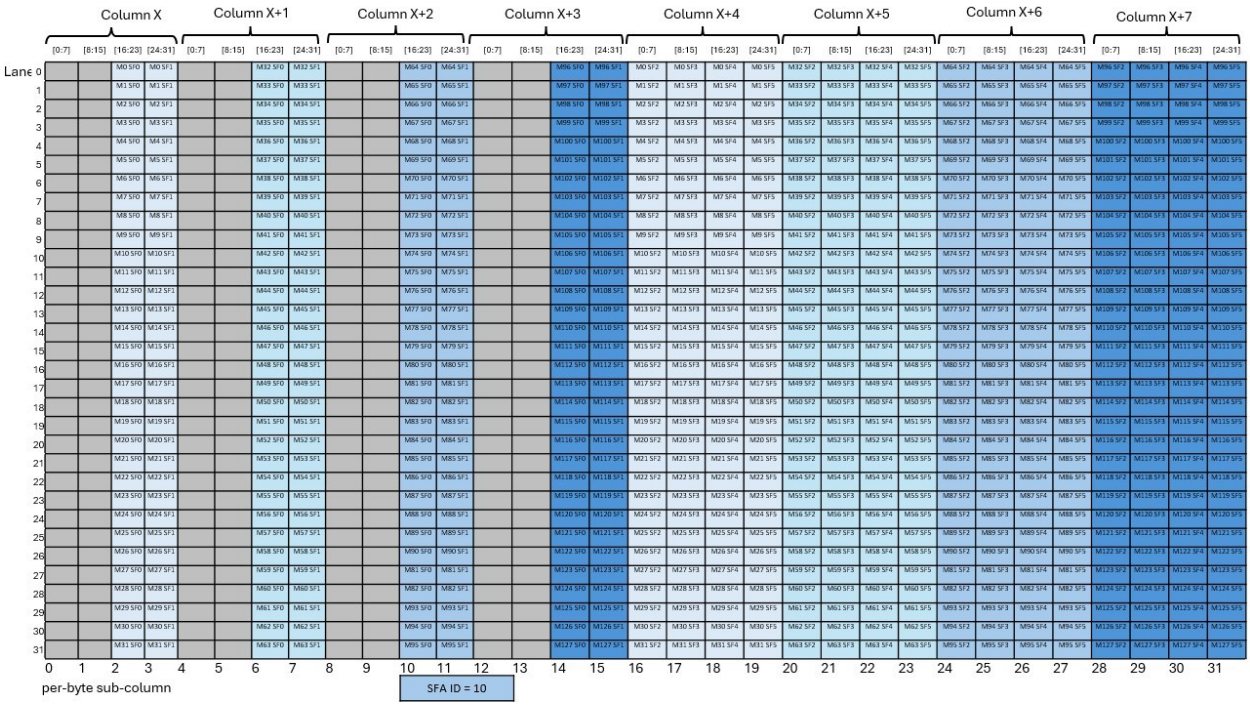

Figure 239: Layout of scale factor A matrix with block16 with K=96 with SFA_ID=10

9.7.16.10.7.8 Scale Factor B ID

The value of the scale factor B `ID` selects the sub-columns in the Tensor Memory to form the scale factor B matrix, which is used to scale the matrix B.

The following shows the scale factor matrix layout for various scale vector sizes:

9.7.16.10.7.9 Layout of the Scale Factor B Matrix for scale_vec::1X/block32 with K=32/K=64

There is one scale factor per row of the B matrix with block size as 32 and the scale factor must be provided in 1-byte aligned sub-column of the Tensor Memory. *SFB_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 240 shows which sub-columns get selected for different values of *SFB_ID*.

For example, if *SFB_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, *SFB_ID* values of 1, 2 and 3 would select the blue, yellow, and red columns, respectively.

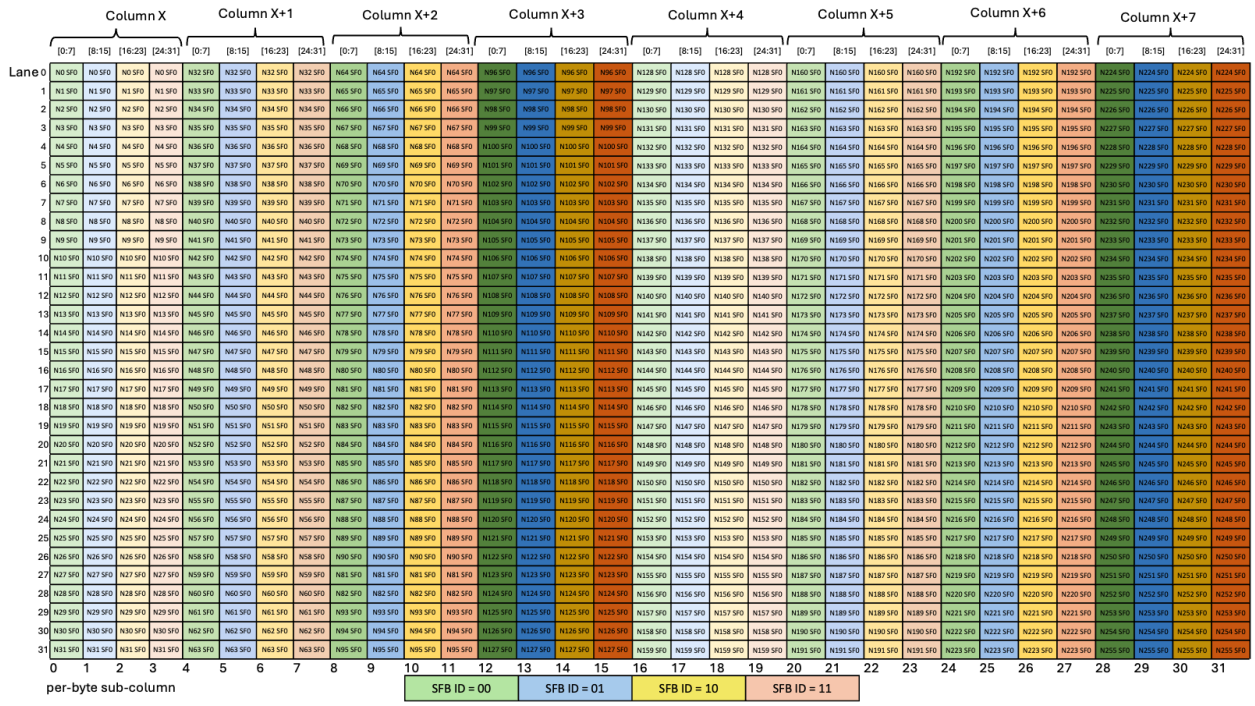

Figure 240: Layout of scale factor B matrix with scale_vec::1X/block32 with K=32/K=64

9.7.16.10.7.10 Layout of the Scale Factor B Matrix for scale_vec::2X/block32 with K=64/K=128

There are two scale factors per row of the B matrix with block size as 32 and the scale factor must be provided in 2-byte aligned sub-column of the Tensor Memory. *SFB_ID* specifies the half word offset in the Tensor Memory word that must be used for the scale factor matrix. Figure 241 shows which sub-columns get selected for different values of *SFB_ID*.

For example, if *SFB_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, if *SFB_ID* is 2, then all of the blue columns are selected to form the scale factor matrix.

9.7.16.10.7.11 Layout of the Scale Factor B Matrix for scale_vec::4X/block16 with K=64/K=128

There are four scale factors per row of the B matrix with block size as 16 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. The *SFB_ID* value must be 0 and this specifies that all of the columns (in green) will be used for the scale factor matrix. Figure 242 shows which sub-columns get selected for different values of *SFB_ID*.

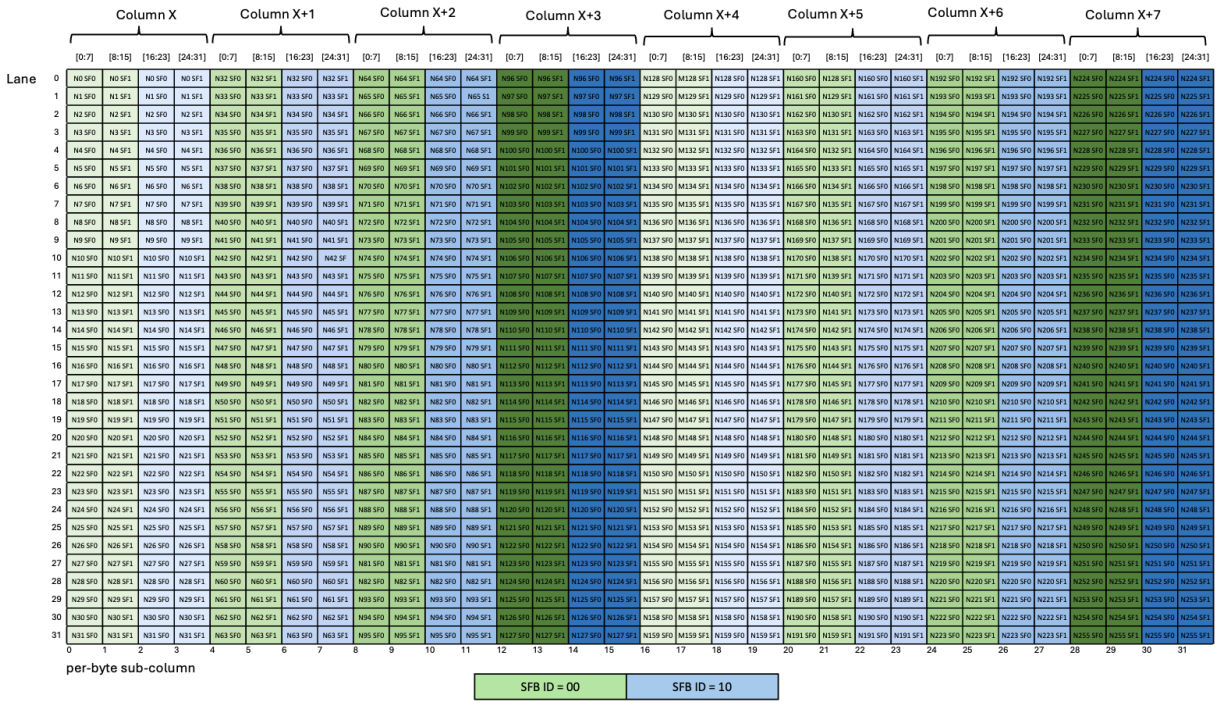

Figure 241: Layout of scale factor B matrix with scale_vec::2X/block32 with K=64/K=128

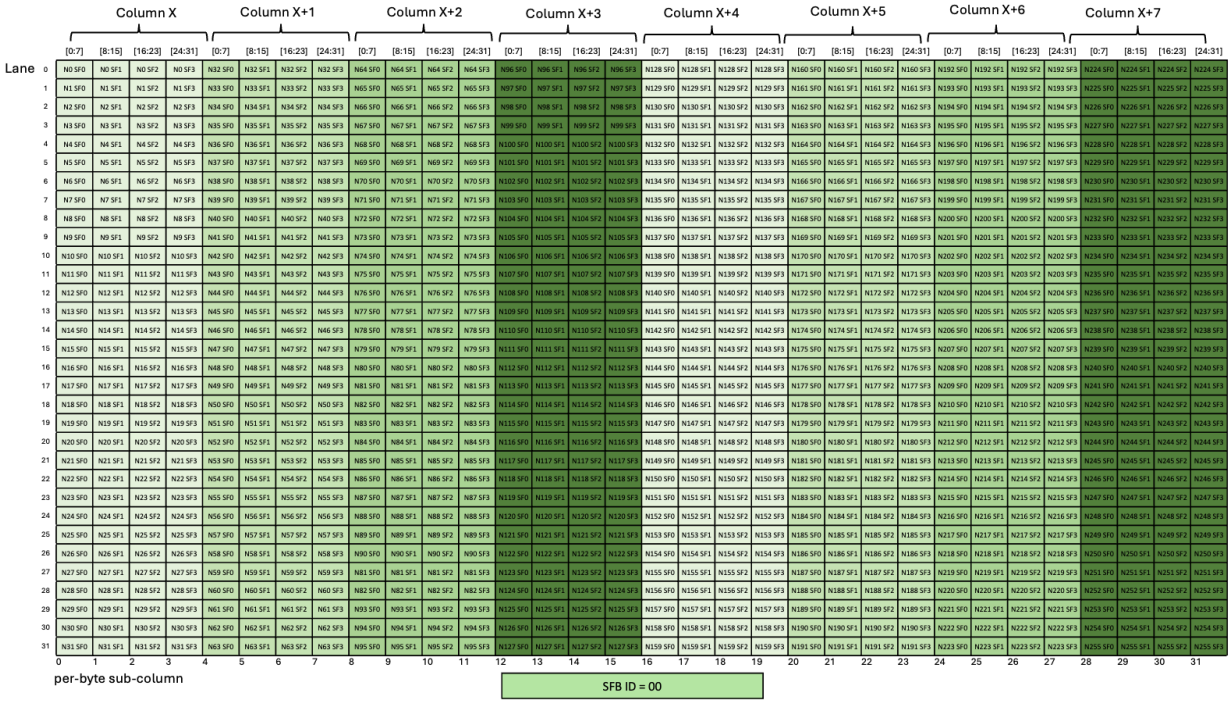

Figure 242: Layout of scale factor B matrix with scale_vec::4X/block16 with K=64/K=128

9.7.16.10.7.12 Layout of the Scale Factor B Matrix for block32 with K=96 (Semantically equivalent to scale_vec::3X)

There are three scale factors per row of the B matrix with block size as 32 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. *SFB_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix.

For N<=128, Figure 243, Figure 244, Figure 245 and Figure 246 show which sub-columns get selected for different values of *SFB_ID*.

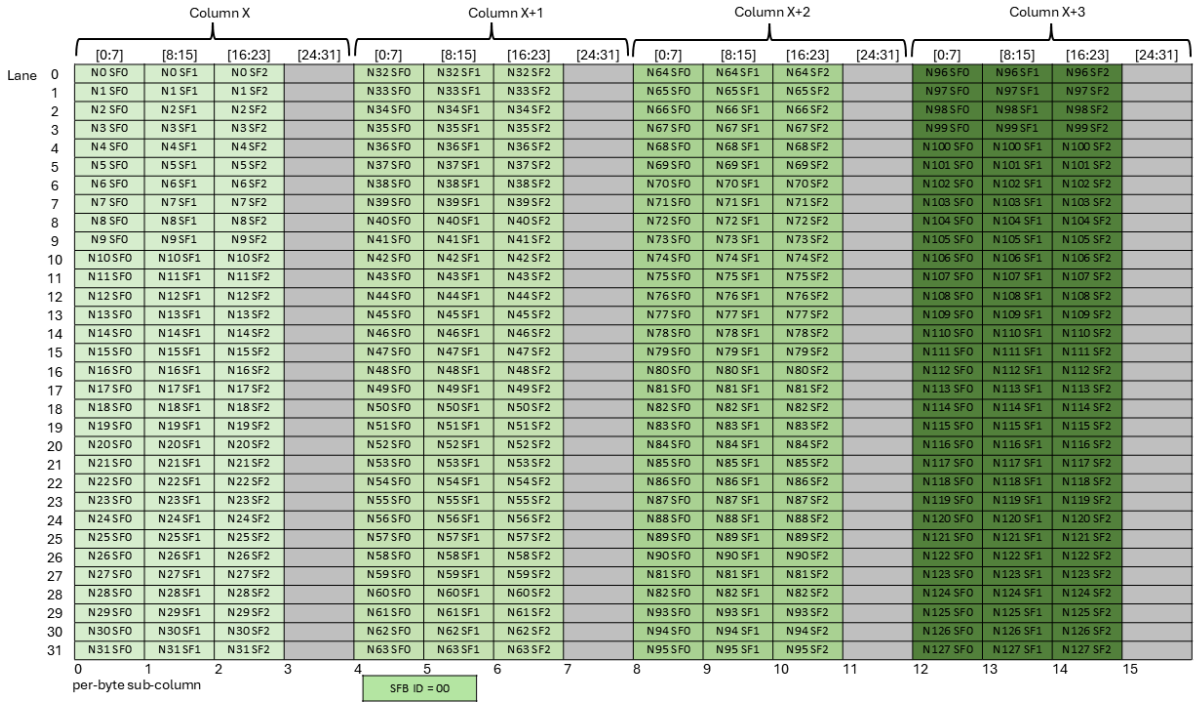

Figure 243: Layout of scale factor B matrix with block32 with K=96 and N<=128 with SFA_ID=00

For N>128, Figure 247, Figure 248, Figure 249, Figure 250, Figure 251 and Figure 252 show which sub-columns get selected for different values of *SFB_ID*.

For example, if *SFB_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, *SFB_ID* values of 1, 2 and 3 would select the blue, yellow, and red columns, respectively.

9.7.16.10.7.13 Layout of the Scale Factor B Matrix for block16 with K=96 (Semantically equivalent to scale_vec::6X)

There are six scale factors per row of the B matrix with block size as 16 and the scale factor must be provided in 4-byte aligned sub-column of the Tensor Memory. *SFB_ID* specifies the byte offset in the Tensor Memory word that must be used for the scale factor matrix.

For N<=128, Figure 253 and Figure 254 show which sub-columns get selected for different values of *SFB_ID*.

For N>128, Figure 255, Figure 256, Figure 257 and Figure 258 show which sub-columns get selected for different values of *SFB_ID*.

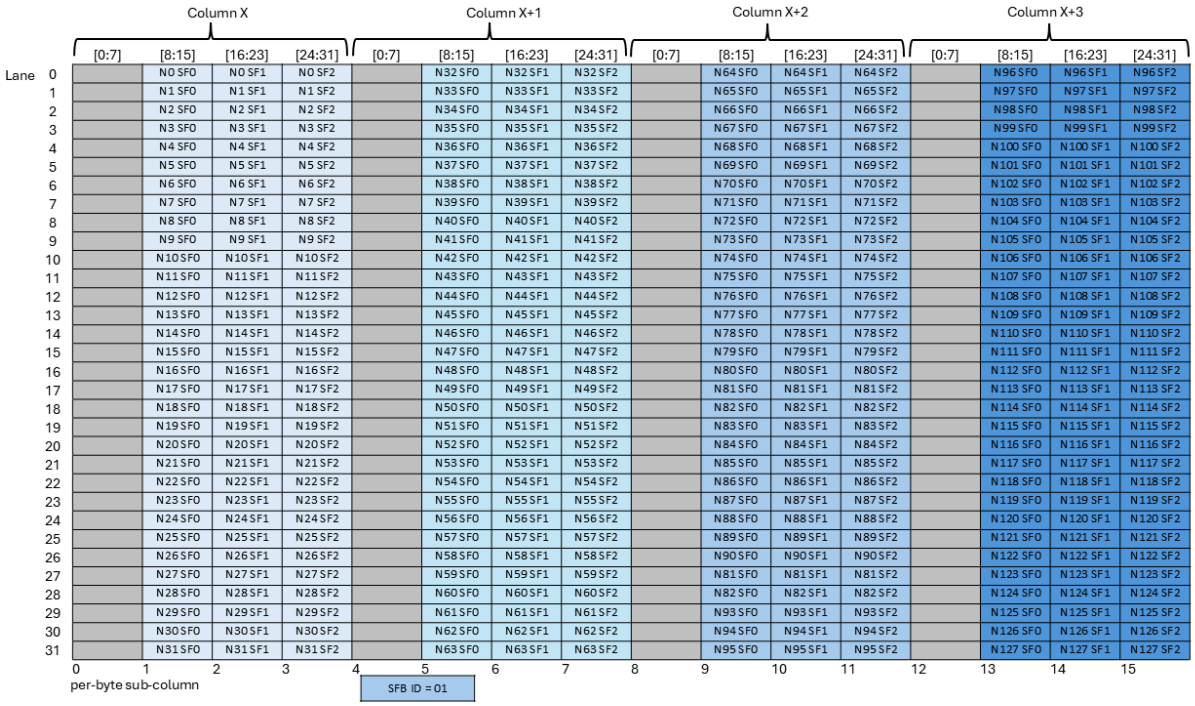

Figure 244: Layout of scale factor B matrix with block32 with K=96 and N<=128 with SFA_ID=01

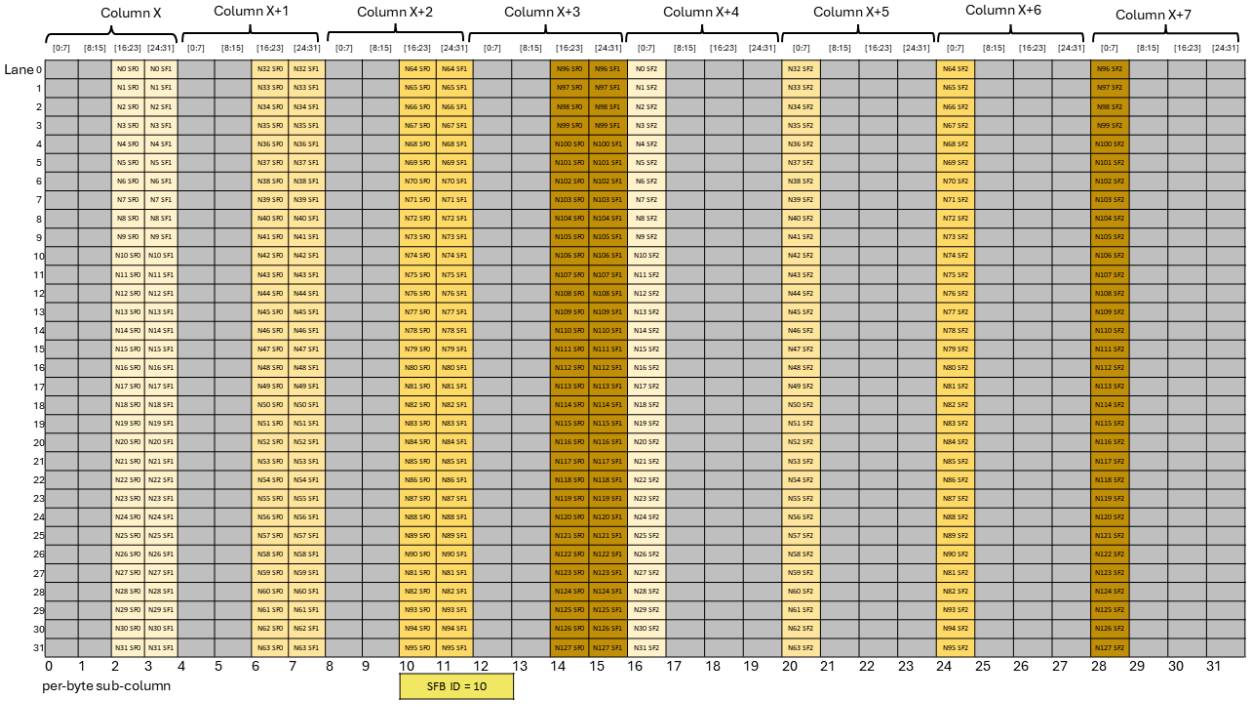

Figure 245: Layout of scale factor B matrix with block32 with K=96 and N<=128 with SFA_ID=10

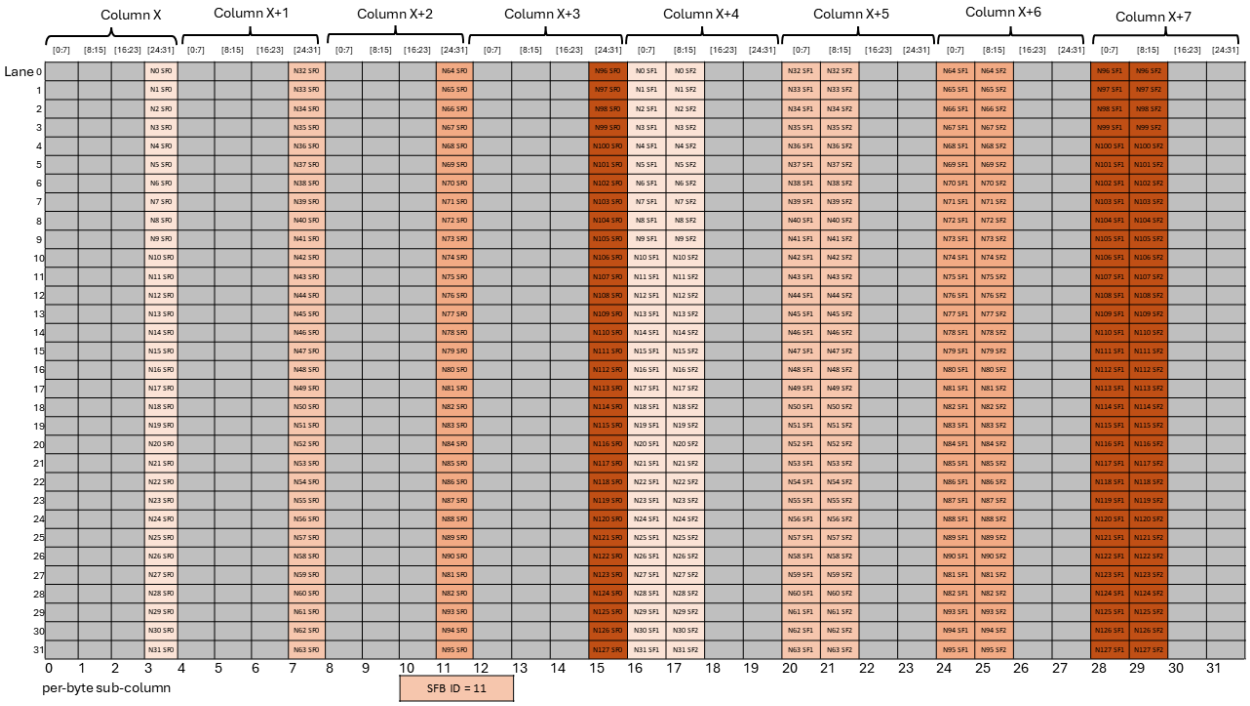

Figure 246: Layout of scale factor B matrix with block32 with K=96 and N<=128 with SFA_ID=11

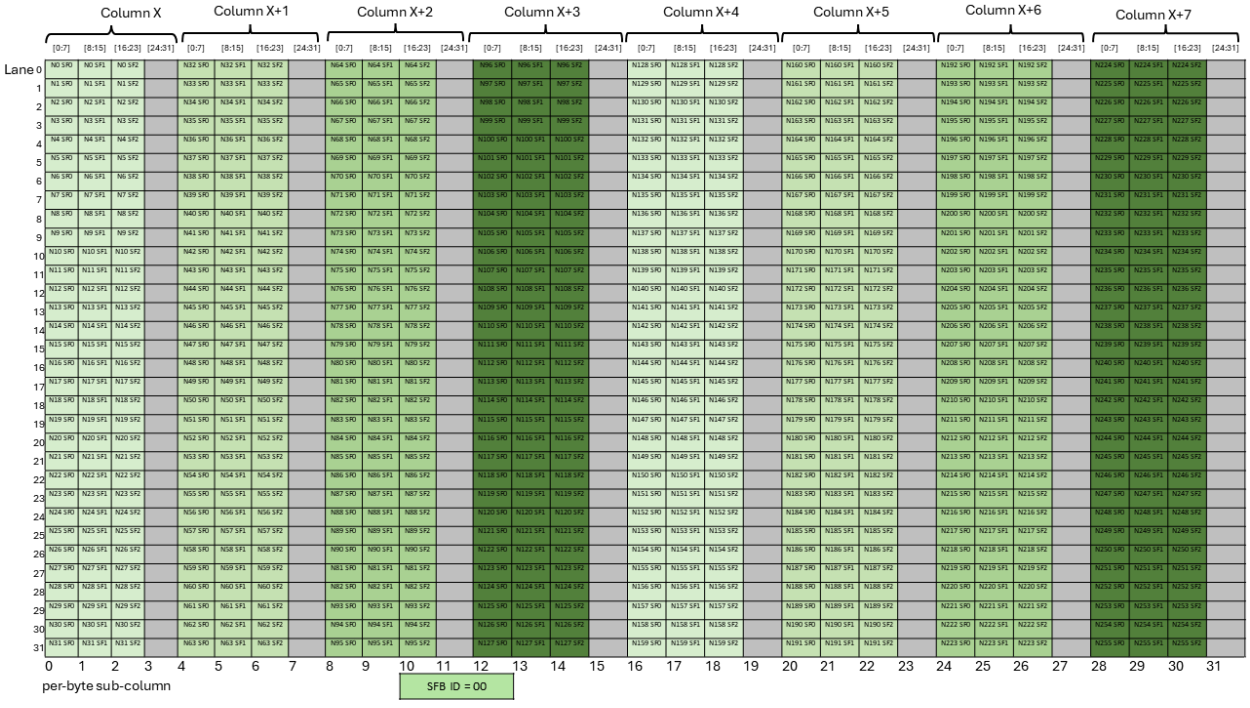

Figure 247: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=00

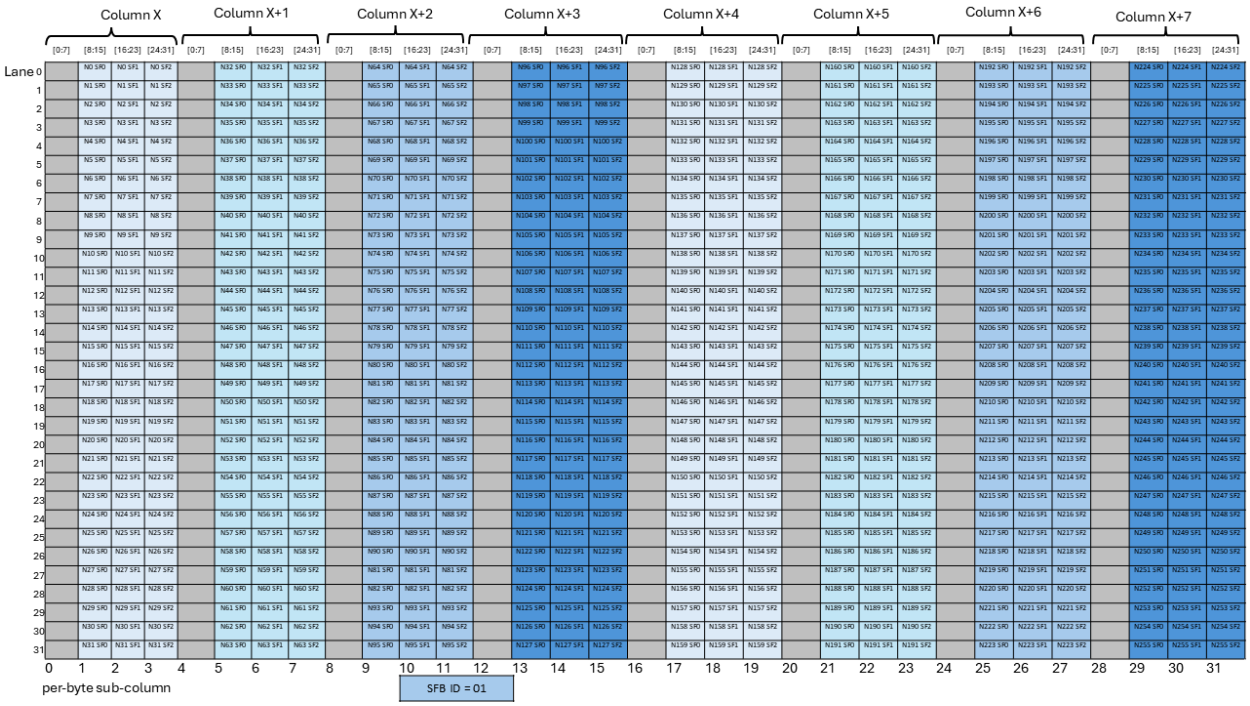

Figure 248: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=01

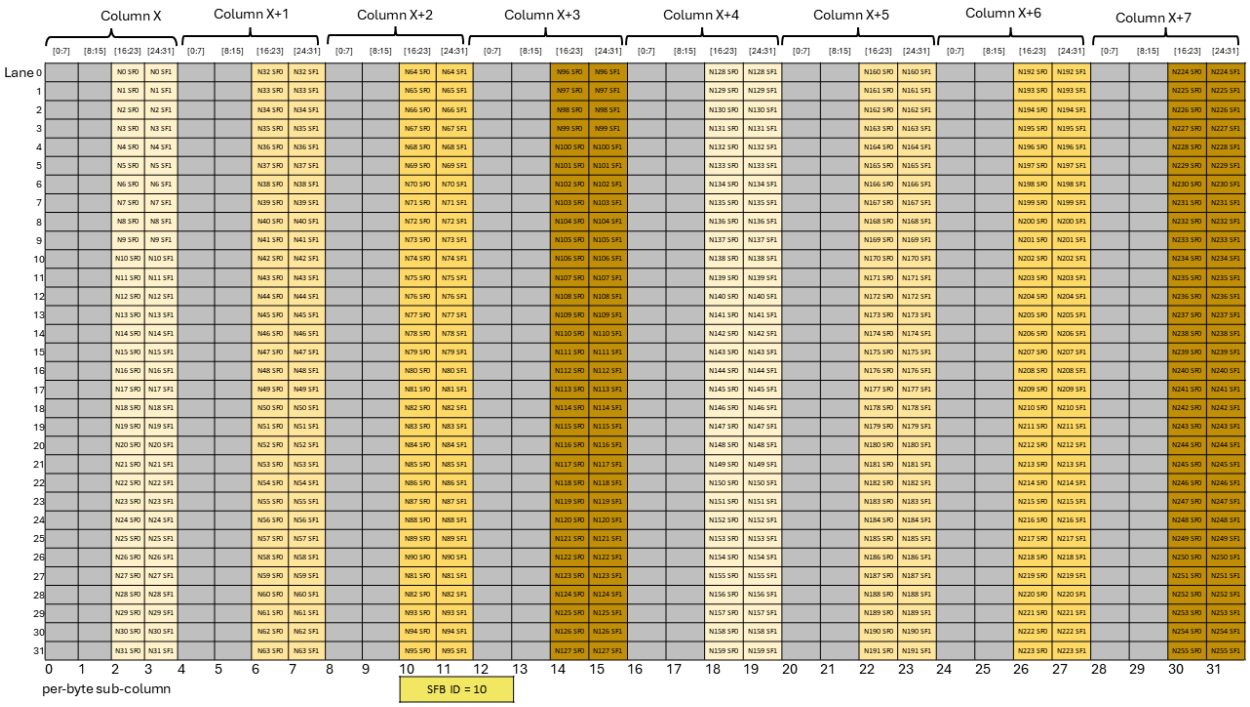

Figure 249: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=10

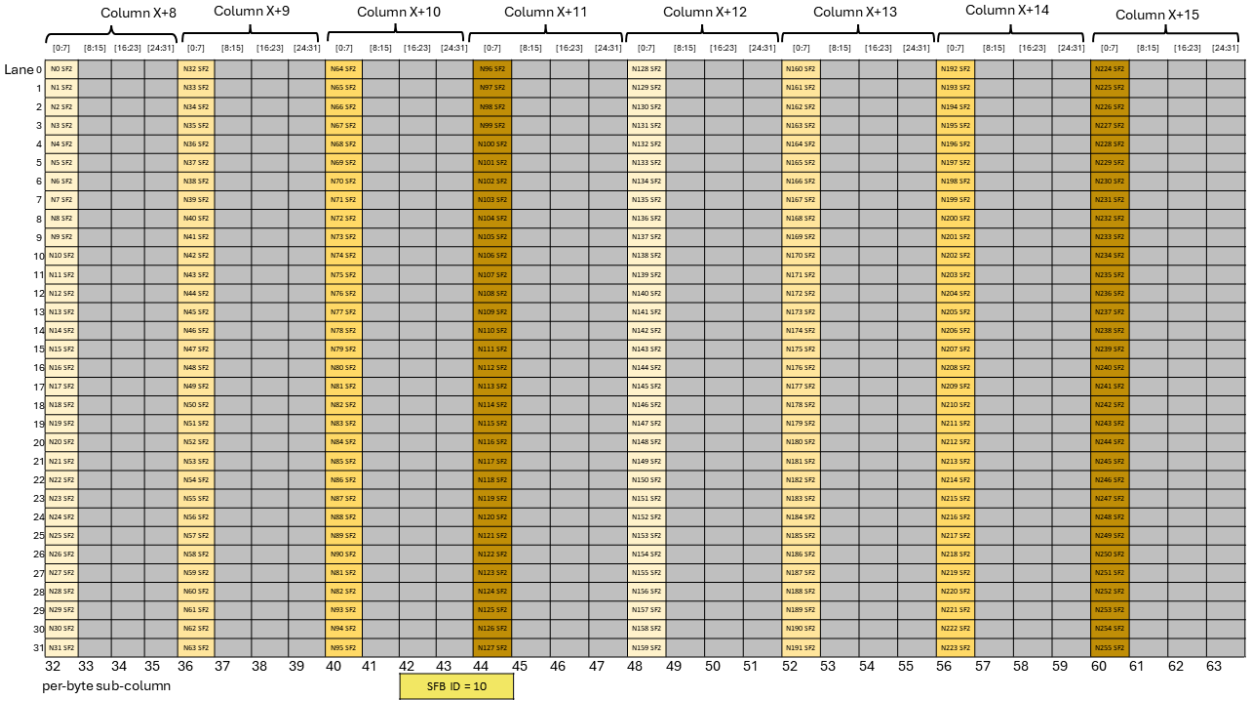

Figure 250: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=10

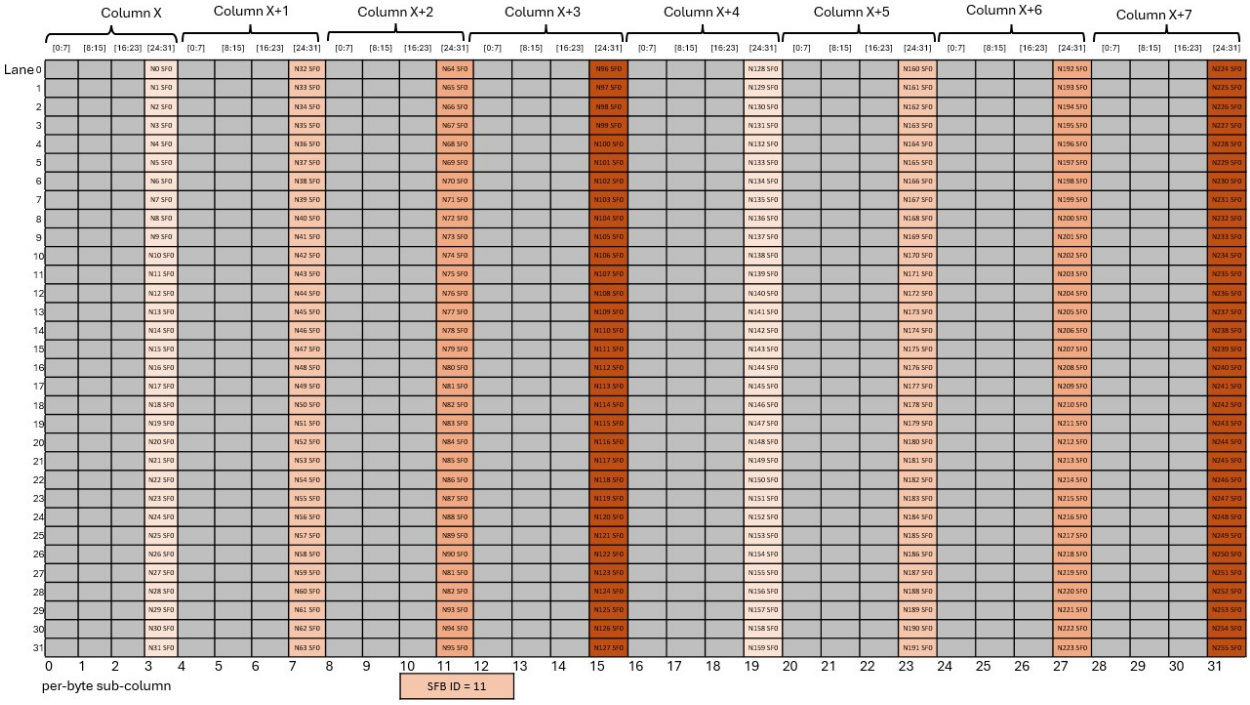

Figure 251: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=11

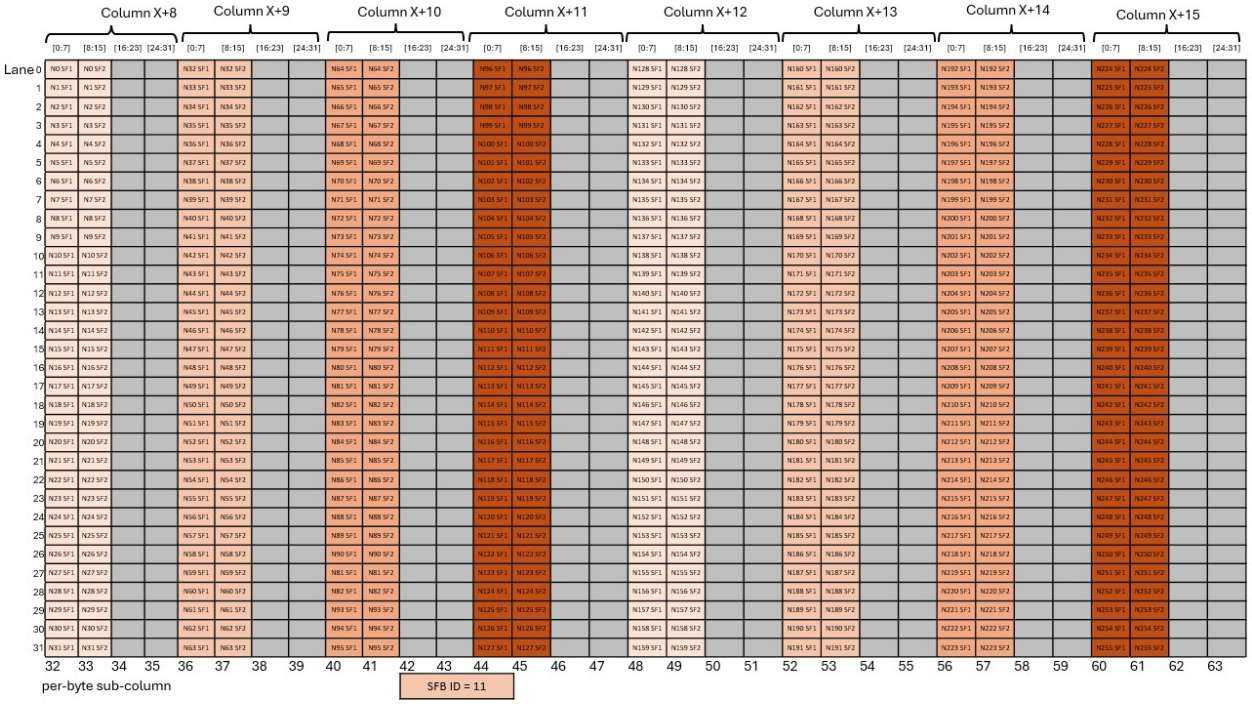

Figure 252: Layout of scale factor B matrix with block32 with K=96 and N>128 with SFA_ID=11

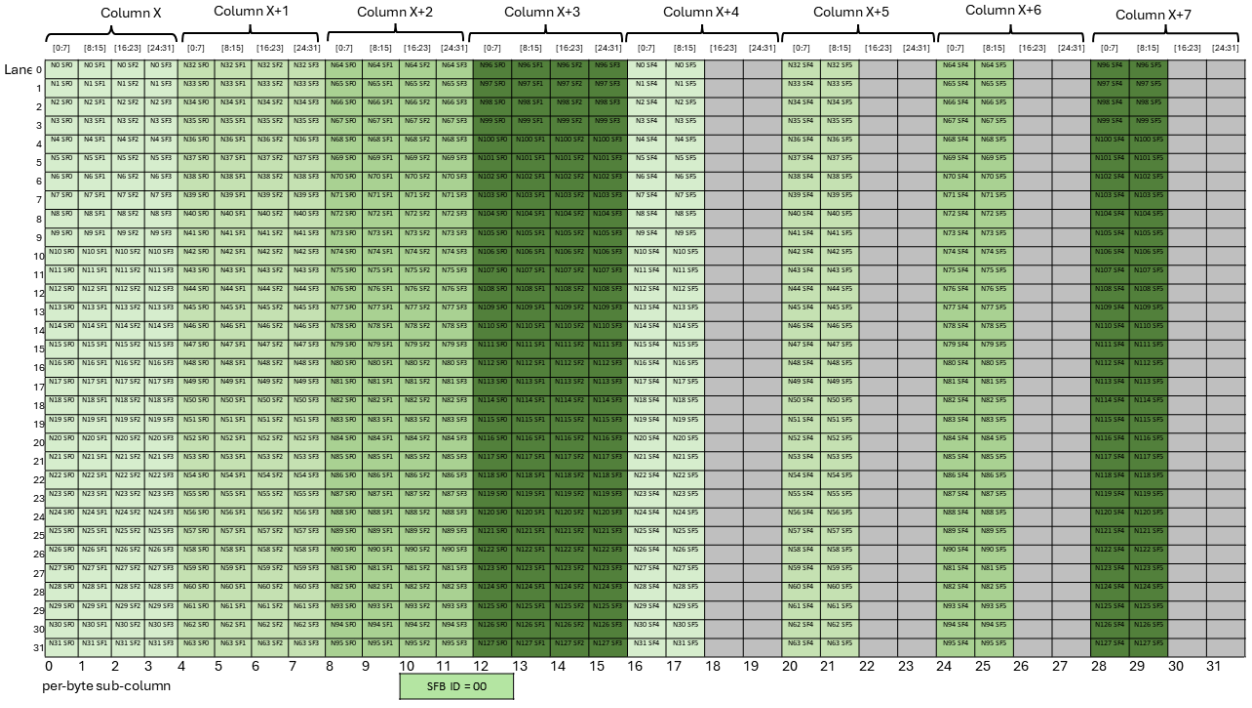

Figure 253: Layout of scale factor B matrix with block16 with K=96 and N<=128 with SFA_ID=00

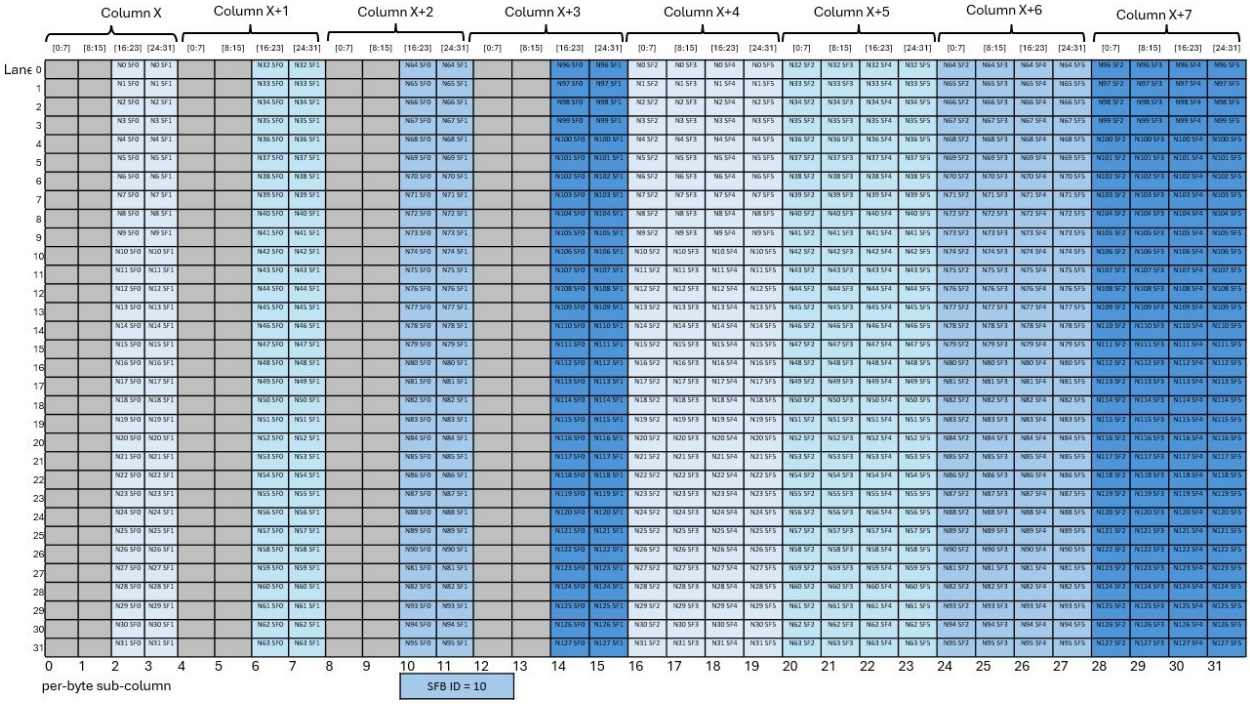

Figure 254: Layout of scale factor B matrix with block16 with K=96 and N<=128 with SFA_ID=10

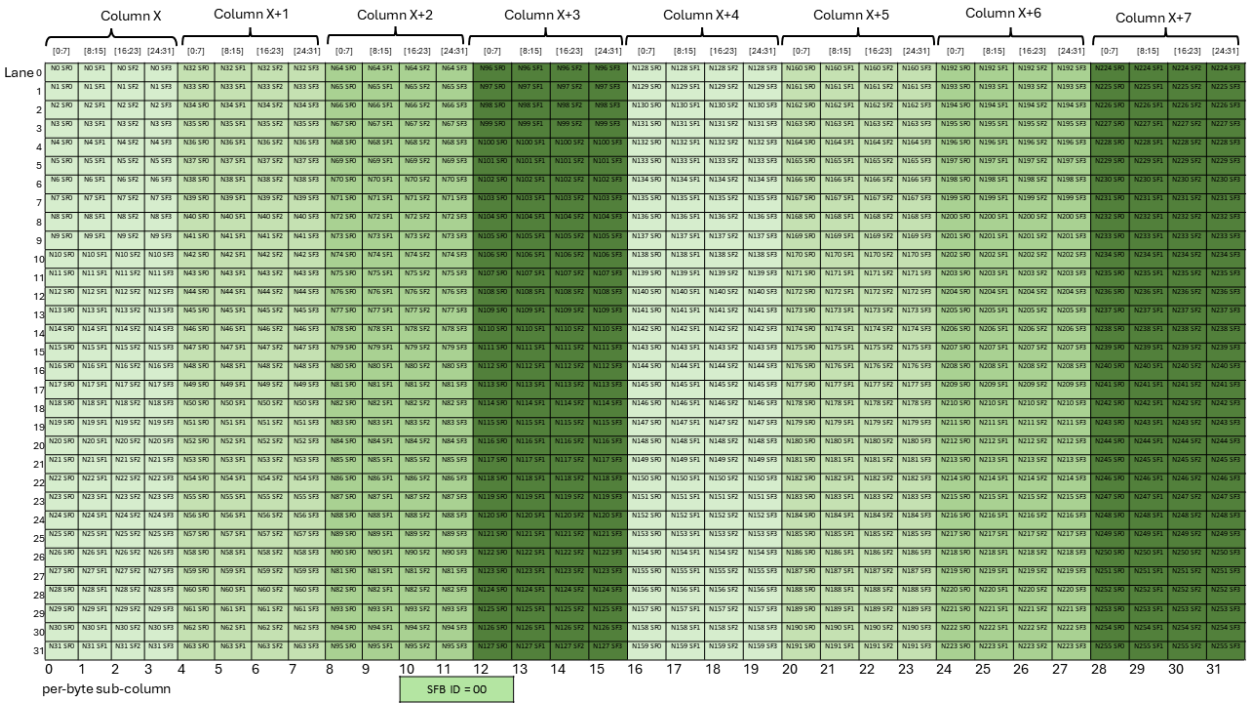

Figure 255: Layout of scale factor B matrix with block16 with K=96 and N>128 with SFA_ID=00

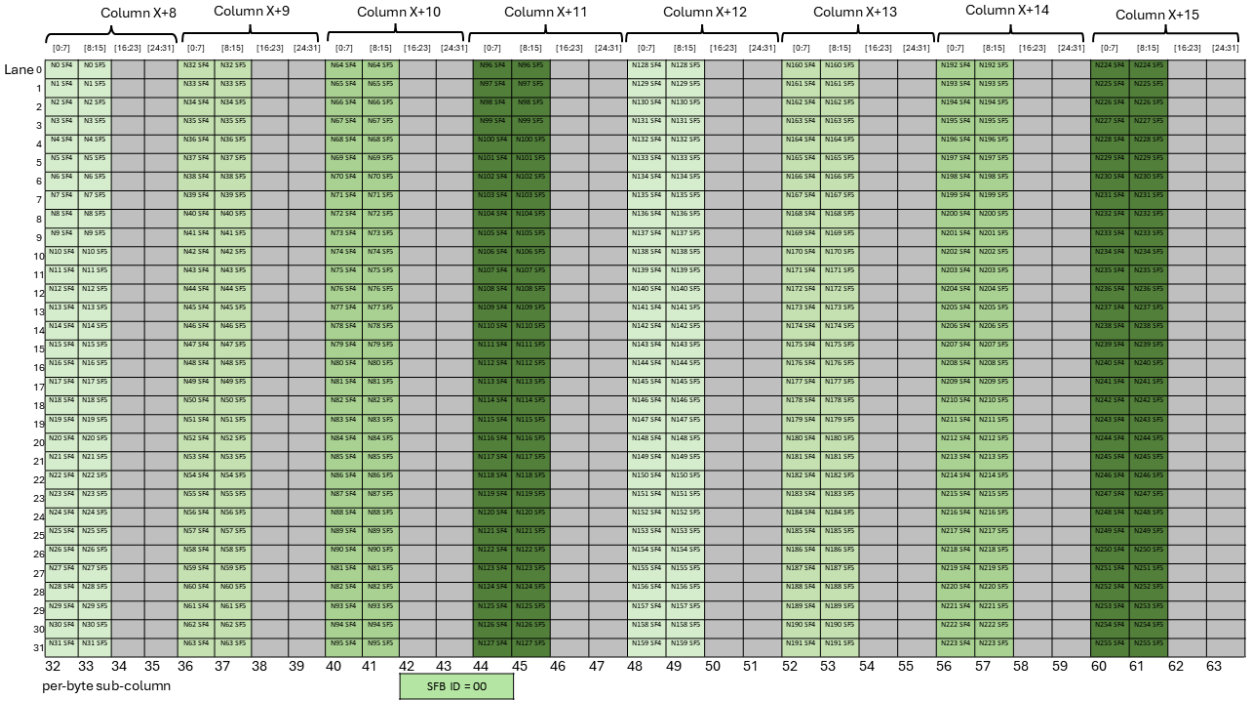

Figure 256: Layout of scale factor B matrix with block16 with K=96 and N>128 with SFA_ID=00

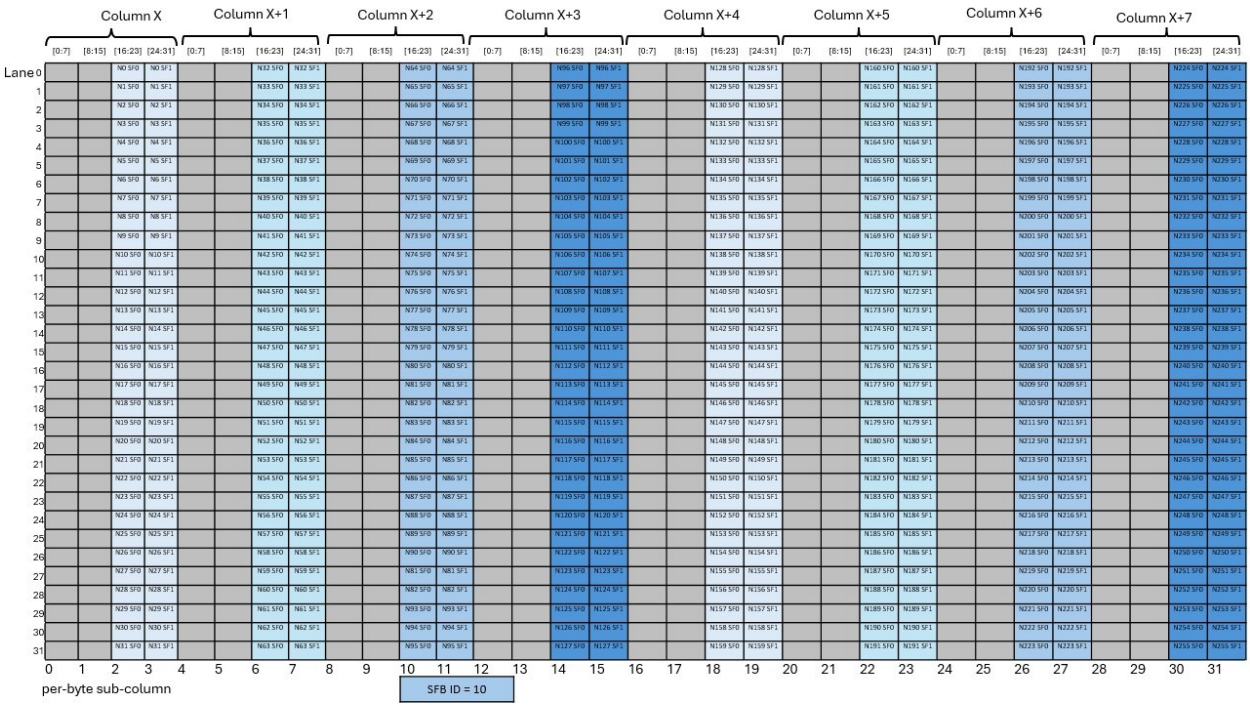

Figure 257: Layout of scale factor B matrix with block16 with K=96 and N>128 with SFA_ID=10

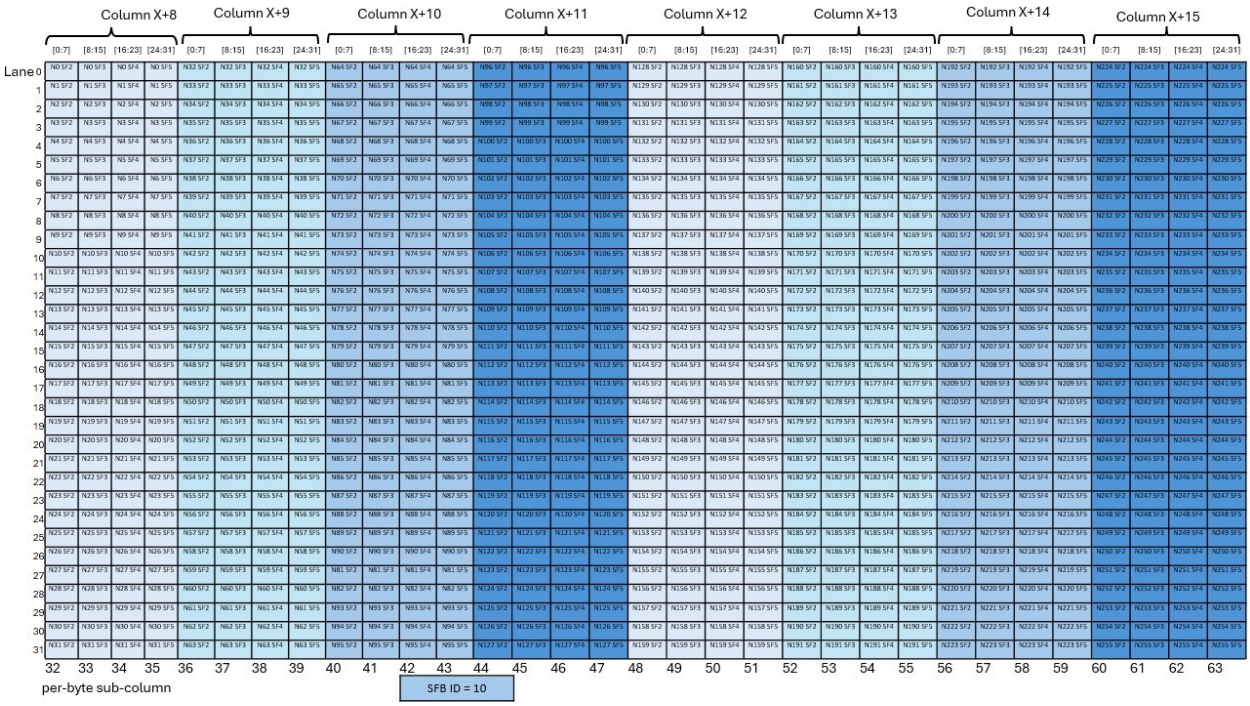

Figure 258: Layout of scale factor B matrix with block16 with K=96 and N>128 with SFA_ID=10

For example, if *SFB_ID* is 0, then all the green columns are selected to form the scale factor matrix. Similarly, if *SFB_ID* is 2, then all of the blue columns are selected to form the scale factor matrix.

9.7.16.10.8 Sparse Matrices

This instruction `tcgen05.mma.sp` can be used when the matrix A is a structured sparse matrix with 50% zeros in each row distributed as per its sparse granularity.

In a *MxNxK* sparse `tcgen05.mma.sp` operation, the matrix A of shape *MxK* is stored in a packed form as *Mx(K/2)* in memory. For each *K-wide* row of matrix A, 50% of elements are zeros and the remaining *K/2* non-zero elements are stored in memory. The metadata specifies the mapping of the *K/2* non-zero elements to the *K* elements before performing the MMA operation.

Granularity of sparse matrix A is defined as the ratio of the number of non-zero elements in a sub-chunk of the matrix row to the total number of elements in that sub-chunk where the size of the sub-chunk is shape-specific. The following table lists the granularity of different `tcgen05.mma.sp` variants:

.kind of tcgen05.mma	Sparse Granularity
.kind::tf32	1:2
.kind::f16	2:4
.kind::f8f6f4	
.kind::mxf8f6f4	
.kind::i8	
.kind::mxf4	4:8 (in pairs)

9.7.16.10.8.1 Sparse tcgen05.mma.sp with .kind::tf32

For .kind::tf32, matrix A is structured sparse at a granularity of 1:2. In other words, each chunk of two adjacent elements in a row of matrix A has one zero and one non-zero element. Only the non-zero element is stored in memory and the 4-bit index in the metadata indicates the position of the non-zero element in the two-wide chunk. The only meaningful values of the index are:

- 0b1110
- 0b0100

Rest of the values result in undefined behavior.

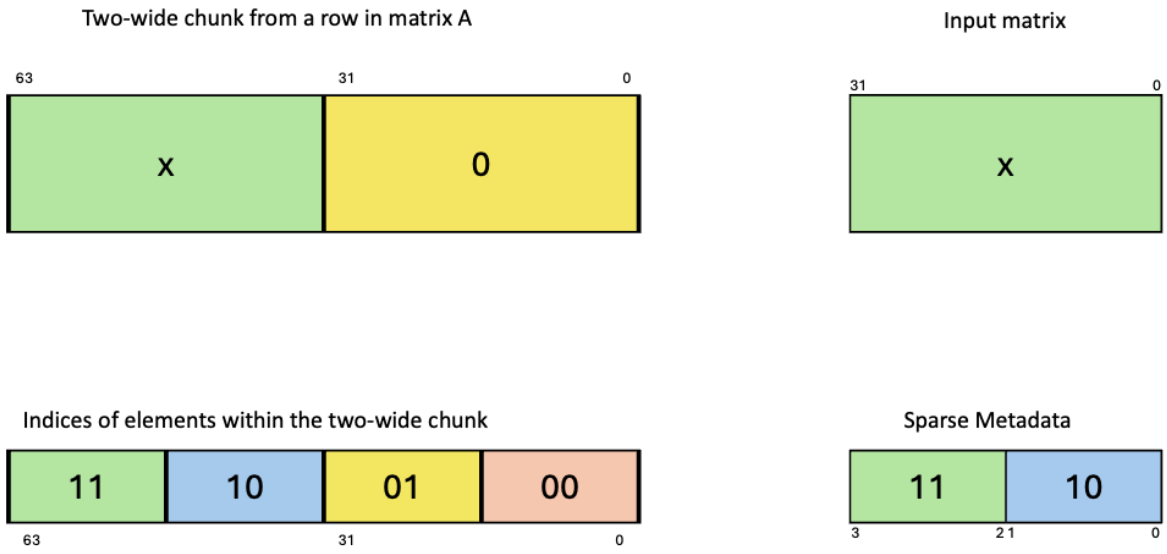

Figure 259: Sparse tcgen05.mma metadata example for tf32 kind

9.7.16.10.8.2 Sparse tcgen05.mma.sp with .kind::f16, .kind::f8f6f4, .kind::mxf8f6f4, .kind::i8

For the following `.kind` variants of `tcgen05.mma`:

- `.kind::f16`
- `.kind::f8f8f4`
- `.kind::mxf8f6f4`
- `.kind::i8`

matrix A is structured sparse at a granularity of `2:4`. In other words, each chunk of four adjacent elements in a row of matrix A has two zero and two non-zero elements. Only the non-zero elements are stored in memory and the two 2-bit indices in the metadata indicates the position of the two non-zero elements in the four-wide chunk. The only meaningful values of the index are:

- `0b0100`
- `0b1000`
- `0b1100`
- `0b1001`
- `0b1101`
- `0b0110`
- `0b1110`

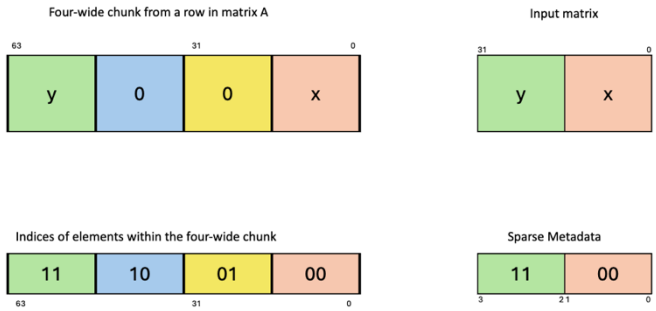

Figure 260: Sparse tcgen05.mma metadata example for f16/f8f6f4/mxf8f6f4 kind

9.7.16.10.8.3 Sparse tcgen05.mma.sp with .kind::mxf4 and .kind::mxf4nvf4

For `.kind::mxf4` and `.kind::mxf4nvf4`, matrix A is pair-wise structured sparse at a granularity of `4:8`. In other words, each chunk of eight adjacent elements in a row of matrix A has four zero and four non-zero elements. The zero and non-zero elements are clustered in sub-chunks of two elements each within the eight-wide chunk, so each two-wide sub-chunk within the eight-wide chunk must be all zeros or all non-zeros. Only the four non-zero elements are stored in memory and the two 2-bit indices in the metadata indicates the position of the two two-wide sub-chunks with non-zero values in the eight-wide chunk of a row of matrix A. The only meaningful values of the index are:

- `0b0100`
- `0b1000`

- `0b1100`
- `0b1001`
- `0b1101`
- `0b0110`
- `0b1110`

Rest of the values result in undefined behavior.

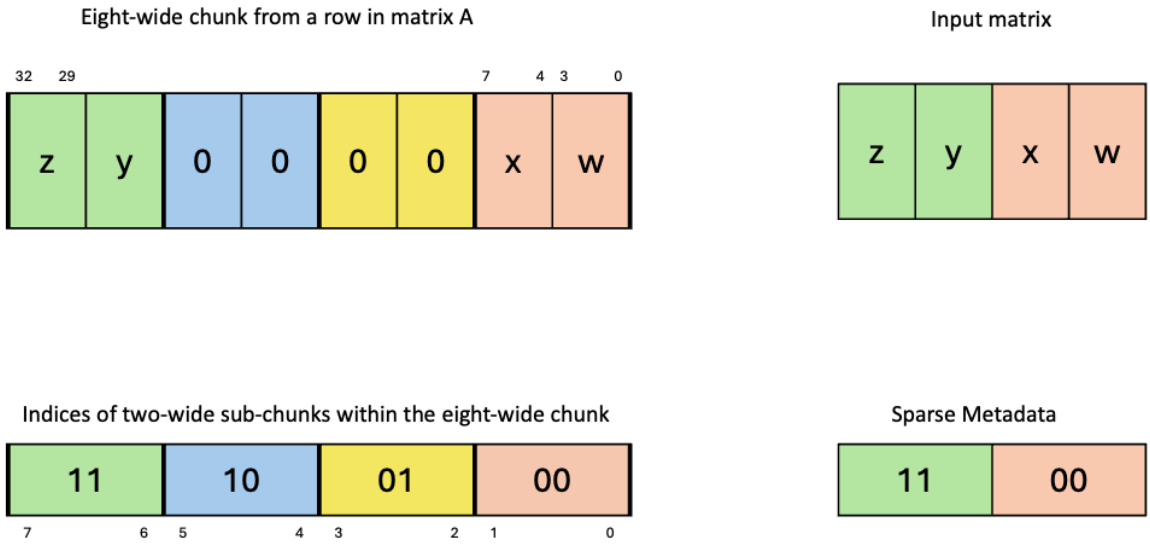

Figure 261: Sparse tcgen05.mma metadata example for mxf4 kind

9.7.16.10.8.4 Sparsity selector

The value of the sparsity selector selects the sub-columns in the Tensor Memory to form the sparsity metadata matrix, which is used with matrix A to form the multiplicand matrix.

The following shows the sparse metadata matrix layout in Tensor Memory for various MMA variants:

9.7.16.10.8.5 Layout of the Sparsity Metadata Matrix for M = 64 for `.kind::f16`

Figure 262 shows which sub-columns gets selected for different values of Sparsity Selector.

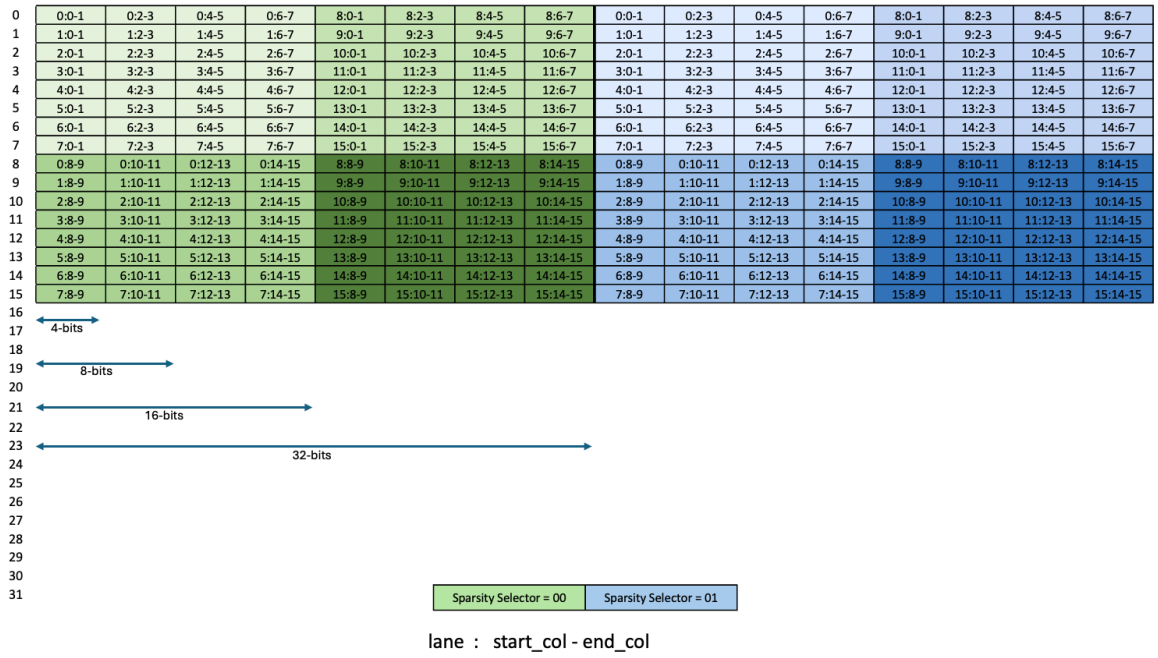

Figure 262: Sparsity Metadata Layout for M = 64 for `.kind::f16`

9.7.16.10.8.6 Layout of the Sparsity Metadata Matrix for M = 128 / M = 256 for `.kind::f16`

Figure 263 shows which sub-columns gets selected for different values of Sparsity Selector.

9.7.16.10.8.7 Layout of the Sparsity Metadata Matrix for M = 64 for `.kind::tf32`

Figure 264 shows which sub-columns gets selected for different values of Sparsity Selector.

9.7.16.10.8.8 Layout of the Sparsity Metadata Matrix for M = 128 / M = 256 for `.kind::tf32`

Figure 265 shows which sub-columns gets selected for different values of Sparsity Selector.

9.7.16.10.8.9 Layout of the Sparsity Metadata Matrix for M = 64 for `.kind::f8f6f4`, `.kind::mxf8f6f4`, `.kind::i8`, `.kind::mxf4`, `.kind::mxf4nvf4`

The value of the sparsity selector:

- must be 0 for `.kind::i8` and `.kind::f8f6f4`
- is assumed to be 0 for `.kind::mxf8f6f4`, `.kind::mxf4` and `.kind::mxf4nvf4`

and all of the columns are selected as shown in Figure 266

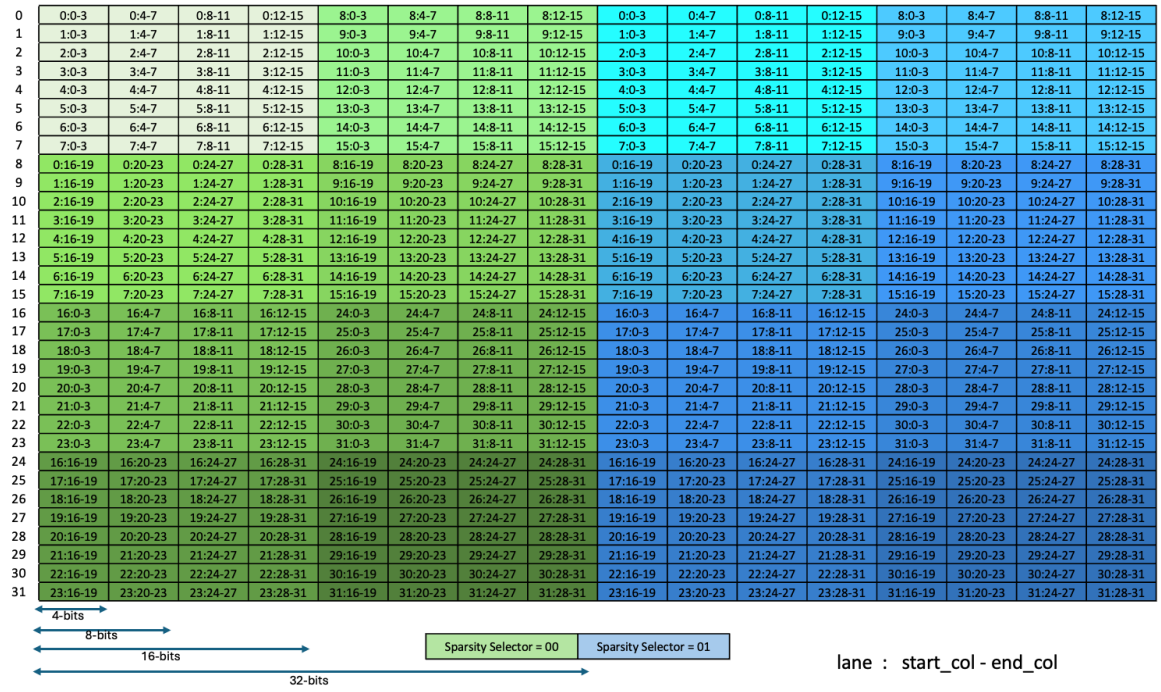

Figure 263: Sparsity Metadata Layout for M = 128 / M = 256 for `.kind::f16`

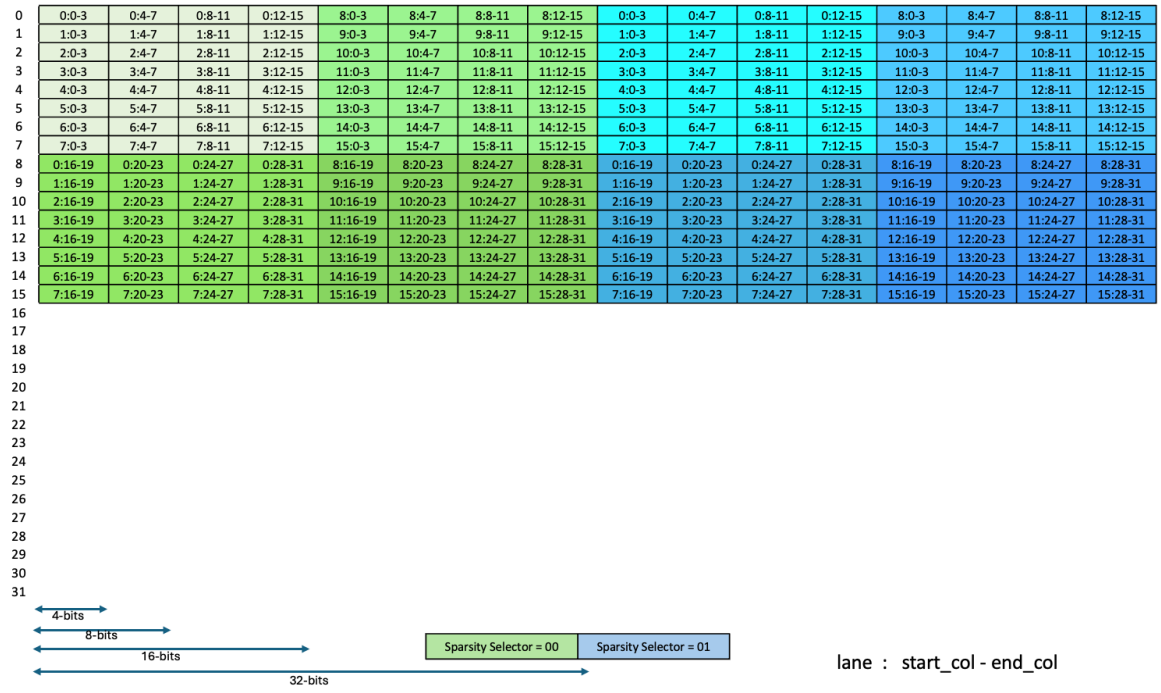

Figure 264: Sparsity Metadata Layout for M = 64 for `.kind::tf32`

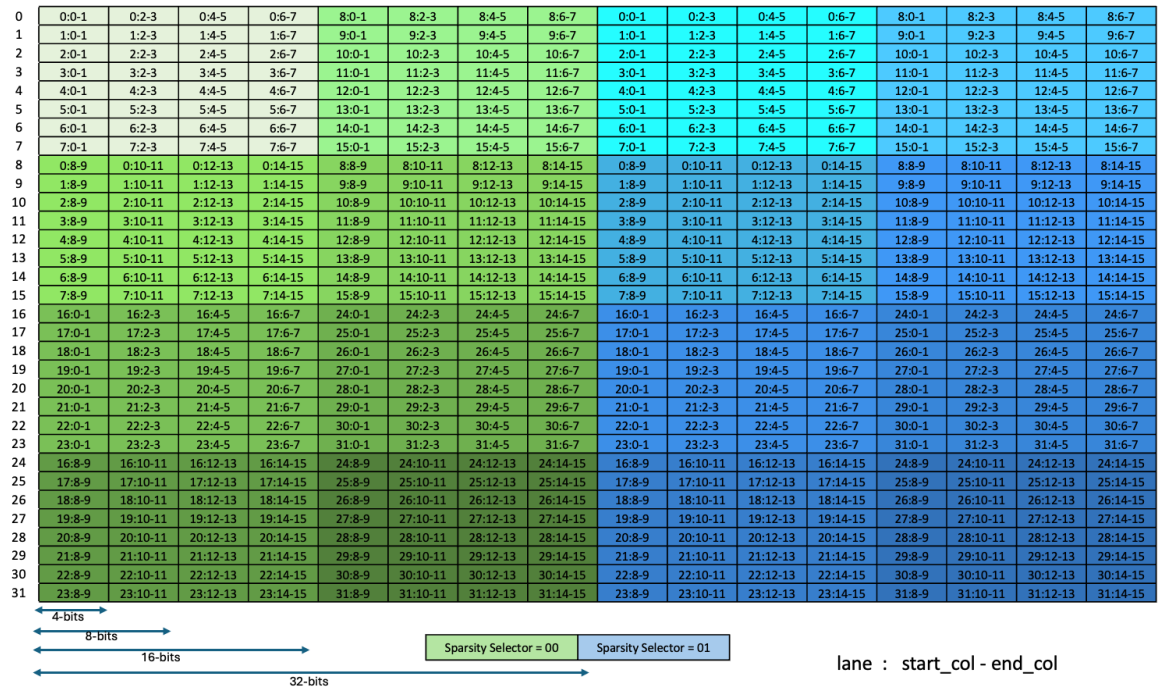

Figure 265: Sparsity Metadata Layout for M = 128 / M = 256 for `.kind::tf32`

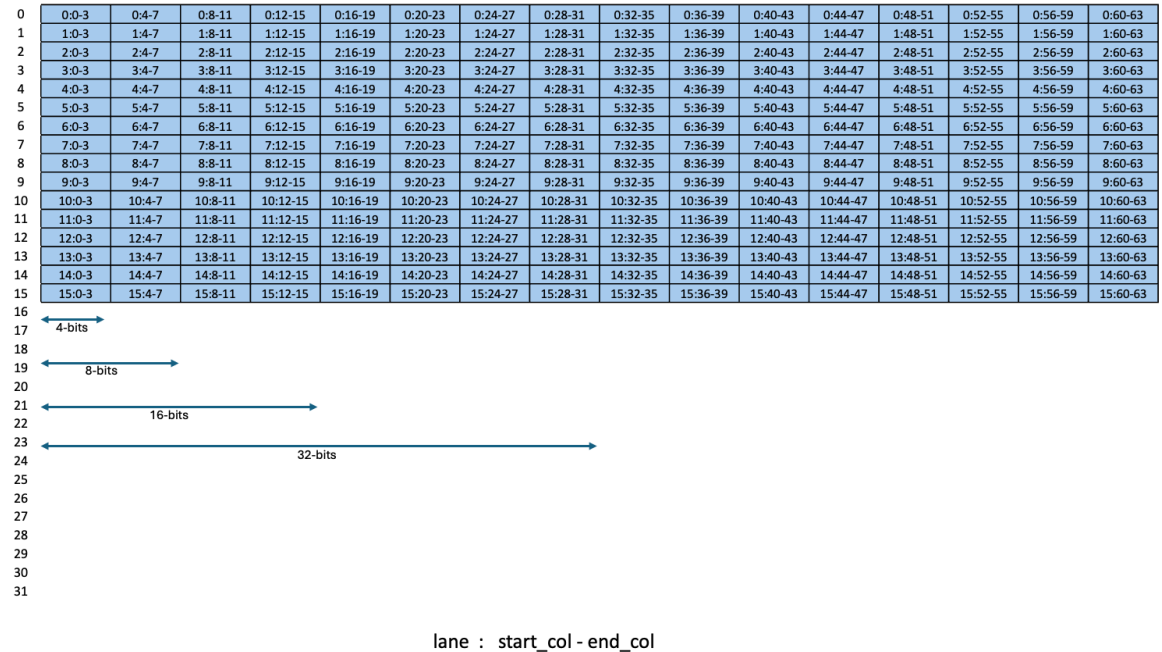

Figure 266: Sparsity Metadata Layout for M = 64 for `.kind::f8f6f4`, `.kind::mxf8f6f4`, `.kind::i8`, `.kind::mxf4`, `.kind::mxf4nvf4`

9.7.16.10.8.10 Layout of the Sparsity Metadata Matrix for M = 128 / M = 256 for `.kind::f8f6f4`, `.kind::mxf8f6f4`, `.kind::i8`, `.kind::mxf4`, `.kind::mxf4nvf4`

The value of the sparsity selector:

- must be 0 for `.kind::i8` and `.kind::f8f6f4`
- is assumed to be 0 for `.kind::mxf8f6f4`, `.kind::mxf4` and `.kind::mxf4nvf4`

and all of the columns are selected as shown in Figure 267

0	0:0-3	0:4-7	0:8-11	0:12-15	0:16-19	0:20-23	0:24-27	0:28-31	0:32-35	0:36-39	0:40-43	0:44-47	0:48-51	0:52-55	0:56-59	0:60-63
1	1:0-3	1:4-7	1:8-11	1:12-15	1:16-19	1:20-23	1:24-27	1:28-31	1:32-35	1:36-39	1:40-43	1:44-47	1:48-51	1:52-55	1:56-59	1:60-63
2	2:0-3	2:4-7	2:8-11	2:12-15	2:16-19	2:20-23	2:24-27	2:28-31	2:32-35	2:36-39	2:40-43	2:44-47	2:48-51	2:52-55	2:56-59	2:60-63
3	3:0-3	3:4-7	3:8-11	3:12-15	3:16-19	3:20-23	3:24-27	3:28-31	3:32-35	3:36-39	3:40-43	3:44-47	3:48-51	3:52-55	3:56-59	3:60-63
4	4:0-3	4:4-7	4:8-11	4:12-15	4:16-19	4:20-23	4:24-27	4:28-31	4:32-35	4:36-39	4:40-43	4:44-47	4:48-51	4:52-55	4:56-59	4:60-63
5	5:0-3	5:4-7	5:8-11	5:12-15	5:16-19	5:20-23	5:24-27	5:28-31	5:32-35	5:36-39	5:40-43	5:44-47	5:48-51	5:52-55	5:56-59	5:60-63
6	6:0-3	6:4-7	6:8-11	6:12-15	6:16-19	6:20-23	6:24-27	6:28-31	6:32-35	6:36-39	6:40-43	6:44-47	6:48-51	6:52-55	6:56-59	6:60-63
7	7:0-3	7:4-7	7:8-11	7:12-15	7:16-19	7:20-23	7:24-27	7:28-31	7:32-35	7:36-39	7:40-43	7:44-47	7:48-51	7:52-55	7:56-59	7:60-63
8	8:0-3	8:4-7	8:8-11	8:12-15	8:16-19	8:20-23	8:24-27	8:28-31	8:32-35	8:36-39	8:40-43	8:44-47	8:48-51	8:52-55	8:56-59	8:60-63
9	9:0-3	9:4-7	9:8-11	9:12-15	9:16-19	9:20-23	9:24-27	9:28-31	9:32-35	9:36-39	9:40-43	9:44-47	9:48-51	9:52-55	9:56-59	9:60-63
10	10:0-3	10:4-7	10:8-11	10:12-15	10:16-19	10:20-23	10:24-27	10:28-31	10:32-35	10:36-39	10:40-43	10:44-47	10:48-51	10:52-55	10:56-59	10:60-63
11	11:0-3	11:4-7	11:8-11	11:12-15	11:16-19	11:20-23	11:24-27	11:28-31	11:32-35	11:36-39	11:40-43	11:44-47	11:48-51	11:52-55	11:56-59	11:60-63
12	12:0-3	12:4-7	12:8-11	12:12-15	12:16-19	12:20-23	12:24-27	12:28-31	12:32-35	12:36-39	12:40-43	12:44-47	12:48-51	12:52-55	12:56-59	12:60-63
13	13:0-3	13:4-7	13:8-11	13:12-15	13:16-19	13:20-23	13:24-27	13:28-31	13:32-35	13:36-39	13:40-43	13:44-47	13:48-51	13:52-55	13:56-59	13:60-63
14	14:0-3	14:4-7	14:8-11	14:12-15	14:16-19	14:20-23	14:24-27	14:28-31	14:32-35	14:36-39	14:40-43	14:44-47	14:48-51	14:52-55	14:56-59	14:60-63
15	15:0-3	15:4-7	15:8-11	15:12-15	15:16-19	15:20-23	15:24-27	15:28-31	15:32-35	15:36-39	15:40-43	15:44-47	15:48-51	15:52-55	15:56-59	15:60-63
16	16:0-3	16:4-7	16:8-11	16:12-15	16:16-19	16:20-23	16:24-27	16:28-31	16:32-35	16:36-39	16:40-43	16:44-47	16:48-51	16:52-55	16:56-59	16:60-63
17	17:0-3	17:4-7	17:8-11	17:12-15	17:16-19	17:20-23	17:24-27	17:28-31	17:32-35	17:36-39	17:40-43	17:44-47	17:48-51	17:52-55	17:56-59	17:60-63
18	18:0-3	18:4-7	18:8-11	18:12-15	18:16-19	18:20-23	18:24-27	18:28-31	18:32-35	18:36-39	18:40-43	18:44-47	18:48-51	18:52-55	18:56-59	18:60-63
19	19:0-3	19:4-7	19:8-11	19:12-15	19:16-19	19:20-23	19:24-27	19:28-31	19:32-35	19:36-39	19:40-43	19:44-47	19:48-51	19:52-55	19:56-59	19:60-63
20	20:0-3	20:4-7	20:8-11	20:12-15	20:16-19	20:20-23	20:24-27	20:28-31	20:32-35	20:36-39	20:40-43	20:44-47	20:48-51	20:52-55	20:56-59	20:60-63
21	21:0-3	21:4-7	21:8-11	21:12-15	21:16-19	21:20-23	21:24-27	21:28-31	21:32-35	21:36-39	21:40-43	21:44-47	21:48-51	21:52-55	21:56-59	21:60-63
22	22:0-3	22:4-7	22:8-11	22:12-15	22:16-19	22:20-23	22:24-27	22:28-31	22:32-35	22:36-39	22:40-43	22:44-47	22:48-51	22:52-55	22:56-59	22:60-63
23	23:0-3	23:4-7	23:8-11	23:12-15	23:16-19	23:20-23	23:24-27	23:28-31	23:32-35	23:36-39	23:40-43	23:44-47	23:48-51	23:52-55	23:56-59	23:60-63
24	24:0-3	24:4-7	24:8-11	24:12-15	24:16-19	24:20-23	24:24-27	24:28-31	24:32-35	24:36-39	24:40-43	24:44-47	24:48-51	24:52-55	24:56-59	24:60-63
25	25:0-3	25:4-7	25:8-11	25:12-15	25:16-19	25:20-23	25:24-27	25:28-31	25:32-35	25:36-39	25:40-43	25:44-47	25:48-51	25:52-55	25:56-59	25:60-63
26	26:0-3	26:4-7	26:8-11	26:12-15	26:16-19	26:20-23	26:24-27	26:28-31	26:32-35	26:36-39	26:40-43	26:44-47	26:48-51	26:52-55	26:56-59	26:60-63
27	27:0-3	27:4-7	27:8-11	27:12-15	27:16-19	27:20-23	27:24-27	27:28-31	27:32-35	27:36-39	27:40-43	27:44-47	27:48-51	27:52-55	27:56-59	27:60-63
28	28:0-3	28:4-7	28:8-11	28:12-15	28:16-19	28:20-23	28:24-27	28:28-31	28:32-35	28:36-39	28:40-43	28:44-47	28:48-51	28:52-55	28:56-59	28:60-63
29	29:0-3	29:4-7	29:8-11	29:12-15	29:16-19	29:20-23	29:24-27	29:28-31	29:32-35	29:36-39	29:40-43	29:44-47	29:48-51	29:52-55	29:56-59	29:60-63
30	30:0-3	30:4-7	30:8-11	30:12-15	30:16-19	30:20-23	30:24-27	30:28-31	30:32-35	30:36-39	30:40-43	30:44-47	30:48-51	30:52-55	30:56-59	30:60-63
31	31:0-3	31:4-7	31:8-11	31:12-15	31:16-19	31:20-23	31:24-27	31:28-31	31:32-35	31:36-39	31:40-43	31:44-47	31:48-51	31:52-55	31:56-59	31:60-63

Figure 267: Sparsity Metadata Layout for M = 128 / M = 256 for `.kind::f8f6f4`, `.kind::mxf8f6f4`, `.kind::i8`, `.kind::mxf4`, `.kind::mxf4nvf4`

9.7.16.10.8.11 Alignment restriction

The layouts which utilize only half the datapath lanes as specified in *Data Path Layout Organization*, i.e. *Layout F* and *Layout C*, must use the same alignment across matrices A, D and the sparsity metadata matrix.

9.7.16.10.9 TensorCore 5th Generation of MMA Instructions

9.7.16.10.9.1 TensorCore 5th Generation Instructions: `tcgen05.mma`

`tcgen05.mma`

Perform the 5th generation of matrix multiply and accumulate operation.

Syntax

```
// 1. Floating-point type without block scaling:

tcgen05.mma.cta_group.kind   [d-tmem],  a-desc,  b-desc, idesc,
                             { disable-output-lane }, enable-input-d {, scale-input-d}
↪;

tcgen05.mma.cta_group.kind   [d-tmem], [a-tmem], b-desc, idesc,
                             { disable-output-lane }, enable-input-d {, scale-input-d}
↪;

.kind      = { .kind::f16, .kind::tf32, .kind::f8f6f4 }
.cta_group = { .cta_group::1, .cta_group::2 }

-----------------------------------------------------------------------------

// 2. Floating-point type with block scaling:

tcgen05.mma.cta_group.kind.block_scale{.scale_vectorsize}
                                       [d-tmem],  a-desc,  b-desc, idesc,
                                       [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

tcgen05.mma.cta_group.kind.block_scale{.scale_vectorsize}
                                       [d-tmem], [a-tmem], b-desc, idesc,
                                       [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

.kind = { .kind::mxf8f6f4, .kind::mxf4, .kind::mxf4nvf4 }
.cta_group      = { .cta_group::1,   .cta_group::2 }
.scale_vectorsize = { .scale_vec::1X, .scale_vec::2X, .scale_vec::4X, .block16, .
↪block32 }

-----------------------------------------------------------------------------

// 3. Convolution MMA for floating-point type without block scaling:

tcgen05.mma.cta_group.kind.collector_usage [d-tmem],  a-desc,  b-desc, idesc,
                                           { disable-output-lane }, enable-input-d {,
↪scale-input-d};

tcgen05.mma.cta_group.kind{.ashift}.collector_usage [d-tmem], [a-tmem], b-desc, idesc,
                                                    { disable-output-lane }, enable-
↪input-d {, scale-input-d};

tcgen05.mma.cta_group.kind.ashift{.collector_usage} [d-tmem], [a-tmem], b-desc, idesc,
                                                    { disable-output-lane }, enable-
↪input-d {, scale-input-d};

.kind      = { .kind::f16, .kind::tf32, .kind::f8f6f4 }
.cta_group = { .cta_group::1,   .cta_group::2 }
.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }

-----------------------------------------------------------------------------
```

(continues on next page)

(continued from previous page)

```
// 4. Activation Stationary MMA for floating-point type with block scaling:

tcgen05.mma.cta_group.kind.block_scale{.scale_vectorsize}.collector_usage
                                          [d-tmem],  a-desc,  b-desc, idesc,
                                          [scale-A-tmem], [scale-B-tmem], enable-
↪input-d;

tcgen05.mma.cta_group.kind.block_scale{.scale_vectorsize}.collector_usage
                                          [d-tmem], [a-tmem], b-desc, idesc,
                                          [scale-A-tmem], [scale-B-tmem], enable-
↪input-d;

.cta_group       = { .cta_group::1,   .cta_group::2 }
.scale_vectorsize  = { .scale_vec::1X, .scale_vec::2X, .scale_vec::4X, .block16, .
↪block32 }
.kind            = { .kind::mxf8f6f4, .kind::mxf4, .kind::mxf4nvf4 }
.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }

-----------------------------------------------------------------------------

// 5. Integer type:

tcgen05.mma.cta_group.kind::i8  [d-tmem],  a-desc,  b-desc, idesc,
                                { disable-output-lane }, enable-input-d;

tcgen05.mma.cta_group.kind::i8  [d-tmem], [a-tmem], b-desc, idesc,
                                { disable-output-lane }, enable-input-d;

.cta_group = { .cta_group::1,   .cta_group::2  }

-----------------------------------------------------------------------------

// 6. Convolution MMA for integer type:

tcgen05.mma.cta_group.kind::i8.collector_usage          [d-tmem],  a-desc,  b-desc,
↪idesc,
                                                        { disable-output-lane },
↪enable-input-d;

tcgen05.mma.cta_group.kind::i8.ashift{.collector_usage} [d-tmem], [a-tmem], b-desc,
↪idesc,
                                                        { disable-output-lane },
↪enable-input-d;

tcgen05.mma.cta_group.kind::i8{.ashift}.collector_usage [d-tmem], [a-tmem], b-desc,
↪idesc,
                                                        { disable-output-lane },
↪enable-input-d;

.cta_group       = { .cta_group::1,   .cta_group::2  }
.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }
```

Description

Instruction `tcgen05.mma` is an asynchronous instruction which initiates an *MxNxK* matrix multiply and accumulate operation, `D = A*B+D` where the `A` matrix is *MxK*, the `B` matrix is *KxN*, and the `D` matrix is *MxN*.

The operation of the form `D = A*B` is issued when the input predicate argument `enable-input-d` is false.

The optional immediate argument `scale-input-d` can be specified to scale the input matrix `D` as follows: `D = A*B+D * (2 ^ - scale-input-d)`

The valid range of values for argument `scale-input-d` is [0, 15]. The argument `scale-input-d` is only valid for `.kind::tf32` and `.kind::f16`.

The 32-bit register operand `idesc` is the instruction descriptor as described in *Instruction descriptor*, specifies the shapes, exact types, sparsity and other details of the input matrices, output matrix and the matrix multiply and accumulate operation.

The qualifier `.cta_group::1` specifies that the matrix multiply and accumulate operation is performed on the *Tensor Memory* of the executing thread's CTA only. The qualifier `.cta_group::2` specifies that the matrix multiply and accumulate operation is performed on the *Tensor Memory* of the executing thread's CTA and its *peer CTA*.

The instruction `tcgen05.mma` has single thread semantics, unlike the collective instructions `mma.sync` or `wgmma.mma_async`. So, a single thread issuing the `tcgen05.mma` will result in the initiation of the whole matrix multiply and accumulate operation. Refer to the section *Issue Granularity*.

The qualifier `.kind` specifies the general kind of the element types of the multiplicand matrices. The exact types of the elements of the input and output matrices for each MMA-kind are specified in the *Instruction descriptor*.

The address operand `d-tmem` specifies the address of the destination and the accumulation matrix `D` in the *Tensor Memory*. The address operand `a-tmem` specifies the address of the matrix `A` in the *Tensor Memory*. The 64-bit register operand `a-desc` and `b-desc` are the matrix descriptors which represent the matrices `A` and `B` in shared memory respectively. The format of the matrix descriptor is described in *Matrix Descriptors*.

The vector operand `disable-output-lane` specifies the lane(s) in the *Tensor Memory* that should be not be updated with the resultant matrix `D`. Elements of the vector operand `disable-output-lane` forms a mask where each bit corresponds to a lane of the *Tensor Memory*, with least significant bit of the first element of the vector (leftmost in syntax) corresponding to the lane 0 of the *Tensor Memory*. If a bit in the mask is 1, then the corresponding lane in the Tensor Memory for the resultant matrix `D` will not be updated. The size of the vector is as follows:

.cta_group	Size of the vector disable-output-lane
::1	4
::2	8

Qualifier `.block_scale` specifies that the matrices `A` and `B` are scaled with `scale_A` and `scale_B` matrices respectively before performing the matrix multiply and accumulate operation as specified in the section *Block Scaling*. The address operand `scale-A-tmem` and `scale-B-tmem` specify the base address the matrices `scale_A` and `scale_B` respectively in the *Tensor Memory*.

For qualifier `.scale_vectorsize`,

- If `.scale_vec::NX` is specified: N specifies the number of columns in `scale_A` matrix and number of rows in `scale_B` matrix.
- If `.blockN` is specified: N specifies the block size for which single scale factor will be applied. In this form, value of N is same as the K-dimension / (N of `.scale_vec::NX`).

Aliased `.scale_vectorsize` variants:

1. `.block16` is aliased with:
    1. `.scale_vec::4X` when `.kind = .kind::mxf4nvf4` and K = 64 or 128
2. `.block32` is aliased with:
    1. `.scale_vec::1X` when `.kind = .kind::mxf8f6f4` for all supported values of K
    2. `.scale_vec::2X` when `.kind = .kind::mxf4` or `.kind::mxf4nvf4` and K = 64 or 128

The valid combinations of MMA-kind and `.scale_vectorsize` are described in Table 56. For `.kind::mxf4` when the qualifier `.scale_vectorsize` is not specified, then it defaults to `.block32`. For `.kind::mxf4nvf4`, the qualifier `.scale_vectorsize` must be explicitly specified.

The qualifier `.ashift` shifts the rows of the A matrix down by one row, except for the last row in the *Tensor Memory*. Qualifier `.ashift` is only allowed with *M* = 128 or *M* = 256.

The qualifier `.collector_usage` specifies the usage of collector buffer for matrix A. Following collector buffer operations can be specified:

.collector_usage	Semantics
`.collector::a::fill`	Specifies that the A matrix read from the memory should be filled in collector buffer.
`.collector::a::use`	Specifies that the A matrix can be read from the collector buffer. This requires a previous fill to the collector buffer to be still valid.
`.collector::a::lastuse`	Specifies that the A matrix can be read from the collector buffer and the contents of the collector buffer can be discarded. This requires a previous fill to the collector buffer to be valid till the collector buffer is read.
`.collector::a::discard`	Specifies that the contents of the collector buffer for A can be discarded.

If no `.collector_usage` qualifier is specified, then it defaults to `.collector::a::discard`. It is illegal to specify either of `.collector::a::use` or `.collector::a::fill` along with `.ashift`.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Qualifier `.kind::mxf4nvf4` introduced in PTX ISA version 8.7.

Qualifiers `.block16` and `.block32` introduced in PTX ISA version 8.8.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8 except `.kind::i8`:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifier `.kind::i8` is supported on following archutectures:

- `sm_100a`
- `sm_101a`

Argument `scale-input-d` requires `sm_100a` and is supported on `sm_100f` or higher in the same family from PTX ISA version 8.8.

For `.scale_vectorsize`,

- `.scale_vec::1X`, `.scale_vec::2X`, `.scale_vec::4X` requires `sm_100a`.
- `.block16`, `.block32` requires `sm_100f` or `sm_101f`.

For Target ISA details on matrix shape, check *Target ISA Note*.

For Target ISA details on shared memory descriptor, check *Target ISA Note*.

Examples

```
tcgen05.mma.cta_group::1.kind::tf32      [taddr0],  adesc,  bdesc, idesc, {m0, m1, m2,
↪ m3}, p;
tcgen05.mma.cta_group::1.kind::mxf8f6f4  [taddr2],  [taddr1],  bdesc, idesc,
                                         [tmem_scaleA], [tmem_scaleB], p;

tcgen05.commit.cta_group::1.mbarrier::arrive::one.b64 [mbarObj0];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj0], 0;
@!p bra loop;
```

9.7.16.10.9.2 TensorCore 5th Generation Instructions: `tcgen05.mma.sp`

`tcgen05.mma.sp`

Perform the 5th generation of matrix multiply and accumulate operation with sparse A matrix.

Syntax

```
// 1. Floating-point type without block scaling:

tcgen05.mma.sp.cta_group.kind  [d-tmem],  a-desc,  b-desc, [sp-meta-tmem] ,  idesc,
                               { disable-output-lane }, enable-input-d{, scale-input-
↪d};

tcgen05.mma.sp.cta_group.kind  [d-tmem], [a-tmem], b-desc, [sp-meta-tmem] , idesc,
                               { disable-output-lane }, enable-input-d{, scale-input-
↪d};

.kind       = { .kind::f16, , .kind::tf32, .kind::f8f6f4 }
.cta_group  = { .cta_group::1,  .cta_group::2 }

-----------------------------------------------------------------------------

// 2. Floating-point type with block scaling:

tcgen05.mma.sp.cta_group.kind.block_scale{.scale_vectorsize}
                                       [d-tmem],  a-desc,  b-desc , [sp-meta-tmem] ,
↪ idesc,
                                       [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

tcgen05.mma.sp.cta_group.kind.block_scale{.scale_vectorsize}
                                       [d-tmem], [a-tmem], b-desc , [sp-meta-tmem] ,
↪ idesc,
                                       [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

.scale_vectorsize = { .scale_vec::1X, .scale_vec::2X, .scale_vec::4X, .block16, .
↪block32 }
.cta_group      = { .cta_group::1,  .cta_group::2 }
.kind = { .kind::mxf8f6f4, .kind::mxf4, .kind::mxf4nvf4 }

-----------------------------------------------------------------------------

// 3. Convolution MMA with floating-point type without block scaling:

tcgen05.mma.sp.cta_group.kind.collector_usage          [d-tmem],  a-desc,  b-desc,
                                                       [sp-meta-tmem] ,  idesc,
                                                       { disable-output-lane },
↪enable-input-d
                                                       {, scale-input-d};

tcgen05.mma.sp.cta_group.kind.ashift{.collector_usage}  [d-tmem], [a-tmem], b-desc,
                                                       [sp-meta-tmem] , idesc,
                                                       { disable-output-lane },
↪enable-input-d
```

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```
                                                                {, scale-input-d};

tcgen05.mma.sp.cta_group.kind{.ashift}.collector_usage  [d-tmem], [a-tmem], b-desc,
                                                                [sp-meta-tmem] , idesc,
                                                                { disable-output-lane },
↪enable-input-d
                                                                {, scale-input-d};

.kind            = { .kind::f16, .kind::tf32, .kind::f8f6f4 }
.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }

-------------------------------------------------------------------------------

// 4. Activation Stationary MMA with floating-point type with block scaling:

tcgen05.mma.sp.cta_group.kind.block_scale{.scale_vectorsize}.collector_usage
                                          [d-tmem],  a-desc,  b-desc , [sp-meta-tmem] ,
↪ idesc,
                                          [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

tcgen05.mma.sp.cta_group.kind.block_scale{.scale_vectorsize}.collector_usage
                                          [d-tmem], [a-tmem], b-desc , [sp-meta-tmem] ,
↪ idesc,
                                          [scale-A-tmem], [scale-B-tmem], enable-input-
↪d;

.kind = { .kind::mxf8f6f4, .kind::mxf4, .kind::mxf4nvf4 }
.scale_vectorsize = { .scale_vec::1X, .scale_vec::2X, .scale_vec::4X, .block16, .
↪block32 }
.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }

-------------------------------------------------------------------------------

// 5. Integer type:

tcgen05.mma.sp.cta_group.kind::i8 [d-tmem],  a-desc,  b-desc, [sp-meta-tmem] , idesc,
                                  { disable-output-lane }, enable-input-d;

tcgen05.mma.sp.cta_group.kind::i8 [d-tmem], [a-tmem], b-desc, [sp-meta-tmem] , idesc,
                                  { disable-output-lane }, enable-input-d;

.cta_group      = { .cta_group::1,  .cta_group::2 }

-------------------------------------------------------------------------------

// 6. Convolution MMA with Integer type:

tcgen05.mma.sp.cta_group.kind::i8.collector_usage          [d-tmem],  a-desc,  b-desc,
                                                           [sp-meta-tmem] , idesc,
                                                           { disable-output-lane },
↪enable-input-d;
```

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```
tcgen05.mma.sp.cta_group.kind::i8.ashift{.collector_usage} [d-tmem], [a-tmem], b-desc,
                                                           [sp-meta-tmem], idesc ,
                                                           { disable-output-lane },
↪enable-input-d;

tcgen05.mma.sp.cta_group.kind::i8{.ashift}.collector_usage [d-tmem], [a-tmem], b-desc,
                                                           [sp-meta-tmem], idesc ,
                                                           { disable-output-lane },
↪enable-input-d;

.collector_usage = { .collector::buffer::op }
::buffer         = { ::a }
::op             = { ::fill, ::use, ::lastuse, ::discard* }
```

Description

Instruction `tcgen05.mma.sp` is an asynchronous instruction which initiates an *MxNxK* matrix multiply and accumulate operation of the form `D = A*B+D` where the `A` matrix is *Mx(K/2)*, the `B` matrix is *KxN*, and the `D` matrix is *MxN*. *Sparse Matrices* describes the details of the sparsity.

The operation of the form `D = A*B` is issued when the input predicate argument `enable-input-d` is false.

The optional immediate argument `scale-input-d` can be specified to scale the input matrix `D` as follows: `D = A*B+D * (2 ^ - scale-input-d)`

The valid range of values for argument `scale-input-d` is [0, 15]. The argument `scale-input-d` is only valid for `.kind::tf32` and `.kind::f16`.

The 32-bit register operand `idesc` is the instruction descriptor as described in *Instruction descriptor*, specifies the shapes, exact types, sparsity and other details of the input matrices, output matrix and the matrix multiply and accumulate operation.

The qualifier `.cta_group::1` specifies that the matrix multiply and accumulate operation is performed on the *Tensor Memory* of the executing thread's CTA only. The qualifier `.cta_group::2` specifies that the matrix multiply and accumulate operation is performed on the *Tensor Memory* of the executing thread's CTA and its *peer CTA*.

The instruction `tcgen05.mma.sp` has single thread semantics, unlike the collective instructions `mma.sync` or `wgmma.mma_async`. So, a single thread issuing the `tcgen05.mma.sp` will result in the initiation of the whole matrix multiply and accumulate operation. Refer to the section *Issue Granularity*.

The qualifier `.kind` specifies the general kind of the element types of the multiplicand matrices. The exact types of the elements of the input and output matrices for each MMA-kind are specified in the *Instruction descriptor*.

The address operand `d-tmem` specifies the address of the destination and the accumulation matrix `D` in the *Tensor Memory*. The address operand `a-tmem` specifies the address of the matrix `A` in the *Tensor Memory*. The 64-bit register operand `a-desc` and `b-desc` are the matrix descriptors which represent the matrices `A` and `B` in shared memory respectively. The format of the matrix descriptor is described in *Matrix Descriptors*.

The vector operand `disable-output-lane` specifies the lane(s) in the *Tensor Memory* that should be not be updated with the resultant matrix `D`. Elements of the vector operand `disable-output-lane` forms a mask where each bit corresponds to a lane of the *Tensor Memory*. with least significant bit of the first element of the vector (leftmost in syntax) corresponding to the lane 0 of the Tensor Memory.

If a bit in the mask is 1, then the corresponding lane in the Tensor Memory for the resultant matrix D will not be updated. The size of the vector is as follows:

.cta_group	Size of the vector disable-output-lane
::1	4
::2	8

Qualifier `.block_scale` specifies that the matrices A and B are scaled with `scale_A` and `scale_B` matrices respectively before performing the matrix multiply and accumulate operation as specified in the section *Block Scaling*. The address operand `scale-A-tmem` and `scale-B-tmem` specify the base address the matrices `scale_A` and `scale_B` respectively in the *Tensor Memory*.

For qualifier `.scale_vectorsize`,

- If `.scale_vec::NX` is specified: N specifies the number of columns in `scale_A` matrix and number of rows in `scale_B` matrix.
- If `.blockN` is specified: N specifies the block size for which single scale factor will be applied. In this form, value of N is same as the K-dimension / (N of `.scale_vec::NX`).

Aliased `.scale_vectorsize` variants:

1. `.block16` is aliased with:
    1. `.scale_vec::4X` when `.kind = .kind::mxf4nvf4` and K = 64 or 128
2. `.block32` is aliased with:
    1. `.scale_vec::1X` when `.kind = .kind::mxf8f6f4` for all supported values of K
    2. `.scale_vec::2X` when `.kind = .kind::mxf4` or `.kind::mxf4nvf4` and K = 64 or 128

The valid combinations of MMA-kind and `.scale_vectorsize` are described in Table 56. For `.kind::mxf4` when the qualifier `.scale_vectorsize` is not specified, then it defaults to `.block32`. For `.kind::mxf4nvf4`, the qualifier `.scale_vectorsize` must be explicitly specified.

The qualifier `.ashift` shifts the rows of the A matrix down by one row, except for the last row in the *Tensor Memory*. Qualifier `.ashift` is only allowed with *M* = 128 or *M* = 256.

The qualifier `.collector_usage` specifies the usage of collector buffer for matrix A. Following collector buffer operations can be specified:

.collector_usage	Semantics
`.collector::a::fill`	Specifies that the A matrix read from the memory should be filled in collector buffer.
`.collector::a::use`	Specifies that the A matrix can be read from the collector buffer. This requires a previous fill to the collector buffer to be still valid.

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Table 59 – continued from previous page

.collector_usage	Semantics
.collector::a::lastuse	Specifies that the A matrix can be read from the collector buffer and the contents of the collector buffer can be discarded. This requires a previous fill to the collector buffer to be valid till the collector buffer is read.
.collector::a::discard	Specifies that the contents of the collector buffer for A can be discarded.

If no .collector_usage qualifier is specified, then it defaults to .collector::a::discard. It is illegal to specify either of .collector::a::use or .collector::a::fill along with .ashift.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Qualifier .kind::mxf4nvf4 introduced in PTX ISA version 8.7.

Qualifiers .block16 and .block32 introduced in PTX ISA version 8.8.

Target ISA Notes

Supported on following architectures:

- sm_100a
- sm_101a
- And is supported on following family-specific architectures from PTX ISA version 8.8 except .kind::i8/.kind::mxf4nvf4/.kind::mxf4:
  - sm_100f or higher in the same family
  - sm_101f or higher in the same family

Qualifier .kind::i8 is supported on following archutectures:

- sm_100a
- sm_101a

Qualifiers .kind::mxf4nvf4 and .kind::mxf4 are supported on following archutectures:

- sm_100a
- sm_101a
- sm_103a

Argument scale-input-d requires sm_100a and is supported on sm_100f or higher in the same family from PTX ISA version 8.8.

For .scale_vectorsize,

- .scale_vec::1X, .scale_vec::2X, .scale_vec::4X requires sm_100a.
- .block16, .block32 requires sm_100f or sm_101f.

For Target ISA details on matrix shape, check *Target ISA Note*.

For Target ISA details on shared memory descriptor, check *Target ISA Note*.

Examples

```
tcgen05.mma.sp.cta_group::1.kind::f16      [taddr0],  adesc,  bdesc, [tmem_spmeta0],
↪idesc, p;

tcgen05.mma.sp.cta_group::1.kind::mxf8f6f4.collector::a:fill
                                           [taddr2],  [taddr1],  bdesc, [tmem_
↪spmeta1], idesc,
                                           [tmem_scaleA], [tmem_scaleB], p;

tcgen05.commit.cta_group::1.mbarrier::arrive::one.b64 [mbarObj0];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj0], 0;
@!p bra loop;
```

9.7.16.10.9.3 TensorCore 5th Generation Instructions: `tcgen05.mma.ws`

`tcgen05.mma.ws`

Perform the 5th generation of weight stationary convolution matrix multiply and accumulate operation.

Syntax

```
// 1. Floating-point type without block scaling:

tcgen05.mma.ws.cta_group::1.kind{.collector_usage}    [d-tmem],  a-desc,  b-desc,
↪idesc,
                                                      enable-input-d {, zero-column-
↪mask-desc };

tcgen05.mma.ws.cta_group::1.kind{.collector_usage}    [d-tmem], [a-tmem], b-desc,
↪idesc,
                                                      enable-input-d {, zero-column-
↪mask-desc };

.kind = { .kind::f16, .kind::tf32, .kind::f8f6f4 }

-------------------------------------------------------------------------------

// 2. Integer type:

tcgen05.mma.ws.cta_group::1.kind::i8{.collector_usage} [d-tmem],  a-desc,  b-desc,
↪idesc,
                                                        enable-input-d {, zero-column-
↪mask-desc};

tcgen05.mma.ws.cta_group::1.kind::i8{.collector_usage} [d-tmem], [a-tmem], b-desc,
↪idesc,
```

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```
                                                    enable-input-d {, zero-column-
↪mask-desc};

.collector_usage = { .collector::buffer::op }
::buffer = { ::b0, ::b1, ::b2, ::b3 }
::op   = { ::fill, ::use, ::lastuse, ::discard}
```

Description

Instruction `tcgen05.mma.ws` is an asynchronous instruction which initiates an *MxNxK* matrix multiply and accumulate operation, `D = A*B+D` where the `A` matrix is *MxK*, the `B` matrix is *KxN*, and the `D` matrix is *MxN*.

The operation of the form `D = A*B` is issued when the input predicate argument `enable-input-d` is false.

The 32-bit register operand `idesc` is the instruction descriptor as described in *Instruction descriptor*, specifies the shapes, exact types, sparsity and other details of the input matrices, output matrix and the matrix multiply and accumulate operation.

The qualifier `.cta_group::1` specifies that the matrix multiply and accumulate operation is performed on the *Tensor Memory* of the executing thread's CTA only.

The instruction `tcgen05.mma.ws` has single thread semantics, unlike the collective instructions `mma.sync` or `wgmma.mma_async`. So, a single thread issuing the `tcgen05.mma.ws` will result in the initiation of the whole matrix multiply and accumulate operation. Refer to the section *Issue Granularity*.

The qualifier `.kind` specifies the general kind of the element types of the multiplicand matrices. The exact types of the elements of the input and output matrices for each MMA-kind are specified in the *Instruction descriptor*.

The address operand `d-tmem` specifies the address of the destination and the accumulation matrix `D` in the *Tensor Memory*. The address operand `a-tmem` specifies the address of the matrix `A` in the *Tensor Memory*. The 64-bit register operand `a-desc` and `b-desc` are the matrix descriptors which represent the matrices `A` and `B` in shared memory respectively. The format of the matrix descriptor is described in *Matrix Descriptors*.

The optional operand `zero-column-mask-desc` is a 64-bit register which specifies the *Zero-Column Mask Descriptor*. The zero-column mask descriptor is used to generate a mask that specifies which columns of `B` matrix will have zero value for the matrix multiply and accumulate operation regardless of the values present in the shared memory.

The qualifier `.collector_usage` specifies the usage of collector buffer for Matrix B. Following collector buffer operations can be specified:

.collector_usage	Semantics
`.collector::bN::fill`	Specifies that the `B` matrix read from the memory should be filled in collector buffer #N.

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Table 60 – continued from previous page

.collector_usage	Semantics
`.collector::bN::use`	Specifies that the B matrix can be read from the collector buffer #N. This requires a previous fill to the collector buffer #N to be still valid.
`.collector::bN::lastuse`	Specifies that the B matrix can be read from the collector buffer #N after which the contents of the collector buffer #N can be discarded. This requires a previous fill to the collector buffer #N to be valid till the collector buffer #N is read.
`.collector::bN::discard`	Specifies that the contents of the collector buffer #N can be discarded.

If no `.collector_usage` qualifier is specified, then it defaults to `.collector::b0::discard`.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8 except `.kind::i8`:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifier `.kind::i8` is supported on following archutectures:

- `sm_100a`
- `sm_101a`

Examples

```
tcgen05.mma.ws.cta_group::1.kind::i8.collector::b2:use [taddr2], [taddr1], bdesc,
↪idesc, p;
tcgen05.commit.cta_group::1.mbarrier::arrive::one.b64 [mbarObj0];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj0], 0;
@!p bra loop;
```

9.7.16.10.9.4 TensorCore 5th Generation Instructions: `tcgen05.mma.ws.sp`

`tcgen05.mma.ws.sp`

Perform the 5th generation of weight stationary convolution matrix multiply and accumulate operation with sparse A matrix.

Syntax

```
// 1. Floating-point type without block scaling:

tcgen05.mma.ws.sp.cta_group::1.kind{.collector_usage} [d-tmem],  a-desc,  b-desc,
                                                      [sp-meta-tmem] ,  idesc,
                                                      enable-input-d {, zero-column-
↪mask-desc};

tcgen05.mma.ws.sp.cta_group::1.kind{.collector_usage} [d-tmem], [a-tmem], b-desc,
                                                      [sp-meta-tmem] , idesc,
                                                      enable-input-d {, zero-column-
↪mask-desc};

.kind = { .kind::f16, .kind::tf32, .kind::f8f6f4 }

-----------------------------------------------------------------------------

// 2. Integer type:

tcgen05.mma.ws.sp.cta_group::1.kind::i8{.collector_usage} [d-tmem], a-desc, b-desc,
                                                          [sp-meta-tmem] , idesc,
                                                          enable-input-d {, zero-
↪column-mask-desc};

tcgen05.mma.ws.sp.cta_group::1.kind::i8{.collector_usage} [d-tmem], [a-tmem], b-desc,
                                                          [sp-meta-tmem] , idesc,
                                                          enable-input-d {, zero-
↪column-mask-desc};

.collector_usage = { .collector::buffer::op }
::buffer = { ::b0, ::b1, ::b2, ::b3 }
::op   = { ::fill, ::use, ::lastuse, ::discard}
```

Description

Instruction `tcgen05.mma.ws.sp` is an asynchronous instruction which initiates an *MxNxK* matrix multiply and accumulate operation, `D = A*B+D` where the `A` matrix is *Mx(K/2)*, the `B` matrix is *KxN*, and the `D` matrix is *MxN*. *Sparse Matrices* describes the details of the sparsity.

The operation of the form `D = A*B` is issued when the input predicate argument `enable-input-d` is false.

The 32-bit register operand `idesc` is the instruction descriptor as described in *Instruction descriptor*, specifies the shapes, exact types, sparsity and other details of the input matrices, output matrix and the matrix multiply and accumulate operation.

The qualifier `.cta_group::1` specifies that the matrix multiply and accumulate operation is performed on the Tensor Memory of the executing thread's CTA only.

The instruction `tcgen05.mma.ws.sp` has single thread semantics, unlike the collective instructions `mma.sync` or `wgmma.mma_async`. So, a single thread issuing the `tcgen05.mma.ws.sp` will result in the initiation of the whole matrix multiply and accumulate operation. Refer to the section *Issue Granularity*.

The qualifier `.kind` specifies the general kind of the element types of the multiplicand matrices. The exact types of the elements of the input and output matrices for each MMA-kind are specified in the *Instruction descriptor*.

The address operand `d-tmem` specifies the address of the destination and the accumulation matrix `D` in the *Tensor Memory*. The address operand `a-tmem` specifies the address of the matrix `A` in the *Tensor Memory*. The 64-bit register operand `a-desc` and `b-desc` are the matrix descriptors which represent the matrices `A` and `B` in shared memory respectively. The format of the matrix descriptor is described in *Matrix Descriptors*.

The optional operand `zero-column-mask-desc` is a 64-bit register which specifies the *Zero-Column Mask Descriptor*. The zero-column mask descriptor is used to generate a mask that specifies which columns of `B` matrix will have zero value for the matrix multiply and accumulate operation regardless of the values present in the shared memory.

The qualifier `.collector_usage` specifies the usage of collector buffer for Matrix `B`. Following collector buffer operations can be specified:

.collector_usage	Semantics
`.collector::bN::fill`	Specifies that the `B` matrix read from the memory should be filled in collector buffer #N.
`.collector::bN::use`	Specifies that the `B` matrix can be read from the collector buffer #N. This requires a previous fill to the collector buffer #N to be still valid.
`.collector::bN::lastuse`	Specifies that the `B` matrix can be read from the collector buffer #N after which the contents of the collector buffer #N can be discarded. This requires a previous fill to the collector buffer #N to be valid till the collector buffer #N is read.

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Table 61 – continued from previous page

.collector_usage	Semantics
`.collector::bN::discard`	Specifies that the contents of the collector buffer #N can be discarded.

If no `.collector_usage` qualifier is specified, then it defaults to `.collector::b0::discard`.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8 except `.kind::i8`:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Qualifier `.kind::i8` is supported on following archutectures:

- `sm_100a`
- `sm_101a`

Examples

```
tcgen05.mma.ws.sp.cta_group::1.kind::tf32.collector::b1::fill  [taddr1], [taddr0],
↪bdesc,
                                                               [tmem_spmeta0], idesc,
↪p;

tcgen05.commit.cta_group::1.mbarrier::arrive::one.b64 [mbarObj0];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj0], 0;
@!p bra loop;
```

9.7.16.11 TensorCore 5th Generation Specialized Synchronization Operations

9.7.16.11.1 TensorCore 5th Generation Instructions: `tcgen05.fence`

`tcgen05.fence`

Specialized fence for the asynchronous tcgen05 operations.

Syntax

```
tcgen05.fence::before_thread_sync ;
tcgen05.fence::after_thread_sync  ;
```

Description

The instruction `tcgen05.fence::before_thread_sync` orders all the prior asynchronous `tcgen05` operations with respect to the subsequent `tcgen05` and the execution ordering operations.

The instruction `tcgen05.fence::after_thread_sync` orders all the subsequent asynchronous `tcgen05` operations with respect to the prior `tcgen05` and the execution ordering operations.

The `tcgen05.fence::*` instructions compose with execution ordering instructions across a thread scope and provide ordering between `tcgen05` instructions across the same scope.

The `tcgen05.fence::before_thread_sync` instructions behave as code motion fence for prior `tcgen05` instructions as they cannot be hoisted across. The `tcgen05.fence::after_thread_sync` instructions behave as code motion fence for subsequent `tcgen05` instructions as they cannot be hoisted across.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
// Producer thread:

tcgen05.cp.cta_group::1.128x256b  [taddr0], sdesc0;

tcgen05.fence::before_thread_sync;
st.relaxed.b32 [flag], 1;

// Consumer thread:

loop:
ld.relaxed.b32 r, [flag];
setp.eq.u32 p, r, 1;
@!p bra loop;

tcgen05.fence::after_thread_sync;
tcgen05.mma.cta_group.kind   [taddr0], adesc, bdesc, idesc, p;
```

9.7.16.12 TensorCore 5th Generation Async Synchronization Operations

9.7.16.12.1 TensorCore 5th Generation Instructions: `tcgen05.commit`

`tcgen05.commit`

Makes the mbarrier object track the completion of all prior async-tcgen05 operations initiated by the executing thread.

Syntax

```
tcgen05.commit.cta_group.completion_mechanism{.shared::cluster}{.multicast}.b64
                                                                    [mbar] {, ctaMask};

.completion_mechanism = { .mbarrier::arrive::one }
.cta_group            = { .cta_group::1, .cta_group::2 }
.multicast            = { .multicast::cluster }
```

Description

The instruction `tcgen05.commit` is an asynchronous instruction which makes the mbarrier object, specified by the address operand `mbar`, track the completion of all the prior asynchronous `tcgen05` operations, as listed in *mbarrier based completion mechanism*, initiated by the executing thread. Upon the completion of the tracked asynchronous `tcgen05` operations, the signal specified by the `.completion_mechanism` is triggered by the system on the mbarrier object.

The instruction `tcgen05.commit.cta_group::1` tracks for the completion of all prior asynchronous `tcgen05` operations with `.cta_group::1` issued by the current thread. Similarly, the instruction `tcgen05.commit.cta_group::2` tracks for the completion of all prior asynchronous `tcgen05` operations with `.cta_group::2` issued by the current thread.

The qualifier `.mbarrier::arrive::one` indicates that upon the completion of the prior asynchronous `tcgen05` operation issued by the current thread, an arrive-on operation, with the count

argument of 1, is signaled on the mbarrier object. The scope of the arrive-on operation is the cluster scope.

The optional qualifier `.multicast::cluster` allows signaling on the mbarrier objects of multiple CTAs in the cluster. Operand `ctaMask` specifies the CTAs in the cluster such that each bit position in the 16-bit `ctaMask` operand corresponds to the `%cluster_ctarank` of the destination CTA. The mbarrier signal is multicast to the same offset as `mbar` in the shared memory of each destination CTA.

If no state space is specified then *Generic Addressing* is used. If the address specified by `mbar` does not fall within the address window of `.shared::cluster` state space then the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.6.

Target ISA Notes

Supported on following architectures:

- `sm_100a`
- `sm_101a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family

Examples

```
Example 1:
tcgen05.cp.cta_group::1.128x256b                      [taddr0], sdesc0;
tcgen05.commit.cta_group::1.mbarrier::arrive::one.b64 [mbarObj1];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj1], 0;
@!p bra loop;

Example 2:
tcgen05.mma.cta_group::2.kind::tf32    [taddr0],  adesc,  bdesc, idesc, p;
tcgen05.commit.cta_group::2.mbarrier::arrive::one.b64 [mbarObj2];

loop:
mbarrier.try_wait.parity.b64 p, [mbarObj2], 0;
@!p bra loop;
```

9.7.17. Stack Manipulation Instructions

The stack manipulation instructions can be used to dynamically allocate and deallocate memory on the stack frame of the current function.

The stack manipulation instrucitons are:

- `stacksave`
- `stackrestore`
- `alloca`

9.7.17.1 Stack Manipulation Instructions: `stacksave`

`stacksave`

Save the value of stack pointer into a register.

Syntax

```
stacksave.type  d;

.type = { .u32, .u64 };
```

Description

Copies the current value of stack pointer into the destination register `d`. Pointer returned by `stacksave` can be used in a subsequent `stackrestore` instruction to restore the stack pointer. If `d` is modified prior to use in `stackrestore` instruction, it may corrupt data in the stack.

Destination operand `d` has the same type as the instruction type.

Semantics

```
d = stackptr;
```

PTX ISA Notes

Introduced in PTX ISA version 7.3.

Preview Feature:
`stacksave` is a preview feature in PTX ISA version 7.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

`stacksave` requires `sm_52` or higher.

Examples

```
.reg .u32 rd;
stacksave.u32 rd;

.reg .u64 rd1;
stacksave.u64 rd1;
```

9.7.17.2 Stack Manipulation Instructions: `stackrestore`

`stackrestore`

Update the stack pointer with a new value.

Syntax

```
stackrestore.type  a;

.type = { .u32, .u64 };
```

Description

Sets the current stack pointer to source register `a`.

When `stackrestore` is used with operand `a` written by a prior `stacksave` instruction, it will effectively restore the state of stack as it was before `stacksave` was executed. Note that if `stackrestore` is used with an arbitrary value of `a`, it may cause corruption of stack pointer. This implies that the correct use of this feature requires that `stackrestore.type a` is used after `stacksave.type a` without redefining the value of `a` between them.

Operand `a` has the same type as the instruction type.

Semantics

```
stackptr = a;
```

PTX ISA Notes

Introduced in PTX ISA version 7.3.

Preview Feature:
`stackrestore` is a preview feature in PTX ISA version 7.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

`stackrestore` requires `sm_52` or higher.

Examples

```
.reg .u32 ra;
stacksave.u32 ra;
// Code that may modify stack pointer
...
stackrestore.u32 ra;
```

9.7.17.3 Stack Manipulation Instructions: `alloca`

`alloca`

Dynamically allocate memory on stack.

Syntax

```
alloca.type  ptr, size{, immAlign};

.type = { .u32, .u64 };
```

Description

The `alloca` instruction dynamically allocates memory on the stack frame of the current function and updates the stack pointer accordingly. The returned pointer `ptr` points to local memory and can be used in the address operand of `ld.local` and `st.local` instructions.

If sufficient memory is unavailable for allocation on the stack, then execution of `alloca` may result in stack overflow. In such cases, attempting to access the allocated memory with `ptr` will result in undefined program behavior.

The memory allocated by `alloca` is deallocated in the following ways:

- It is automatically deallocated when the function exits.
- It can be explicitly deallocated using `stacksave` and `stackrestore` instructions: `stacksave` can be used to save the value of stack pointer before executing `alloca`, and `stackrestore` can be used after `alloca` to restore stack pointer to the original value which was previously saved with `stacksave`. Note that accessing deallocated memory after executing `stackrestore` results in undefined behavior.

`size` is an unsigned value which specifies the amount of memory in number of bytes to be allocated on stack. `size = 0` may not lead to a valid memory allocation.

Both `ptr` and `size` have the same type as the instruction type.

`immAlign` is a 32-bit value which specifies the alignment requirement in number of bytes for the memory allocated by `alloca`. It is an integer constant, must be a power of 2 and must not exceed 2^23. `immAlign` is an optional argument with default value being 8 which is the minimum guaranteed alignment.

Semantics

```
alloca.type ptr, size, immAlign:

a = max(immAlign, frame_align); // frame_align is the minimum guaranteed alignment

// Allocate size bytes of stack memory with alignment a and update the stack pointer.
// Since the stack grows down, the updated stack pointer contains a lower address.
stackptr = alloc_stack_mem(size, a);

// Return the new value of stack pointer as ptr. Since ptr is the lowest address of
↪the memory
// allocated by alloca, the memory can be accessed using ptr up to (ptr + size of
↪allocated memory).
stacksave ptr;
```

PTX ISA Notes

Introduced in PTX ISA version 7.3.

Preview Feature:
`alloca` is a preview feature in PTX ISA version 7.3. All details are subject to change with no guarantees of backward compatibility on future PTX ISA versions or SM architectures.

Target ISA Notes

`alloca` requires `sm_52` or higher.

Examples

```
.reg .u32 ra, stackptr, ptr, size;

stacksave.u32 stackptr;     // Save the current stack pointer
alloca ptr, size, 8;        // Allocate stack memory
st.local.u32 [ptr], ra;     // Use the allocated stack memory
stackrestore.u32 stackptr;  // Deallocate memory by restoring the stack pointer
```

9.7.18. Video Instructions

All video instructions operate on 32-bit register operands. However, the video instructions may be classified as either scalar or SIMD based on whether their core operation applies to one or multiple values.

The video instructions are:

- `vadd`, `vadd2`, `vadd4`
- `vsub`, `vsub2`, `vsub4`
- `vmad`
- `vavrg2`, `vavrg4`
- `vabsdiff`, `vabsdiff2`, `vabsdiff4`
- `vmin`, `vmin2`, `vmin4`
- `vmax`, `vmax2`, `vmax4`
- `vshl`
- `vshr`
- `vset`, `vset2`, `vset4`

9.7.18.1 Scalar Video Instructions

All scalar video instructions operate on 32-bit register operands. The scalar video instructions are:

- `vadd`
- `vsub`
- `vabsdiff`
- `vmin`
- `vmax`
- `vshl`
- `vshr`
- `vmad`
- `vset`

The scalar video instructions execute the following stages:

1. Extract and sign- or zero-extend byte, half-word, or word values from its source operands, to produce signed 33-bit input values.
2. Perform a scalar arithmetic operation to produce a signed 34-bit result.
3. Optionally clamp the result to the range of the destination type.
4. Optionally perform one of the following:
   - apply a second operation to the intermediate result and a third operand, or
   - truncate the intermediate result to a byte or half-word value and merge into a specified position in the third operand to produce the final result.

The general format of scalar video instructions is as follows:

```
// 32-bit scalar operation, with optional secondary operation
vop.dtype.atype.btype{.sat}        d, a{.asel}, b{.bsel};
vop.dtype.atype.btype{.sat}.secop  d, a{.asel}, b{.bsel}, c;

// 32-bit scalar operation, with optional data merge
vop.dtype.atype.btype{.sat}   d.dsel, a{.asel}, b{.bsel}, c;


.dtype = .atype = .btype = { .u32, .s32 };
.dsel  = .asel  = .bsel  = { .b0, .b1, .b2, .b3, .h0, .h1 };
.secop = { .add, .min, .max };
```

The source and destination operands are all 32-bit registers. The type of each operand (`.u32` or `.s32`) is specified in the instruction type; all combinations of `dtype`, `atype`, and `btype` are valid. Using the `atype/btype` and `asel/bsel` specifiers, the input values are extracted and sign- or zero-extended internally to `.s33` values. The primary operation is then performed to produce an `.s34` intermediate result. The sign of the intermediate result depends on dtype.

The intermediate result is optionally clamped to the range of the destination type (signed or unsigned), taking into account the subword destination size in the case of optional data merging.

```
.s33 optSaturate( .s34 tmp, Bool sat, Bool sign, Modifier dsel ) {
    if ( !sat )  return tmp;

    switch ( dsel ) {
        case .b0, .b1, .b2, .b3:
            if ( sign )  return CLAMP( tmp, S8_MAX, S8_MIN );
            else         return CLAMP( tmp, U8_MAX, U8_MIN );
        case .h0, .h1:
            if ( sign )  return CLAMP( tmp, S16_MAX, S16_MIN );
            else         return CLAMP( tmp, U16_MAX, U16_MIN );
        default:
            if ( sign )  return CLAMP( tmp, S32_MAX, S32_MIN );
            else         return CLAMP( tmp, U32_MAX, U32_MIN );
    }
}
```

This intermediate result is then optionally combined with the third source operand using a secondary arithmetic operation or subword data merge, as shown in the following pseudocode. The sign of the third operand is based on `dtype`.

```
.s33 optSecOp(Modifier secop, .s33 tmp, .s33 c) {
    switch ( secop ) {
        .add:     return tmp + c;
        .min:     return MIN(tmp, c);
        .max      return MAX(tmp, c);
        default:  return tmp;
    }
}
```

```
.s33 optMerge( Modifier dsel, .s33 tmp, .s33 c ) {
    switch ( dsel ) {
        case .h0:  return ((tmp & 0xffff)        | (0xffff0000 & c);
        case .h1:  return ((tmp & 0xffff) << 16) | (0x0000ffff & c);
        case .b0:  return ((tmp & 0xff)          | (0xffffff00 & c);
        case .b1:  return ((tmp & 0xff) <<  8)   | (0xffff00ff & c);
```

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```
        case .b2:  return ((tmp & 0xff) << 16)   | (0xff00ffff & c);
        case .b3:  return ((tmp & 0xff) << 24)   | (0x00ffffff & c);
        default:   return tmp;
    }
}
```

The lower 32-bits are then written to the destination operand.

9.7.18.1.1 Scalar Video Instructions: vadd, vsub, vabsdiff, vmin, vmax

vadd, vsub

Integer byte/half-word/word addition/subtraction.

vabsdiff

Integer byte/half-word/word absolute value of difference.

vmin, vmax

Integer byte/half-word/word minimum/maximum.

Syntax

```
// 32-bit scalar operation, with optional secondary operation
vop.dtype.atype.btype{.sat}       d, a{.asel}, b{.bsel};
vop.dtype.atype.btype{.sat}.op2   d, a{.asel}, b{.bsel}, c;

// 32-bit scalar operation, with optional data merge
vop.dtype.atype.btype{.sat}  d.dsel, a{.asel}, b{.bsel}, c;

 vop   = { vadd, vsub, vabsdiff, vmin, vmax };
.dtype = .atype = .btype = { .u32, .s32 };
.dsel  = .asel  = .bsel  = { .b0, .b1, .b2, .b3, .h0, .h1 };
.op2   = { .add, .min, .max };
```

Description

Perform scalar arithmetic operation with optional saturate, and optional secondary arithmetic operation or subword data merge.

Semantics

```
// extract byte/half-word/word and sign- or zero-extend
// based on source operand type
ta = partSelectSignExtend( a, atype, asel );
tb = partSelectSignExtend( b, btype, bsel );

switch ( vop ) {
    case vadd:     tmp = ta + tb;
    case vsub:     tmp = ta - tb;
    case vabsdiff: tmp = | ta - tb |;
    case vmin:     tmp = MIN( ta, tb );
    case vmax:     tmp = MAX( ta, tb );
}
// saturate, taking into account destination type and merge operations
tmp = optSaturate( tmp, sat, isSigned(dtype), dsel );
d = optSecondaryOp( op2, tmp, c );  // optional secondary operation
d = optMerge( dsel, tmp, c );       // optional merge with c operand
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`vadd`, `vsub`, `vabsdiff`, `vmin`, `vmax` require `sm_20` or higher.

Examples

```
vadd.s32.u32.s32.sat      r1, r2.b0, r3.h0;
vsub.s32.s32.u32.sat      r1, r2.h1, r3.h1;
vabsdiff.s32.s32.s32.sat  r1.h0, r2.b0, r3.b2, c;
vmin.s32.s32.s32.sat.add  r1, r2, r3, c;
```

9.7.18.1.2 Scalar Video Instructions: vshl, vshr

vshl, vshr

Integer byte/half-word/word left/right shift.

Syntax

```
// 32-bit scalar operation, with optional secondary operation
vop.dtype.atype.u32{.sat}.mode       d, a{.asel}, b{.bsel};
vop.dtype.atype.u32{.sat}.mode.op2   d, a{.asel}, b{.bsel}, c;

// 32-bit scalar operation, with optional data merge
vop.dtype.atype.u32{.sat}.mode  d.dsel, a{.asel}, b{.bsel}, c;

 vop   = { vshl, vshr };
.dtype = .atype = { .u32, .s32 };
.mode  = { .clamp, .wrap };
.dsel  = .asel  = .bsel  = { .b0, .b1, .b2, .b3, .h0, .h1 };
.op2   = { .add, .min, .max };
```

Description

vshl
Shift a left by unsigned amount in b with optional saturate, and optional secondary arithmetic operation or subword data merge. Left shift fills with zero.

vshr
Shift a right by unsigned amount in b with optional saturate, and optional secondary arithmetic operation or subword data merge. Signed shift fills with the sign bit, unsigned shift fills with zero.

Semantics

```
// extract byte/half-word/word and sign- or zero-extend
// based on source operand type
ta = partSelectSignExtend( a,atype, asel );
tb = partSelectSignExtend( b, .u32, bsel );
if ( mode == .clamp  && tb > 32 )  tb = 32;
if ( mode == .wrap )                      tb = tb & 0x1f;
switch ( vop ){
   case vshl:  tmp = ta << tb;
   case vshr:  tmp = ta >> tb;
}
// saturate, taking into account destination type and merge operations
tmp = optSaturate( tmp, sat, isSigned(dtype), dsel );
d = optSecondaryOp( op2, tmp, c );  // optional secondary operation
d = optMerge( dsel, tmp, c );       // optional merge with c operand
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`vshl`, `vshr` require `sm_20` or higher.

Examples

```
vshl.s32.u32.u32.clamp  r1, r2, r3;
vshr.u32.u32.u32.wrap   r1, r2, r3.h1;
```

9.7.18.1.3 Scalar Video Instructions: vmad

vmad

Integer byte/half-word/word multiply-accumulate.

Syntax

```
// 32-bit scalar operation
vmad.dtype.atype.btype{.sat}{.scale}     d, {-}a{.asel}, {-}b{.bsel},
                                         {-}c;
vmad.dtype.atype.btype.po{.sat}{.scale}  d, a{.asel}, b{.bsel}, c;

.dtype = .atype = .btype = { .u32, .s32 };
.asel  = .bsel  = { .b0, .b1, .b2, .b3, .h0, .h1 };
.scale = { .shr7, .shr15 };
```

Description

Calculate `(a*b) + c`, with optional operand negates, *plus one* mode, and scaling.

The source operands support optional negation with some restrictions. Although PTX syntax allows separate negation of the `a` and `b` operands, internally this is represented as negation of the product `(a*b)`. That is, `(a*b)` is negated if and only if exactly one of `a` or `b` is negated. PTX allows negation of either `(a*b)` or `c`.

The plus one mode (`.po`) computes `(a*b) + c + 1`, which is used in computing averages. Source operands may not be negated in `.po` mode.

The intermediate result of `(a*b)` is unsigned if atype and btype are unsigned and the product `(a*b)` is not negated; otherwise, the intermediate result is signed. Input `c` has the same sign as the intermediate result.

The final result is unsigned if the intermediate result is unsigned and `c` is not negated.

Depending on the sign of the `a` and `b` operands, and the operand negates, the following combinations of operands are supported for VMAD:

```
 (u32 * u32) + u32  // intermediate unsigned; final unsigned
-(u32 * u32) + s32  // intermediate   signed; final   signed
 (u32 * u32) - u32  // intermediate unsigned; final   signed
 (u32 * s32) + s32  // intermediate   signed; final   signed
```

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```
-(u32 * s32) + s32  // intermediate   signed; final   signed
 (u32 * s32) - s32  // intermediate   signed; final   signed
 (s32 * u32) + s32  // intermediate   signed; final   signed
-(s32 * u32) + s32  // intermediate   signed; final   signed
 (s32 * u32) - s32  // intermediate   signed; final   signed
 (s32 * s32) + s32  // intermediate   signed; final   signed
-(s32 * s32) + s32  // intermediate   signed; final   signed
 (s32 * s32) - s32  // intermediate   signed; final   signed
```

The intermediate result is optionally scaled via right-shift; this result is sign-extended if the final result is signed, and zero-extended otherwise.

The final result is optionally saturated to the appropriate 32-bit range based on the type (signed or unsigned) of the final result.

Semantics

```
// extract byte/half-word/word and sign- or zero-extend
// based on source operand type
ta = partSelectSignExtend( a, atype, asel );
tb = partSelectSignExtend( b, btype, bsel );
signedFinal = isSigned(atype) || isSigned(btype) ||
                                 (a.negate ^ b.negate) || c.negate;
tmp[127:0] = ta * tb;

lsb = 0;
if ( .po )                  {             lsb = 1; } else
if ( a.negate ^ b.negate )  { tmp = ~tmp;  lsb = 1; } else
if ( c.negate )             { c   = ~c;    lsb = 1; }

c128[127:0] = (signedFinal) sext32( c ) : zext ( c );
tmp = tmp + c128 + lsb;
switch( scale ) {
   case .shr7:   result = (tmp >>  7) & 0xffffffffffffffff;
   case .shr15:  result = (tmp >> 15) & 0xffffffffffffffff;
}
if ( .sat ) {
     if (signedFinal) result = CLAMP(result, S32_MAX, S32_MIN);
     else             result = CLAMP(result, U32_MAX, U32_MIN);
}
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

vmad requires sm_20 or higher.

Examples

```
vmad.s32.s32.u32.sat    r0, r1, r2, -r3;
vmad.u32.u32.u32.shr15  r0, r1.h0, r2.h0, r3;
```

9.7.18.1.4 Scalar Video Instructions: vset

vset

Integer byte/half-word/word comparison.

Syntax

```
// 32-bit scalar operation, with optional secondary operation
vset.atype.btype.cmp       d, a{.asel}, b{.bsel};
vset.atype.btype.cmp.op2   d, a{.asel}, b{.bsel}, c;

// 32-bit scalar operation, with optional data merge
vset.atype.btype.cmp  d.dsel, a{.asel}, b{.bsel}, c;

.atype = .btype = { .u32, .s32 };
.cmp   = { .eq, .ne, .lt, .le, .gt, .ge };
.dsel  = .asel  = .bsel  = { .b0, .b1, .b2, .b3, .h0, .h1 };
.op2   = { .add, .min, .max };
```

Description

Compare input values using specified comparison, with optional secondary arithmetic operation or subword data merge.

The intermediate result of the comparison is always unsigned, and therefore destination d and operand c are also unsigned.

Semantics

```
// extract byte/half-word/word and sign- or zero-extend
// based on source operand type
ta = partSelectSignExtend( a, atype, asel );
tb = partSelectSignExtend( b, btype, bsel );
tmp = compare( ta, tb, cmp ) ? 1 : 0;
d = optSecondaryOp( op2, tmp, c );    // optional secondary operation
d = optMerge( dsel, tmp, c );         // optional merge with c operand
```

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`vset` requires `sm_20` or higher.

Examples

```
vset.s32.u32.lt    r1, r2, r3;
vset.u32.u32.ne    r1, r2, r3.h1;
```

9.7.18.2 SIMD Video Instructions

The SIMD video instructions operate on pairs of 16-bit values and quads of 8-bit values.

The SIMD video instructions are:

- `vadd2`, `vadd4`
- `vsub2`, `vsub4`
- `vavrg2`, `vavrg4`
- `vabsdiff2`, `vabsdiff4`
- `vmin2`, `vmin4`
- `vmax2`, `vmax4`
- `vset2`, `vset4`

PTX includes SIMD video instructions for operation on pairs of 16-bit values and quads of 8-bit values. The SIMD video instructions execute the following stages:

1. Form input vectors by extracting and sign- or zero-extending byte or half-word values from the source operands, to form pairs of signed 17-bit values.
2. Perform a SIMD arithmetic operation on the input pairs.
3. Optionally clamp the result to the appropriate signed or unsigned range, as determinted by the destination type.
4. Optionally perform one of the following:

a. perform a second SIMD merge operation, or

b. apply a scalar accumulate operation to reduce the intermediate SIMD results to a single scalar.

The general format of dual half-word SIMD video instructions is as follows:

```
// 2-way SIMD operation, with second SIMD merge or accumulate
vop2.dtype.atype.btype{.sat}{.add}  d{.mask}, a{.asel}, b{.bsel}, c;

.dtype = .atype = .btype = { .u32, .s32 };
.mask  = { .h0, .h1, .h10 };
.asel  = .bsel = { .hxy, where x,y are from { 0, 1, 2, 3 } };
```

The general format of quad byte SIMD video instructions is as follows:

```
// 4-way SIMD operation, with second SIMD merge or accumulate
vop4.dtype.atype.btype{.sat}{.add}  d{.mask}, a{.asel}, b{.bsel}, c;

.dtype = .atype = .btype = { .u32, .s32 };
.mask  = { .b0,
           .b1, .b10
           .b2, .b20, .b21, .b210,
           .b3, .b30, .b31, .b310, .b32, .b320, .b321, .b3210 };
.asel = .bsel = .bxyzw, where x,y,z,w are from { 0, ..., 7 };
```

The source and destination operands are all 32-bit registers. The type of each operand (`.u32` or `.s32`) is specified in the instruction type; all combinations of `dtype`, `atype`, and `btype` are valid. Using the `atype/btype` and `asel/bsel` specifiers, the input values are extracted and sign- or zero-extended internally to `.s33` values. The primary operation is then performed to produce an `.s34` intermediate result. The sign of the intermediate result depends on `dtype`.

The intermediate result is optionally clamped to the range of the destination type (signed or unsigned), taking into account the subword destination size in the case of optional data merging.

9.7.18.2.1 SIMD Video Instructions: vadd2, vsub2, vavrg2, vabsdiff2, vmin2, vmax2

vadd2, vsub2

Integer dual half-word SIMD addition/subtraction.

vavrg2

Integer dual half-word SIMD average.

vabsdiff2

Integer dual half-word SIMD absolute value of difference.

vmin2, vmax2

Integer dual half-word SIMD minimum/maximum.

Syntax

```
// SIMD instruction with secondary SIMD merge operation
vop2.dtype.atype.btype{.sat}  d{.mask}, a{.asel}, b{.bsel}, c;

// SIMD instruction with secondary accumulate operation
vop2.dtype.atype.btype.add  d{.mask}, a{.asel}, b{.bsel}, c;

 vop2  = { vadd2, vsub2, vavrg2, vabsdiff2, vmin2, vmax2 };
.dtype = .atype = .btype = { .u32, .s32 };
.mask  = { .h0, .h1, .h10 };  // defaults to .h10
.asel  = .bsel  = { .hxy, where x,y are from { 0, 1, 2, 3 } };
   .asel defaults to .h10
   .bsel defaults to .h32
```

Description

Two-way SIMD parallel arithmetic operation with secondary operation.

Elements of each dual half-word source to the operation are selected from any of the four half-words in the two source operands a and b using the `asel` and `bsel` modifiers.

The selected half-words are then operated on in parallel.

The results are optionally clamped to the appropriate range determined by the destination type (signed or unsigned). Saturation cannot be used with the secondary accumulate operation.

For instructions with a secondary SIMD merge operation:

- For half-word positions indicated in mask, the selected half-word results are copied into destination d. For all other positions, the corresponding half-word from source operand c is copied to d.

For instructions with a secondary accumulate operation:

- For half-word positions indicated in mask, the selected half-word results are added to operand c, producing a result in d.

Semantics

```
// extract pairs of half-words and sign- or zero-extend
// based on operand type
Va = extractAndSignExt_2( a, b, .asel, .atype );
Vb = extractAndSignExt_2( a, b, .bsel, .btype );
Vc = extractAndSignExt_2( c );

for (i=0; i<2; i++) {
    switch ( vop2 ) {
       case vadd2:             t[i] = Va[i] + Vb[i];
       case vsub2:             t[i] = Va[i] - Vb[i];
       case vavrg2:            if ( ( Va[i] + Vb[i] ) >= 0 ) {
                                   t[i] = ( Va[i] + Vb[i] + 1 ) >> 1;
                               } else {
                                   t[i] = ( Va[i] + Vb[i] ) >> 1;
                               }
       case vabsdiff2:         t[i] = | Va[i] - Vb[i] |;
       case vmin2:             t[i] = MIN( Va[i], Vb[i] );
       case vmax2:             t[i] = MAX( Va[i], Vb[i] );
    }
    if (.sat) {
        if ( .dtype == .s32 )  t[i] = CLAMP( t[i], S16_MAX, S16_MIN );
        else                   t[i] = CLAMP( t[i], U16_MAX, U16_MIN );
    }
}
// secondary accumulate or SIMD merge
mask = extractMaskBits( .mask );
if (.add) {
    d = c;
    for (i=0; i<2; i++) {  d += mask[i] ? t[i] : 0;  }
} else {
    d = 0;
    for (i=0; i<2; i++)  {  d |= mask[i] ? t[i] : Vc[i];  }
}
```

PTX ISA Notes

Introduced in PTX ISA version 3.0.

Target ISA Notes

vadd2, vsub2, varvg2, vabsdiff2, vmin2, vmax2 require sm_30 or higher.

Examples

```
vadd2.s32.s32.u32.sat  r1, r2, r3, r1;
vsub2.s32.s32.s32.sat  r1.h0, r2.h10, r3.h32, r1;
vmin2.s32.u32.u32.add  r1.h10, r2.h00, r3.h22, r1;
```

9.7.18.2.2 SIMD Video Instructions: vset2

vset2

Integer dual half-word SIMD comparison.

Syntax

```
// SIMD instruction with secondary SIMD merge operation
vset2.atype.btype.cmp  d{.mask}, a{.asel}, b{.bsel}, c;

// SIMD instruction with secondary accumulate operation
vset2.atype.btype.cmp.add  d{.mask}, a{.asel}, b{.bsel}, c;

.atype = .btype = { .u32, .s32 };
.cmp   = { .eq, .ne, .lt, .le, .gt, .ge };
.mask  = { .h0, .h1, .h10 };  // defaults to .h10
.asel  = .bsel  = { .hxy, where x,y are from { 0, 1, 2, 3 } };
   .asel defaults to .h10
   .bsel defaults to .h32
```

Description

Two-way SIMD parallel comparison with secondary operation.

Elements of each dual half-word source to the operation are selected from any of the four half-words in the two source operands a and b using the asel and bsel modifiers.

The selected half-words are then compared in parallel.

The intermediate result of the comparison is always unsigned, and therefore the half-words of destination d and operand c are also unsigned.

For instructions with a secondary SIMD merge operation:

- For half-word positions indicated in mask, the selected half-word results are copied into destination d. For all other positions, the corresponding half-word from source operand b is copied to d.

For instructions with a secondary accumulate operation:

- For half-word positions indicated in mask, the selected half-word results are added to operand c, producing a result in d.

Semantics

```
// extract pairs of half-words and sign- or zero-extend
// based on operand type
Va = extractAndSignExt_2( a, b, .asel, .atype );
Vb = extractAndSignExt_2( a, b, .bsel, .btype );
Vc = extractAndSignExt_2( c );
for (i=0; i<2; i++) {
    t[i] = compare( Va[i], Vb[i], .cmp ) ? 1 : 0;
}
// secondary accumulate or SIMD merge
mask = extractMaskBits( .mask );
if (.add) {
    d = c;
    for (i=0; i<2; i++) {  d += mask[i] ? t[i] : 0;  }
} else {
    d = 0;
    for (i=0; i<2; i++)  {  d |= mask[i] ? t[i] : Vc[i];  }
}
```

PTX ISA Notes

Introduced in PTX ISA version 3.0.

Target ISA Notes

`vset2` requires `sm_30` or higher.

Examples

```
vset2.s32.u32.lt      r1, r2, r3, r0;
vset2.u32.u32.ne.add  r1, r2, r3, r0;
```

9.7.18.2.3 SIMD Video Instructions: vadd4, vsub4, vavrg4, vabsdiff4, vmin4, vmax4

vadd4, vsub4

Integer quad byte SIMD addition/subtraction.

vavrg4

Integer quad byte SIMD average.

vabsdiff4

Integer quad byte SIMD absolute value of difference.

vmin4, vmax4

Integer quad byte SIMD minimum/maximum.

Syntax

```
// SIMD instruction with secondary SIMD merge operation
vop4.dtype.atype.btype{.sat}  d{.mask}, a{.asel}, b{.bsel}, c;

// SIMD instruction with secondary accumulate operation
vop4.dtype.atype.btype.add  d{.mask}, a{.asel}, b{.bsel}, c;
vop4  = { vadd4, vsub4, vavrg4, vabsdiff4, vmin4, vmax4 };

.dtype = .atype = .btype = { .u32, .s32 };
.mask  = { .b0,
           .b1, .b10
           .b2, .b20, .b21, .b210,
           .b3, .b30, .b31, .b310, .b32, .b320, .b321, .b3210 };
    defaults to .b3210
.asel = .bsel = .bxyzw, where x,y,z,w are from { 0, ..., 7 };
   .asel defaults to .b3210
   .bsel defaults to .b7654
```

Description

Four-way SIMD parallel arithmetic operation with secondary operation.

Elements of each quad byte source to the operation are selected from any of the eight bytes in the two source operands a and b using the `asel` and `bsel` modifiers.

The selected bytes are then operated on in parallel.

The results are optionally clamped to the appropriate range determined by the destination type (signed or unsigned). Saturation cannot be used with the secondary accumulate operation.

For instructions with a secondary SIMD merge operation:

- For byte positions indicated in mask, the selected byte results are copied into destination d. For all other positions, the corresponding byte from source operand c is copied to d.

For instructions with a secondary accumulate operation:

- For byte positions indicated in mask, the selected byte results are added to operand c, producing a result in d.

Semantics

```
// extract quads of bytes and sign- or zero-extend
// based on operand type
Va = extractAndSignExt_4( a, b, .asel, .atype );
Vb = extractAndSignExt_4( a, b, .bsel, .btype );
Vc = extractAndSignExt_4( c );
for (i=0; i<4; i++) {
    switch ( vop4 ) {
        case vadd4:            t[i] = Va[i] + Vb[i];
        case vsub4:            t[i] = Va[i] - Vb[i];
        case vavrg4:           if ( ( Va[i] + Vb[i] ) >= 0 ) {
                                   t[i] = ( Va[i] + Vb[i] + 1 ) >> 1;
                               } else {
                                   t[i] = ( Va[i] + Vb[i] ) >> 1;
                               }
        case vabsdiff4:        t[i] = | Va[i] - Vb[i] |;
        case vmin4:            t[i] = MIN( Va[i], Vb[i] );
        case vmax4:            t[i] = MAX( Va[i], Vb[i] );
    }
    if (.sat) {
        if ( .dtype == .s32 )  t[i] = CLAMP( t[i], S8_MAX, S8_MIN );
        else                   t[i] = CLAMP( t[i], U8_MAX, U8_MIN );
    }
}
// secondary accumulate or SIMD merge
mask = extractMaskBits( .mask );
if (.add) {
    d = c;
    for (i=0; i<4; i++) {  d += mask[i] ? t[i] : 0;  }
} else {
    d = 0;
    for (i=0; i<4; i++)  {  d |= mask[i] ? t[i] : Vc[i];  }
}
```

PTX ISA Notes

Introduced in PTX ISA version 3.0.

Target ISA Notes

`vadd4`, `vsub4`, `varvg4`, `vabsdiff4`, `vmin4`, `vmax4` require `sm_30` or higher.

Examples

```
vadd4.s32.s32.u32.sat  r1, r2, r3, r1;
vsub4.s32.s32.s32.sat  r1.b0, r2.b3210, r3.b7654, r1;
vmin4.s32.u32.u32.add  r1.b00, r2.b0000, r3.b2222, r1;
```

9.7.18.2.4 SIMD Video Instructions: vset4

vset4

Integer quad byte SIMD comparison.

Syntax

```
// SIMD instruction with secondary SIMD merge operation
vset4.atype.btype.cmp  d{.mask}, a{.asel}, b{.bsel}, c;

// SIMD instruction with secondary accumulate operation
vset4.atype.btype.cmp.add  d{.mask}, a{.asel}, b{.bsel}, c;

.atype = .btype = { .u32, .s32 };
.cmp   = { .eq, .ne, .lt, .le, .gt, .ge };
.mask  = { .b0,
           .b1, .b10
           .b2, .b20, .b21, .b210,
           .b3, .b30, .b31, .b310, .b32, .b320, .b321, .b3210 };
    defaults to .b3210
.asel = .bsel = .bxyzw, where x,y,z,w are from { 0, ..., 7 };
   .asel defaults to .b3210
   .bsel defaults to .b7654
```

Description

Four-way SIMD parallel comparison with secondary operation.

Elements of each quad byte source to the operation are selected from any of the eight bytes in the two source operands a and b using the `asel` and `bsel` modifiers.

The selected bytes are then compared in parallel.

The intermediate result of the comparison is always unsigned, and therefore the bytes of destination d and operand c are also unsigned.

For instructions with a secondary SIMD merge operation:

- For byte positions indicated in mask, the selected byte results are copied into destination d. For all other positions, the corresponding byte from source operand b is copied to d.

For instructions with a secondary accumulate operation:

- For byte positions indicated in mask, the selected byte results are added to operand c, producing a result in d.

Semantics

```
// extract quads of bytes and sign- or zero-extend
// based on operand type
Va = extractAndSignExt_4( a, b, .asel, .atype );
Vb = extractAndSignExt_4( a, b, .bsel, .btype );
Vc = extractAndSignExt_4( c );
for (i=0; i<4; i++) {
    t[i] = compare( Va[i], Vb[i], cmp ) ? 1 : 0;
}
// secondary accumulate or SIMD merge
mask = extractMaskBits( .mask );
if (.add) {
    d = c;
    for (i=0; i<4; i++) {  d += mask[i] ? t[i] : 0;  }
} else {
    d = 0;
    for (i=0; i<4; i++)  {  d |= mask[i] ? t[i] : Vc[i];  }
}
```

PTX ISA Notes

Introduced in PTX ISA version 3.0.

Target ISA Notes

`vset4` requires `sm_30` or higher.

Examples

```
vset4.s32.u32.lt      r1, r2, r3, r0;
vset4.u32.u32.ne.max  r1, r2, r3, r0;
```

9.7.19. Miscellaneous Instructions

The Miscellaneous instructions are:

- `brkpt`
- `nanosleep`
- `pmevent`
- `trap`
- `setmaxnreg`

9.7.19.1 Miscellaneous Instructions: `brkpt`

`brkpt`

Breakpoint.

Syntax

```
brkpt;
```

Description

Suspends execution.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

`brkpt` requires `sm_11` or higher.

Examples

```
    brkpt;
@p  brkpt;
```

9.7.19.2 Miscellaneous Instructions: `nanosleep`

`nanosleep`

Suspend the thread for an approximate delay given in nanoseconds.

Syntax

```
nanosleep.u32 t;
```

Description

Suspends the thread for a sleep duration approximately close to the delay `t`, specified in nanoseconds. `t` may be a register or an immediate value.

The sleep duration is approximated, but guaranteed to be in the interval `[0, 2*t]`. The maximum sleep duration is `1` millisecond. The implementation may reduce the sleep duration for individual threads within a warp such that all sleeping threads in the warp wake up together.

PTX ISA Notes

`nanosleep` introduced in PTX ISA 6.3.

Target ISA Notes

`nanosleep` requires `sm_70` or higher.

Examples

```
.reg .b32 r;
.reg .pred p;

nanosleep.u32 r;
nanosleep.u32 42;
@p nanosleep.u32 r;
```

9.7.19.3 Miscellaneous Instructions: `pmevent`

`pmevent`

Trigger one or more Performance Monitor events.

Syntax

```
pmevent       a;    // trigger a single performance monitor event
pmevent.mask  a;    // trigger one or more performance monitor events
```

Description

Triggers one or more of a fixed number of performance monitor events, with event index or mask specified by immediate operand `a`.

`pmevent` (without modifier `.mask`) triggers a single performance monitor event indexed by immediate operand `a`, in the range `0..15`.

`pmevent.mask` triggers one or more of the performance monitor events. Each bit in the 16-bit immediate operand `a` controls an event.

Programmatic performance moniter events may be combined with other hardware events using Boolean functions to increment one of the four performance counters. The relationship between events and counters is programmed via API calls from the host.

Notes

Currently, there are sixteen performance monitor events, numbered 0 through 15.

PTX ISA Notes

`pmevent` introduced in PTX ISA version 1.4.

`pmevent.mask` introduced in PTX ISA version 3.0.

Target ISA Notes

pmevent supported on all target architectures.

`pmevent.mask` requires `sm_20` or higher.

Examples

```
    pmevent      1;
@p  pmevent      7;
@q  pmevent.mask 0xff;
```

9.7.19.4 Miscellaneous Instructions: `trap`

`trap`

Perform trap operation.

Syntax

```
trap;
```

Description

Abort execution and generate an interrupt to the host CPU.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
    trap;
@p  trap;
```

9.7.19.5 Miscellaneous Instructions: setmaxnreg

setmaxnreg

Hint to change the number of registers owned by the warp.

Syntax

```
setmaxnreg.action.sync.aligned.u32 imm-reg-count;

.action = { .inc, .dec };
```

Description

`setmaxnreg` provides a hint to the system to update the maximum number of per-thread registers owned by the executing warp to the value specified by the `imm-reg-count` operand.

Qualifier `.dec` is used to release extra registers such that the absolute per-thread maximum register count is reduced from its current value to `imm-reg-count`. Qualifier `.inc` is used to request additional registers such that the absolute per-thread maximum register count is increased from its current value to `imm-reg-count`.

A pool of available registers is maintained per-CTA. Register adjustments requested by the `setmaxnreg` instructions are handled by supplying extra registers from this pool to the requesting warp or by releasing extra registers from the requesting warp to this pool, depending upon the value of the `.action` qualifier.

The `setmaxnreg.inc` instruction blocks the execution until enough registers are available in the CTA's register pool. After the instruction `setmaxnreg.inc` obtains new registers from the CTA pool, the initial contents of the new registers are undefined. The new registers must be initialized before they are used.

The same `setmaxnreg` instruction must be executed by all warps in a *warpgroup*. After executing a `setmaxnreg` instruction, all warps in the *warpgroup* must synchronize explicitly before executing subsequent setmaxnreg instructions. If a `setmaxnreg` instruction is not executed by all warps in the *warpgroup*, then the behavior is undefined.

Operand `imm-reg-count` is an integer constant. The value of `imm-reg-count` must be in the range 24 to 256 (both inclusive) and must be a multiple of 8.

Changes to the register file of the warp always happen at the tail-end of the register file.

The `setmaxnreg` instruction requires that the kernel has been launched with a valid value of maximum number of per-thread registers specified via the appropriate compilation via the appropriate compile-time option or the appropriate performance tuning directive. Otherwise, the `setmaxnreg` instruction may have no effect.

When qualifier `.dec` is specified, the maximum number of per-thread registers owned by the warp prior to the execution of `setmaxnreg` instruction should be greater than or equal to the `imm-reg-count`. Otherwise, the behaviour is undefined.

When qualifier `.inc` is specified, the maximum number of per-thread registers owned by the warp prior to the execution of `setmaxnreg` instruction should be less than or equal to the `imm-reg-count`. Otherwise, the behaviour is undefined.

The mandatory `.sync` qualifier indicates that `setmaxnreg` instruction causes the executing thread to wait until all threads in the warp execute the same `setmaxnreg` instruction before resuming execution.

The mandatory `.aligned` qualifier indicates that all threads in the warpgroup must execute the same `setmaxnreg` instruction. In conditionally executed code, `setmaxnreg` instruction should only be used if it is known that all threads in warpgroup evaluate the condition identically, otherwise the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Supported on following architectures:

- `sm_90a`
- `sm_100a`
- `sm_101a`
- `sm_120a`
- And is supported on following family-specific architectures from PTX ISA version 8.8:
  - `sm_100f` or higher in the same family
  - `sm_101f` or higher in the same family
  - `sm_120f` or higher in the same family

Examples

```
setmaxnreg.dec.sync.aligned.u32 64;
setmaxnreg.inc.sync.aligned.u32 192;
```

Chapter 10. Special Registers

PTX includes a number of predefined, read-only variables, which are visible as special registers and accessed through `mov` or `cvt` instructions.

The special registers are:

- `%tid`
- `%ntid`
- `%laneid`
- `%warpid`
- `%nwarpid`
- `%ctaid`
- `%nctaid`
- `%smid`
- `%nsmid`
- `%gridid`
- `%is_explicit_cluster`
- `%clusterid`
- `%nclusterid`
- `%cluster_ctaid`
- `%cluster_nctaid`
- `%cluster_ctarank`
- `%cluster_nctarank`
- `%lanemask_eq`, `%lanemask_le`, `%lanemask_lt`, `%lanemask_ge`, `%lanemask_gt`
- `%clock`, `%clock_hi`, `%clock64`
- `%pm0, ..., %pm7`
- `%pm0_64, ..., %pm7_64`
- `%envreg0, ..., %envreg31`
- `%globaltimer`, `%globaltimer_lo`, `%globaltimer_hi`
- `%reserved_smem_offset_begin`, `%reserved_smem_offset_end`, `%reserved_smem_offset_cap`, `%reserved_smem_offset<2>`

- %total_smem_size
- %aggr_smem_size
- %dynamic_smem_size
- %current_graph_exec

10.1. Special Registers: %tid

%tid

Thread identifier within a CTA.

Syntax (predefined)

```
.sreg .v4 .u32 %tid;                    // thread id vector
.sreg .u32 %tid.x, %tid.y, %tid.z;    // thread id components
```

Description

A predefined, read-only, per-thread special register initialized with the thread identifier within the CTA. The %tid special register contains a 1D, 2D, or 3D vector to match the CTA shape; the %tid value in unused dimensions is 0. The fourth element is unused and always returns zero. The number of threads in each dimension are specified by the predefined special register %ntid.

Every thread in the CTA has a unique %tid.

%tid component values range from 0 through %ntid-1 in each CTA dimension.

%tid.y == %tid.z == 0 in 1D CTAs. %tid.z == 0 in 2D CTAs.

It is guaranteed that:

```
0  <=  %tid.x <  %ntid.x
0  <=  %tid.y <  %ntid.y
0  <=  %tid.z <  %ntid.z
```

PTX ISA Notes

Introduced in PTX ISA version 1.0 with type .v4.u16.

Redefined as type .v4.u32 in PTX ISA version 2.0. For compatibility with legacy PTX code, 16-bit mov and cvt instructions may be used to read the lower 16-bits of each component of %tid.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32      %r1,%tid.x;  // move tid.x to %rh

// legacy code accessing 16-bit components of %tid
mov.u16      %rh,%tid.x;
cvt.u32.u16  %r2,%tid.z;  // zero-extend tid.z to %r2
```

10.2. Special Registers: %ntid

%ntid

Number of thread IDs per CTA.

Syntax (predefined)

```
.sreg .v4 .u32 %ntid;                   // CTA shape vector
.sreg .u32 %ntid.x, %ntid.y, %ntid.z;   // CTA dimensions
```

Description

A predefined, read-only special register initialized with the number of thread ids in each CTA dimension. The `%ntid` special register contains a 3D CTA shape vector that holds the CTA dimensions. CTA dimensions are non-zero; the fourth element is unused and always returns zero. The total number of threads in a CTA is (`%ntid.x * %ntid.y * %ntid.z`).

```
%ntid.y == %ntid.z == 1 in 1D CTAs.
%ntid.z ==1 in 2D CTAs.
```

Maximum values of %ntid.{x,y,z} are as follows:

.target architecture	%ntid.x	%ntid.y	%ntid.z
sm_1x	512	512	64
sm_20, sm_3x, sm_5x, sm_6x, sm_7x, sm_8x, sm_9x	1024	1024	64

PTX ISA Notes

Introduced in PTX ISA version 1.0 with type `.v4.u16`.

Redefined as type `.v4.u32` in PTX ISA version 2.0. For compatibility with legacy PTX code, 16-bit `mov` and `cvt` instructions may be used to read the lower 16-bits of each component of `%ntid`.

Target ISA Notes

Supported on all target architectures.

Examples

```
// compute unified thread id for 2D CTA
mov.u32  %r0,%tid.x;
mov.u32  %h1,%tid.y;
mov.u32  %h2,%ntid.x;
mad.u32  %r0,%h1,%h2,%r0;

mov.u16  %rh,%ntid.x;      // legacy code
```

10.3. Special Registers: `%laneid`

`%laneid`

Lane Identifier.

Syntax (predefined)

```
.sreg .u32 %laneid;
```

Description

A predefined, read-only special register that returns the thread's lane within the warp. The lane identifier ranges from zero to `WARP_SZ-1`.

PTX ISA Notes

Introduced in PTX ISA version 1.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32  %r, %laneid;
```

10.4. Special Registers: %warpid

%warpid

Warp identifier.

Syntax (predefined)

```
.sreg .u32 %warpid;
```

Description

A predefined, read-only special register that returns the thread's warp identifier. The warp identifier provides a unique warp number within a CTA but not across CTAs within a grid. The warp identifier will be the same for all threads within a single warp.

Note that %warpid returns the location of a thread at the moment when read, but its value may change during execution, e.g., due to rescheduling of threads following preemption. For this reason, %ctaid and %tid should be used to compute a virtual warp index if such a value is needed in kernel code; %warpid is intended mainly to enable profiling and diagnostic code to sample and log information such as work place mapping and load distribution.

PTX ISA Notes

Introduced in PTX ISA version 1.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32  %r, %warpid;
```

10.5. Special Registers: %nwarpid

%nwarpid

Number of warp identifiers.

Syntax (predefined)

```
.sreg .u32 %nwarpid;
```

Description

A predefined, read-only special register that returns the maximum number of warp identifiers.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%nwarpid` requires `sm_20` or higher.

Examples

```
mov.u32  %r, %nwarpid;
```

10.6. Special Registers: %ctaid

%ctaid

CTA identifier within a grid.

Syntax (predefined)

```
.sreg .v4 .u32 %ctaid;                      // CTA id vector
.sreg .u32 %ctaid.x, %ctaid.y, %ctaid.z;    // CTA id components
```

Description

A predefined, read-only special register initialized with the CTA identifier within the CTA grid. The `%ctaid` special register contains a 1D, 2D, or 3D vector, depending on the shape and rank of the CTA grid. The fourth element is unused and always returns zero.

It is guaranteed that:

```
0  <=  %ctaid.x <  %nctaid.x
0  <=  %ctaid.y <  %nctaid.y
0  <=  %ctaid.z <  %nctaid.z
```

PTX ISA Notes

Introduced in PTX ISA version 1.0 with type `.v4.u16`.

Redefined as type `.v4.u32` in PTX ISA version 2.0. For compatibility with legacy PTX code, 16-bit `mov` and `cvt` instructions may be used to read the lower 16-bits of each component of `%ctaid`.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32  %r0,%ctaid.x;
mov.u16  %rh,%ctaid.y;   // legacy code
```

10.7. Special Registers: %nctaid

%nctaid

Number of CTA ids per grid.

Syntax (predefined)

```
.sreg .v4 .u32 %nctaid                          // Grid shape vector
.sreg .u32 %nctaid.x,%nctaid.y,%nctaid.z;   // Grid dimensions
```

Description

A predefined, read-only special register initialized with the number of CTAs in each grid dimension. The `%nctaid` special register contains a 3D grid shape vector, with each element having a value of at least 1. The fourth element is unused and always returns zero.

Maximum values of %nctaid.{x,y,z} are as follows:

.target architecture	%nctaid.x	%nctaid.y	%nctaid.z
sm_1x, sm_20	65535	65535	65535
sm_3x, sm_5x, sm_6x, sm_7x, sm_8x, sm_9x	2^{31} -1	65535	65535

PTX ISA Notes

Introduced in PTX ISA version 1.0 with type `.v4.u16`.

Redefined as type `.v4.u32` in PTX ISA version 2.0. For compatibility with legacy PTX code, 16-bit `mov` and `cvt` instructions may be used to read the lower 16-bits of each component of `%nctaid`.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32  %r0,%nctaid.x;
mov.u16  %rh,%nctaid.x;     // legacy code
```

10.8. Special Registers: %smid

%smid

SM identifier.

Syntax (predefined)

```
.sreg .u32 %smid;
```

Description

A predefined, read-only special register that returns the processor (SM) identifier on which a particular thread is executing. The SM identifier ranges from `0` to `%nsmid-1`. The SM identifier numbering is not guaranteed to be contiguous.

Notes

Note that `%smid` returns the location of a thread at the moment when read, but its value may change during execution, e.g. due to rescheduling of threads following preemption. `%smid` is intended mainly to enable profiling and diagnostic code to sample and log information such as work place mapping and load distribution.

PTX ISA Notes

Introduced in PTX ISA version 1.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u32  %r, %smid;
```

10.9. Special Registers: %nsmid

%nsmid

Number of SM identifiers.

Syntax (predefined)

```
.sreg .u32 %nsmid;
```

Description

A predefined, read-only special register that returns the maximum number of SM identifiers. The SM identifier numbering is not guaranteed to be contiguous, so `%nsmid` may be larger than the physical number of SMs in the device.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%nsmid` requires `sm_20` or higher.

Examples

```
mov.u32  %r, %nsmid;
```

10.10. Special Registers: %gridid

%gridid

Grid identifier.

Syntax (predefined)

```
.sreg .u64 %gridid;
```

Description

A predefined, read-only special register initialized with the per-grid temporal grid identifier. The `%gridid` is used by debuggers to distinguish CTAs and clusters within concurrent (small) grids.

During execution, repeated launches of programs may occur, where each launch starts a grid-of-CTAs. This variable provides the temporal grid launch number for this context.

For `sm_1x` targets, `%gridid` is limited to the range [0..2^{16}-1]. For `sm_20`, `%gridid` is limited to the range [0..2^{32}-1]. `sm_30` supports the entire 64-bit range.

PTX ISA Notes

Introduced in PTX ISA version 1.0 as type `.u16`.

Redefined as type `.u32` in PTX ISA version 1.3.

Redefined as type `.u64` in PTX ISA version 3.0.

For compatibility with legacy PTX code, 16-bit and 32-bit `mov` and `cvt` instructions may be used to read the lower 16-bits or 32-bits of each component of `%gridid`.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.u64  %s, %gridid;  // 64-bit read of %gridid
mov.u32  %r, %gridid;  // legacy code with 32-bit %gridid
```

10.11. Special Registers: %is_explicit_cluster

%is_explicit_cluster

Checks if user has explicitly specified cluster launch.

Syntax (predefined)

```
.sreg .pred %is_explicit_cluster;
```

Description

A predefined, read-only special register initialized with the predicate value of whether the cluster launch is explicitly specified by user.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.reg .pred p;

mov.pred  p, %is_explicit_cluster;
```

10.12. Special Registers: `%clusterid`

`%clusterid`

Cluster identifier within a grid.

Syntax (predefined)

```
.sreg .v4 .u32 %clusterid;
.sreg .u32 %clusterid.x, %clusterid.y, %clusterid.z;
```

Description

A predefined, read-only special register initialized with the cluster identifier in a grid in each dimension. Each cluster in a grid has a unique identifier.

The `%clusterid` special register contains a 1D, 2D, or 3D vector, depending upon the shape and rank of the cluster. The fourth element is unused and always returns zero.

It is guaranteed that:

```
0  <=  %clusterid.x <  %nclusterid.x
0  <=  %clusterid.y <  %nclusterid.y
0  <=  %clusterid.z <  %nclusterid.z
```

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.reg .b32 %r<2>;
.reg .v4 .b32 %rx;

mov.u32     %r0, %clusterid.x;
mov.u32     %r1, %clusterid.z;
mov.v4.u32  %rx, %clusterid;
```

10.13. Special Registers: `%nclusterid`

`%nclusterid`

Number of cluster identifiers per grid.

Syntax (predefined)

```
.sreg .v4 .u32 %nclusterid;
.sreg .u32 %nclusterid.x, %nclusterid.y, %nclusterid.z;
```

Description

A predefined, read-only special register initialized with the number of clusters in each grid dimension.

The `%nclusterid` special register contains a 3D grid shape vector that holds the grid dimensions in terms of clusters. The fourth element is unused and always returns zero.

Refer to the *Cuda Programming Guide* for details on the maximum values of `%nclusterid.{x,y,z}`.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.reg .b32 %r<2>;
.reg .v4 .b32 %rx;

mov.u32     %r0, %nclusterid.x;
mov.u32     %r1, %nclusterid.z;
mov.v4.u32  %rx, %nclusterid;
```

10.14. Special Registers: `%cluster_ctaid`

`%cluster_ctaid`

CTA identifier within a cluster.

Syntax (predefined)

```
.sreg .v4 .u32 %cluster_ctaid;
.sreg .u32 %cluster_ctaid.x, %cluster_ctaid.y, %cluster_ctaid.z;
```

Description

A predefined, read-only special register initialized with the CTA identifier in a cluster in each dimension. Each CTA in a cluster has a unique CTA identifier.

The `%cluster_ctaid` special register contains a 1D, 2D, or 3D vector, depending upon the shape of the cluster. The fourth element is unused and always returns zero.

It is guaranteed that:

```
0  <=  %cluster_ctaid.x <  %cluster_nctaid.x
0  <=  %cluster_ctaid.y <  %cluster_nctaid.y
0  <=  %cluster_ctaid.z <  %cluster_nctaid.z
```

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.reg .b32 %r<2>;
.reg .v4 .b32 %rx;

mov.u32     %r0, %cluster_ctaid.x;
mov.u32     %r1, %cluster_ctaid.z;
mov.v4.u32  %rx, %cluster_ctaid;
```

10.15. Special Registers: `%cluster_nctaid`

`%cluster_nctaid`

Number of CTA identifiers per cluster.

Syntax (predefined)

```
.sreg .v4 .u32 %cluster_nctaid;
.sreg .u32 %cluster_nctaid.x, %cluster_nctaid.y, %cluster_nctaid.z;
```

Description

A predefined, read-only special register initialized with the number of CTAs in a cluster in each dimension.

The `%cluster_nctaid` special register contains a 3D grid shape vector that holds the cluster dimensions in terms of CTAs. The fourth element is unused and always returns zero.

Refer to the *Cuda Programming Guide* for details on the maximum values of `%cluster_nctaid.{x,y,z}`.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.reg .b32 %r<2>;
.reg .v4 .b32 %rx;

mov.u32     %r0, %cluster_nctaid.x;
mov.u32     %r1, %cluster_nctaid.z;
mov.v4.u32  %rx, %cluster_nctaid;
```

10.16. Special Registers: `%cluster_ctarank`

`%cluster_ctarank`

CTA identifier in a cluster across all dimensions.

Syntax (predefined)

```
.sreg .u32 %cluster_ctarank;
```

Description

A predefined, read-only special register initialized with the CTA rank within a cluster across all dimensions.

It is guaranteed that:

```
0  <=  %cluster_ctarank <  %cluster_nctarank
```

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires sm_90 or higher.

Examples

```
.reg .b32 %r;

mov.u32  %r, %cluster_ctarank;
```

10.17. Special Registers: %cluster_nctarank

%cluster_nctarank

Number of CTA identifiers in a cluster across all dimensions.

Syntax (predefined)

```
.sreg .u32 %cluster_nctarank;
```

Description

A predefined, read-only special register initialized with the nunber of CTAs within a cluster across all dimensions.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires sm_90 or higher.

Examples

```
.reg .b32 %r;

mov.u32  %r, %cluster_nctarank;
```

10.18. Special Registers: %lanemask_eq

%lanemask_eq

32-bit mask with bit set in position equal to the thread's lane number in the warp.

Syntax (predefined)

```
.sreg .u32 %lanemask_eq;
```

Description

A predefined, read-only special register initialized with a 32-bit mask with a bit set in the position equal to the thread's lane number in the warp.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%lanemask_eq` requires `sm_20` or higher.

Examples

```
mov.u32     %r, %lanemask_eq;
```

10.19. Special Registers: %lanemask_le

%lanemask_le

32-bit mask with bits set in positions less than or equal to the thread's lane number in the warp.

Syntax (predefined)

```
.sreg .u32 %lanemask_le;
```

Description

A predefined, read-only special register initialized with a 32-bit mask with bits set in positions less than or equal to the thread's lane number in the warp.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%lanemask_le` requires `sm_20` or higher.

Examples

```
mov.u32     %r, %lanemask_le
```

10.20. Special Registers: `%lanemask_lt`

`%lanemask_lt`

32-bit mask with bits set in positions less than the thread's lane number in the warp.

Syntax (predefined)

```
.sreg .u32 %lanemask_lt;
```

Description

A predefined, read-only special register initialized with a 32-bit mask with bits set in positions less than the thread's lane number in the warp.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%lanemask_lt` requires `sm_20` or higher.

Examples

```
mov.u32     %r, %lanemask_lt;
```

10.21. Special Registers: %lanemask_ge

%lanemask_ge

32-bit mask with bits set in positions greater than or equal to the thread's lane number in the warp.

Syntax (predefined)

```
.sreg .u32 %lanemask_ge;
```

Description

A predefined, read-only special register initialized with a 32-bit mask with bits set in positions greater than or equal to the thread's lane number in the warp.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%lanemask_ge` requires `sm_20` or higher.

Examples

```
mov.u32     %r, %lanemask_ge;
```

10.22. Special Registers: %lanemask_gt

%lanemask_gt

32-bit mask with bits set in positions greater than the thread's lane number in the warp.

Syntax (predefined)

```
.sreg .u32 %lanemask_gt;
```

Description

A predefined, read-only special register initialized with a 32-bit mask with bits set in positions greater than the thread's lane number in the warp.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%lanemask_gt` requires `sm_20` or higher.

Examples

```
mov.u32     %r, %lanemask_gt;
```

10.23. Special Registers: %clock, %clock_hi

%clock, %clock_hi

%clock
A predefined, read-only 32-bit unsigned cycle counter.

%clock_hi
The upper 32-bits of `%clock64` special register.

Syntax (predefined)

```
.sreg .u32 %clock;
.sreg .u32 %clock_hi;
```

Description

Special register `%clock` and `%clock_hi` are unsigned 32-bit read-only cycle counters that wrap silently.

PTX ISA Notes

`%clock` introduced in PTX ISA version 1.0.

`%clock_hi` introduced in PTX ISA version 5.0.

Target ISA Notes

`%clock` supported on all target architectures.

`%clock_hi` requires `sm_20` or higher.

Examples

```
mov.u32 r1,%clock;
mov.u32 r2, %clock_hi;
```

10.24. Special Registers: %clock64

%clock64

A predefined, read-only 64-bit unsigned cycle counter.

Syntax (predefined)

```
.sreg .u64 %clock64;
```

Description

Special register `%clock64` is an unsigned 64-bit read-only cycle counter that wraps silently.

Notes

The lower 32-bits of `%clock64` are identical to `%clock`.

The upper 32-bits of `%clock64` are identical to `%clock_hi`.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

`%clock64` requires `sm_20` or higher.

Examples

```
mov.u64  r1,%clock64;
```

10.25. Special Registers: %pm0 ... %pm7

%pm0 ... %pm7

Performance monitoring counters.

Syntax (predefined)

```
.sreg .u32 %pm<8>;
```

Description

Special registers `%pm0` ... `%pm7` are unsigned 32-bit read-only performance monitor counters. Their behavior is currently undefined.

PTX ISA Notes

%pm0 ... %pm3 introduced in PTX ISA version 1.3.

%pm4 ... %pm7 introduced in PTX ISA version 3.0.

Target ISA Notes

%pm0 ... %pm3 supported on all target architectures.

%pm4 ... %pm7 require sm_20 or higher.

Examples

```
mov.u32  r1,%pm0;
mov.u32  r1,%pm7;
```

10.26. Special Registers: %pm0_64 ... %pm7_64

%pm0_64 ... %pm7_64

64 bit Performance monitoring counters.

Syntax (predefined)

```
.sreg .u64 %pm0_64;
.sreg .u64 %pm1_64;
.sreg .u64 %pm2_64;
.sreg .u64 %pm3_64;
.sreg .u64 %pm4_64;
.sreg .u64 %pm5_64;
.sreg .u64 %pm6_64;
.sreg .u64 %pm7_64;
```

Description

Special registers %pm0_64 ... %pm7_64 are unsigned 64-bit read-only performance monitor counters. Their behavior is currently undefined.

Notes

The lower 32bits of `%pm0_64` ... `%pm7_64` are identical to `%pm0` ... `%pm7`.

PTX ISA Notes

`%pm0_64` ... `%pm7_64` introduced in PTX ISA version 4.0.

Target ISA Notes

`%pm0_64` ... `%pm7_64` require `sm_50` or higher.

Examples

```
mov.u32  r1,%pm0_64;
mov.u32  r1,%pm7_64;
```

10.27. Special Registers: %envreg<32>

%envreg<32>

Driver-defined read-only registers.

Syntax (predefined)

```
.sreg .b32 %envreg<32>;
```

Description

A set of 32 pre-defined read-only registers used to capture execution environment of PTX program outside of PTX virtual machine. These registers are initialized by the driver prior to kernel launch and can contain cta-wide or grid-wide values.

Precise semantics of these registers is defined in the driver documentation.

PTX ISA Notes

Introduced in PTX ISA version 2.1.

Target ISA Notes

Supported on all target architectures.

Examples

```
mov.b32      %r1,%envreg0;  // move envreg0 to %r1
```

10.28. Special Registers: %globaltimer, %globaltimer_lo, %globaltimer_hi

%globaltimer, %globaltimer_lo, %globaltimer_hi

%globaltimer
A predefined, 64-bit global nanosecond timer.

%globaltimer_lo
The lower 32-bits of %globaltimer.

%globaltimer_hi
The upper 32-bits of %globaltimer.

Syntax (predefined)

```
.sreg .u64 %globaltimer;
.sreg .u32 %globaltimer_lo, %globaltimer_hi;
```

Description

Special registers intended for use by NVIDIA tools. The behavior is target-specific and may change or be removed in future GPUs. When JIT-compiled to other targets, the value of these registers is unspecified.

PTX ISA Notes

Introduced in PTX ISA version 3.1.

Target ISA Notes

Requires target `sm_30` or higher.

Examples

```
mov.u64  r1,%globaltimer;
```

10.29. Special Registers: %reserved_smem_offset_begin, %reserved_smem_offset_end, %reserved_smem_offset_cap, %reserved_smem_offset_<2>

%reserved_smem_offset_begin, %reserved_smem_offset_end, %reserved_smem_offset_cap, %reserved_smem_offset_<2>

%reserved_smem_offset_begin
Start of the reserved shared memory region.

%reserved_smem_offset_end
End of the reserved shared memory region.

%reserved_smem_offset_cap
Total size of the reserved shared memory region.

%reserved_smem_offset_<2>
Offsets in the reserved shared memory region.

Syntax (predefined)

```
.sreg .b32 %reserved_smem_offset_begin;
.sreg .b32 %reserved_smem_offset_end;
.sreg .b32 %reserved_smem_offset_cap;
.sreg .b32 %reserved_smem_offset_<2>;
```

Description

These are predefined, read-only special registers containing information about the shared memory region which is reserved for the NVIDIA system software use. This region of shared memory is not available to users, and accessing this region from user code results in undefined behavior. Refer to *CUDA Programming Guide* for details.

PTX ISA Notes

Introduced in PTX ISA version 7.6.

Target ISA Notes

Require `sm_80` or higher.

Examples

```
.reg .b32 %reg_begin, %reg_end, %reg_cap, %reg_offset0, %reg_offset1;

mov.b32 %reg_begin,   %reserved_smem_offset_begin;
mov.b32 %reg_end,     %reserved_smem_offset_end;
mov.b32 %reg_cap,     %reserved_smem_offset_cap;
mov.b32 %reg_offset0, %reserved_smem_offset_0;
mov.b32 %reg_offset1, %reserved_smem_offset_1;
```

10.30. Special Registers: `%total_smem_size`

`%total_smem_size`

Total size of shared memory used by a CTA of a kernel.

Syntax (predefined)

```
.sreg .u32 %total_smem_size;
```

Description

A predefined, read-only special register initialized with total size of shared memory allocated (statically and dynamically, excluding the shared memory reserved for the NVIDIA system software use) for the CTA of a kernel at launch time.

Size is returned in multiples of shared memory allocation unit size supported by target architecture.

Allocation unit values are as follows:

Target architecture	Shared memory allocation unit size
sm_2x	128 bytes
sm_3x, sm_5x, sm_6x, sm_7x	256 bytes
sm_8x, sm_9x	128 bytes

PTX ISA Notes

Introduced in PTX ISA version 4.1.

Target ISA Notes

Requires sm_20 or higher.

Examples

```
mov.u32  %r, %total_smem_size;
```

10.31. Special Registers: %aggr_smem_size

%aggr_smem_size

Total size of shared memory used by a CTA of a kernel.

Syntax (predefined)

```
.sreg .u32 %aggr_smem_size;
```

Description

A predefined, read-only special register initialized with total aggregated size of shared memory consisting of the size of user shared memory allocated (statically and dynamically) at launch time and the size of shared memory region which is reserved for the NVIDIA system software use.

PTX ISA Notes

Introduced in PTX ISA version 8.1.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
mov.u32  %r, %aggr_smem_size;
```

10.32. Special Registers: %dynamic_smem_size

%dynamic_smem_size

Size of shared memory allocated dynamically at kernel launch.

Syntax (predefined)

```
.sreg .u32 %dynamic_smem_size;
```

Description

Size of shared memory allocated dynamically at kernel launch.

A predefined, read-only special register initialized with size of shared memory allocated dynamically for the CTA of a kernel at launch time.

PTX ISA Notes

Introduced in PTX ISA version 4.1.

Target ISA Notes

Requires `sm_20` or higher.

Examples

```
mov.u32  %r, %dynamic_smem_size;
```

10.33. Special Registers: %current_graph_exec

%current_graph_exec

An Identifier for currently executing CUDA device graph.

Syntax (predefined)

```
.sreg .u64 %current_graph_exec;
```

Description

A predefined, read-only special register initialized with the identifier referring to the CUDA device graph being currently executed. This register is 0 if the executing kernel is not part of a CUDA device graph.

Refer to the *CUDA Programming Guide* for more details on CUDA device graphs.

PTX ISA Notes

Introduced in PTX ISA version 8.0.

Target ISA Notes

Requires `sm_50` or higher.

Examples

```
mov.u64  r1, %current_graph_exec;
```

Chapter 11. Directives

11.1. PTX Module Directives

The following directives declare the PTX ISA version of the code in the module, the target architecture for which the code was generated, and the size of addresses within the PTX module.

- `.version`
- `.target`
- `.address_size`

11.1.1. PTX Module Directives: `.version`

`.version`

PTX ISA version number.

Syntax

```
.version  major.minor    // major, minor are integers
```

Description

Specifies the PTX language version number.

The *major* number is incremented when there are incompatible changes to the PTX language, such as changes to the syntax or semantics. The version major number is used by the PTX compiler to ensure correct execution of legacy PTX code.

The *minor* number is incremented when new features are added to PTX.

Semantics

Indicates that this module must be compiled with tools that support an equal or greater version number.

Each PTX module must begin with a `.version` directive, and no other `.version` directive is allowed anywhere else within the module.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
.version 3.1
.version 3.0
.version 2.3
```

11.1.2. PTX Module Directives: `.target`

`.target`

Architecture and Platform target.

Syntax

```
.target stringlist         // comma separated list of target specifiers
string = { sm_120a, sm_120f, sm_120,         // sm_12x target architectures
           sm_121a, sm_121f, sm_121,         // sm_12x target architectures
           sm_100a, sm_100f, sm_100,         // sm_10x target architectures
           sm_101a, sm_101f, sm_101,         // sm_10x target architectures
           sm_103a, sm_103f, sm_103          // sm_10x target architectures
           sm_90a, sm_90,                    // sm_9x target architectures
           sm_80, sm_86, sm_87, sm_89,       // sm_8x target architectures
           sm_70, sm_72, sm_75,              // sm_7x target architectures
           sm_60, sm_61, sm_62,              // sm_6x target architectures
           sm_50, sm_52, sm_53,              // sm_5x target architectures
           sm_30, sm_32, sm_35, sm_37,       // sm_3x target architectures
           sm_20,                            // sm_2x target architectures
           sm_10, sm_11, sm_12, sm_13,       // sm_1x target architectures
           texmode_unified, texmode_independent,   // texturing mode
           debug,                                  // platform option
           map_f64_to_f32 };                       // platform option
```

Description

Specifies the set of features in the target architecture for which the current PTX code was generated. In general, generations of SM architectures follow an *onion layer* model, where each generation adds new features and retains all features of previous generations. The onion layer model allows the PTX code generated for a given target to be run on later generation devices.

Target architectures with suffix "a", such as `sm_90a`, include architecture-specific features that are supported on the specified architecture only, hence such targets do not follow the onion layer model. Therefore, PTX code generated for such targets cannot be run on later generation devices. Architecture-specific features can only be used with targets that support these features.

Target architectures with suffix "`f`", such as `sm_100f`, include family-specific features that are supported only within the same architecture family. Therefore, PTX code generated for such targets can run only on later generation devices in the same family. Family-specific features can be used with f-targets as well as a-targets of later generation devices in the same family.

Architecture family definition:

Family	Target SM architectures included
sm_10x family	sm_100f, sm_103f, future targets in sm_10x family
sm_101 family	sm_101f
sm_12x family	sm_120f, sm_121f, future targets in sm_12x family

Semantics

Each PTX module must begin with a `.version` directive, immediately followed by a `.target` directive containing a target architecture and optional platform options. A `.target` directive specifies a single target architecture, but subsequent `.target` directives can be used to change the set of target features allowed during parsing. A program with multiple `.target` directives will compile and run only on devices that support all features of the highest-numbered architecture listed in the program.

PTX features are checked against the specified target architecture, and an error is generated if an unsupported feature is used. The following table summarizes the features in PTX that vary according to target architecture.

Target	Description
`sm_120`	Baseline feature set for `sm_120` architecture.
`sm_120f`	Adds support for `sm_120f` family specific features.
`sm_120a`	Adds support for `sm_120a` architecture-specific features.
`sm_121`	Baseline feature set for `sm_121` architecture.
`sm_121f`	Adds support for `sm_121f` family specific features.
`sm_121a`	Adds support for `sm_121a` architecture-specific features.

Target	Description
sm_100	Baseline feature set for sm_100 architecture.
sm_100f	Adds support for sm_100f family specific features.
sm_100a	Adds support for sm_100a architecture-specific features.
sm_101	Baseline feature set for sm_101 architecture.
sm_101f	Adds support for sm_101f family specific features.
sm_101a	Adds support for sm_101a architecture-specific features.
sm_103	Baseline feature set for sm_103 architecture.
sm_103f	Adds support for sm_103f family specific features.
sm_103a	Adds support for sm_103a architecture-specific features.

Target	Description
sm_90	Baseline feature set for sm_90 architecture.
sm_90a	Adds support for sm_90a architecture-specific features.

Target	Description
sm_80	Baseline feature set for sm_80 architecture.
sm_86	Adds support for .xorsign modifier on min and max instructions.
sm_87	Baseline feature set for sm_86 architecture.
sm_89	Baseline feature set for sm_86 architecture.

Target	Description
sm_70	Baseline feature set for sm_70 architecture.
sm_72	Adds support for integer multiplicand and accumulator matrices in wmma instructions. Adds support for cvt.pack instruction.
sm_75	Adds support for sub-byte integer and single-bit multiplicant matrices in wmma instructions. Adds support for ldmatrix instruction. Adds support for movmatrix instruction. Adds support for tanh instruction.

Target	Description
sm_60	Baseline feature set for sm_60 architecture.
sm_61	Adds support for dp2a and dp4a instructions.
sm_62	Baseline feature set for sm_61 architecture.

Target	Description
sm_50	Baseline feature set for sm_50 architecture.
sm_52	Baseline feature set for sm_50 architecture.
sm_53	Adds support for arithmetic, comparsion and texture instructions for .f16 and .f16x2 types.

Target	Description
sm_30	Baseline feature set for sm_30 architecture.
sm_32	Adds 64-bit {atom,red}.{and,or,xor,min,max} instructions. Adds shf instruction. Adds ld.global.nc instruction.
sm_35	Adds support for CUDA Dynamic Parallelism.
sm_37	Baseline feature set for sm_35 architecture.

Target	Description
sm_20	Baseline feature set for sm_20 architecture.

Target	Description
sm_10	Baseline feature set for sm_10 architecture. Requires map_f64_to_f32 if any .f64 instructions used.
sm_11	Adds 64-bit {atom,red}.{and,or,xor,min,max} instructions. Requires map_f64_to_f32 if any .f64 instructions used.
sm_12	Adds {atom,red}.shared, 64-bit {atom,red}.global, vote instructions. Requires map_f64_to_f32 if any .f64 instructions used.
sm_13	Adds double-precision support, including expanded rounding modifiers. Disallows use of map_f64_to_f32.

The texturing mode is specified for an entire module and cannot be changed within the module.

The .target debug option declares that the PTX file contains DWARF debug information, and subsequent compilation of PTX will retain information needed for source-level debugging. If the debug option is declared, an error message is generated if no DWARF information is found in the file. The debug option requires PTX ISA version 3.0 or later.

map_f64_to_f32 indicates that all double-precision instructions map to single-precision regardless of the target architecture. This enables high-level language compilers to compile programs containing type double to target device that do not support double-precision operations. Note that .f64 storage remains as 64-bits, with only half being used by instructions converted from .f64 to .f32.

Notes

Targets of the form `compute_xx` are also accepted as synonyms for `sm_xx` targets.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target strings `sm_10` and `sm_11` introduced in PTX ISA version 1.0.

Target strings `sm_12` and `sm_13` introduced in PTX ISA version 1.2.

Texturing mode introduced in PTX ISA version 1.5.

Target string `sm_20` introduced in PTX ISA version 2.0.

Target string `sm_30` introduced in PTX ISA version 3.0.

Platform option `debug` introduced in PTX ISA version 3.0.

Target string `sm_35` introduced in PTX ISA version 3.1.

Target strings `sm_32` and `sm_50` introduced in PTX ISA version 4.0.

Target strings `sm_37` and `sm_52` introduced in PTX ISA version 4.1.

Target string `sm_53` introduced in PTX ISA version 4.2.

Target string `sm_60`, `sm_61`, `sm_62` introduced in PTX ISA version 5.0.

Target string `sm_70` introduced in PTX ISA version 6.0.

Target string `sm_72` introduced in PTX ISA version 6.1.

Target string `sm_75` introduced in PTX ISA version 6.3.

Target string `sm_80` introduced in PTX ISA version 7.0.

Target string `sm_86` introduced in PTX ISA version 7.1.

Target string `sm_87` introduced in PTX ISA version 7.4.

Target string `sm_89` introduced in PTX ISA version 7.8.

Target string `sm_90` introduced in PTX ISA version 7.8.

Target string `sm_90a` introduced in PTX ISA version 8.0.

Target string `sm_100` introduced in PTX ISA version 8.6.

Target string `sm_100f` introduced in PTX ISA version 8.8.

Target string `sm_100a` introduced in PTX ISA version 8.6.

Target string `sm_101` introduced in PTX ISA version 8.6.

Target string `sm_101f` introduced in PTX ISA version 8.8.

Target string `sm_101a` introduced in PTX ISA version 8.6.

Target string `sm_103` introduced in PTX ISA version 8.8.

Target string `sm_103f` introduced in PTX ISA version 8.8.

Target string `sm_103a` introduced in PTX ISA version 8.8.

Target string `sm_120` introduced in PTX ISA version 8.7.

Target string `sm_120f` introduced in PTX ISA version 8.8.

Target string `sm_120a` introduced in PTX ISA version 8.7.

Target string `sm_121` introduced in PTX ISA version 8.8.

Target string `sm_121f` introduced in PTX ISA version 8.8.

Target string `sm_121a` introduced in PTX ISA version 8.8.

Target ISA Notes

The `.target` directive is supported on all target architectures.

Examples

```
.target sm_10       // baseline target architecture
.target sm_13       // supports double-precision
.target sm_20, texmode_independent
.target sm_90       // baseline target architecture
.target sm_90a      // PTX using architecture-specific features
.target sm_100f     // PTX using family-specific features
```

11.1.3. PTX Module Directives: `.address_size`

`.address_size`

Address size used throughout PTX module.

Syntax

```
.address_size  address-size
address-size = { 32, 64 };
```

Description

Specifies the address size assumed throughout the module by the PTX code and the binary DWARF information in PTX.

Redefinition of this directive within a module is not allowed. In the presence of separate compilation all modules must specify (or default to) the same address size.

The `.address_size` directive is optional, but it must immediately follow the `.target`directive if present within a module.

Semantics

If the `.address_size` directive is omitted, the address size defaults to 32.

PTX ISA Notes

Introduced in PTX ISA version 2.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
// example directives
   .address_size 32       // addresses are 32 bit
   .address_size 64       // addresses are 64 bit

// example of directive placement within a module
   .version 2.3
   .target sm_20
   .address_size 64
...
.entry foo () {
...
}
```

11.2. Specifying Kernel Entry Points and Functions

The following directives specify kernel entry points and functions.

- `.entry`
- `.func`

11.2.1. Kernel and Function Directives: `.entry`

`.entry`

Kernel entry point and body, with optional parameters.

Syntax

```
.entry kernel-name ( param-list )  kernel-body
.entry kernel-name  kernel-body
```

Description

Defines a kernel entry point name, parameters, and body for the kernel function.

Parameters are passed via `.param` space memory and are listed within an optional parenthesized parameter list. Parameters may be referenced by name within the kernel body and loaded into registers using `ld.param{::entry}` instructions.

In addition to normal parameters, opaque `.texref`, `.samplerref`, and `.surfref` variables may be passed as parameters. These parameters can only be referenced by name within texture and surface load, store, and query instructions and cannot be accessed via `ld.param` instructions.

The shape and size of the CTA executing the kernel are available in special registers.

Semantics

Specify the entry point for a kernel program.

At kernel launch, the kernel dimensions and properties are established and made available via special registers, e.g., `%ntid`, `%nctaid`, etc.

PTX ISA Notes

For PTX ISA version 1.4 and later, parameter variables are declared in the kernel parameter list. For PTX ISA versions 1.0 through 1.3, parameter variables are declared in the kernel body.

The maximum memory size supported by PTX for normal (non-opaque type) parameters is 32764 bytes. Depending upon the PTX ISA version, the parameter size limit varies. The following table shows the allowed parameter size for a PTX ISA version:

PTX ISA Version	Maximum parameter size (In bytes)
PTX ISA version 8.1 and above	32764
PTX ISA version 1.5 and above	4352
PTX ISA version 1.4 and above	256

The CUDA and OpenCL drivers support the following limits for parameter memory:

Driver	Parameter memory size
CUDA	256 bytes for `sm_1x`, 4096 bytes for `sm_2x and higher`, 32764 bytes fo `sm_70` and higher
OpenCL	32764 bytes for `sm_70` and higher, 4352 bytes on `sm_6x` and lower

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry cta_fft
.entry filter ( .param .b32 x, .param .b32 y, .param .b32 z )
{
    .reg .b32 %r<99>;
    ld.param.b32  %r1, [x];
    ld.param.b32  %r2, [y];
    ld.param.b32  %r3, [z];
    ...
}

.entry prefix_sum ( .param .align 4 .s32 pitch[8000] )
{
    .reg .s32 %t;
    ld.param::entry.s32  %t, [pitch];
    ...
}
```

11.2.2. Kernel and Function Directives: .func

.func

Function definition.

Syntax

```
.func {.attribute(attr-list)} fname {.noreturn} function-body
.func {.attribute(attr-list)} fname (param-list) {.noreturn} function-body
.func {.attribute(attr-list)} (ret-param) fname (param-list) function-body
```

Description

Defines a function, including input and return parameters and optional function body.

An optional `.noreturn` directive indicates that the function does not return to the caller function. `.noreturn` directive cannot be specified on functions which have return parameters. See the description of `.noreturn` directive in *Performance-Tuning Directives: .noreturn*.

An optional `.attribute` directive specifies additional information associated with the function. See the description of *Variable and Function Attribute Directive: .attribute* for allowed attributes.

A `.func` definition with no body provides a function prototype.

The parameter lists define locally-scoped variables in the function body. Parameters must be base types in either the register or parameter state space. Parameters in register state space may be referenced directly within instructions in the function body. Parameters in `.param` space are accessed

using `ld.param{::func}` and `st.param{::func}` instructions in the body. Parameter passing is call-by-value.

The last parameter in the parameter list may be a `.param` array of type `.b8` with no size specified. It is used to pass an arbitrary number of parameters to the function packed into a single array object.

When calling a function with such an unsized last argument, the last argument may be omitted from the `call` instruction if no parameter is passed through it. Accesses to this array parameter must be within the bounds of the array. The result of an access is undefined if no array was passed, or if the access was outside the bounds of the actual array being passed.

Semantics

The PTX syntax hides all details of the underlying calling convention and ABI.

The implementation of parameter passing is left to the optimizing translator, which may use a combination of registers and stack locations to pass parameters.

Release Notes

For PTX ISA version 1.x code, parameters must be in the register state space, there is no stack, and recursion is illegal.

PTX ISA versions 2.0 and later with target `sm_20` or higher allow parameters in the `.param` state space, implements an ABI with stack, and supports recursion.

PTX ISA versions 2.0 and later with target `sm_20` or higher support at most one return value.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Support for unsized array parameter introduced in PTX ISA version 6.0.

Support for `.noreturn` directive introduced in PTX ISA version 6.4.

Support for `.attribute` directive introduced in PTX ISA version 8.0.

Target ISA Notes

Functions without unsized array parameter supported on all target architectures.

Unsized array parameter requires `sm_30` or higher.

`.noreturn` directive requires `sm_30` or higher.

`.attribute` directive requires `sm_90` or higher.

Examples

```
.func (.reg .b32 rval) foo (.reg .b32 N, .reg .f64 dbl)
{
.reg .b32 localVar;

... use N, dbl;
other code;

mov.b32 rval,result;
ret;
}

...
call (fooval), foo, (val0, val1);  // return value in fooval
...

.func foo (.reg .b32 N, .reg .f64 dbl) .noreturn
{
.reg .b32 localVar;
... use N, dbl;
other code;
mov.b32 rval, result;
ret;
}
...
call foo, (val0, val1);
...

.func (.param .u32 rval) bar(.param .u32 N, .param .align 4 .b8 numbers[])
{
    .reg .b32 input0, input1;
    ld.param.b32   input0, [numbers + 0];
    ld.param.b32   input1, [numbers + 4];
    ...
    other code;
    ret;
}
...

.param .u32 N;
.param .align 4 .b8 numbers[8];
st.param.u32    [N], 2;
st.param.b32    [numbers + 0], 5;
st.param.b32    [numbers + 4], 10;
call (rval), bar, (N, numbers);
...
```

11.2.3. Kernel and Function Directives: .alias

.alias

Define an alias to existing function symbol.

Syntax

```
.alias fAlias, fAliasee;
```

Description

`.alias` is a module scope directive that defines identifier `fAlias` to be an alias to function specified by `fAliasee`.

Both `fAlias` and `fAliasee` are non-entry function symbols.

Identifier `fAlias` is a function declaration without body.

Identifier `fAliasee` is a function symbol which must be defined in the same module as `.alias` declaration. Function `fAliasee` cannot have `.weak` linkage.

Prototype of `fAlias` and `fAliasee` must match.

Program can use either `fAlias` or `fAlisee` identifiers to reference function defined with `fAliasee`.

PTX ISA Notes

`.alias` directive introduced in PTX ISA 6.3.

Target ISA Notes

`.alias` directive requires `sm_30` or higher.

Examples

```
.visible .func foo(.param .u32 p) {
   ...
}
.visible .func bar(.param .u32 p);
.alias bar, foo;
.entry test()
{
      .param .u32 p;
      ...
      call foo, (p);       // call foo directly
       ...
       .param .u32 p;
       call bar, (p);        // call foo through alias
}
```

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```
.entry filter ( .param .b32 x, .param .b32 y, .param .b32 z )
{
    .reg .b32 %r1, %r2, %r3;
    ld.param.b32  %r1, [x];
    ld.param.b32  %r2, [y];
    ld.param.b32  %r3, [z];
    ...
}
```

11.3. Control Flow Directives

PTX provides directives for specifying potential targets for `brx.idx` and `call` instructions. See the descriptions of `brx.idx` and `call` for more information.

- `.branchtargets`
- `.calltargets`
- `.callprototype`

11.3.1. Control Flow Directives: `.branchtargets`

`.branchtargets`

Declare a list of potential branch targets.

Syntax

```
Label:   .branchtargets  list-of-labels ;
```

Description

Declares a list of potential branch targets for a subsequent `brx.idx`, and associates the list with the label at the start of the line.

All control flow labels in the list must occur within the same function as the declaration.

The list of labels may use the compact, shorthand syntax for enumerating a range of labels having a common prefix, similar to the syntax described in *Parameterized Variable Names*.

PTX ISA Notes

Introduced in PTX ISA version 2.1.

Target ISA Notes

Requires `sm_20` or higher.

Examples

```
  .function foo () {
      .reg .u32 %r0;
      ...
      L1:
      ...
      L2:
      ...
      L3:
      ...
      ts: .branchtargets L1, L2, L3;
      @p brx.idx %r0, ts;
      ...

.function bar() {
      .reg .u32 %r0;
      ...
      N0:
      ...
      N1:
      ...
      N2:
      ...
      N3:
      ...
      N4:
      ...
      ts: .branchtargets N<5>;
      @p brx.idx %r0, ts;
      ...
```

11.3.2. Control Flow Directives: `.calltargets`

`.calltargets`

Declare a list of potential call targets.

Syntax

```
Label:   .calltargets  list-of-functions ;
```

Description

Declares a list of potential call targets for a subsequent indirect call, and associates the list with the label at the start of the line.

All functions named in the list must be declared prior to the `.calltargets` directive, and all functions must have the same type signature.

PTX ISA Notes

Introduced in PTX ISA version 2.1.

Target ISA Notes

Requires `sm_20` or higher.

Examples

```
calltgt:  .calltargets  fastsin, fastcos;
...
@p   call  (%f1), %r0, (%x), calltgt;
...
```

11.3.3. Control Flow Directives: `.callprototype`

`.callprototype`

Declare a prototype for use in an indirect call.

Syntax

```
 // no input or return parameters
label: .callprototype _ .noreturn;
// input params, no return params
label: .callprototype _ (param-list) .noreturn;
// no input params, // return params
label: .callprototype (ret-param) _ ;
// input, return parameters
label: .callprototype (ret-param) _ (param-list);
```

Description

Defines a prototype with no specific function name, and associates the prototype with a label. The prototype may then be used in indirect call instructions where there is incomplete knowledge of the possible call targets.

Parameters may have either base types in the register or parameter state spaces, or array types in parameter state space. The sink symbol '_' may be used to avoid dummy parameter names.

An optional `.noreturn` directive indicates that the function does not return to the caller function. `.noreturn` directive cannot be specified on functions which have return parameters. See the description of .noreturn directive in *Performance-Tuning Directives: .noreturn*.

PTX ISA Notes

Introduced in PTX ISA version 2.1.

Support for `.noreturn` directive introduced in PTX ISA version 6.4.

Target ISA Notes

Requires `sm_20` or higher.

`.noreturn` directive requires `sm_30` or higher.

Examples

```
Fproto1: .callprototype  _ ;
Fproto2: .callprototype  _ (.param .f32 _);
Fproto3: .callprototype  (.param .u32 _) _ ;
Fproto4: .callprototype  (.param .u32 _) _ (.param .f32 _);
...
@p   call  (%val), %r0, (%f1), Fproto4;
...

// example of array parameter
Fproto5: .callprototype _ (.param .b8 _[12]);

Fproto6: .callprototype  _ (.param .f32 _) .noreturn;
...
@p   call  %r0, (%f1), Fproto6;
...
```

11.4. Performance-Tuning Directives

To provide a mechanism for low-level performance tuning, PTX supports the following directives, which pass information to the backend optimizing compiler.

- `.maxnreg`
- `.maxntid`
- `.reqntid`
- `.minnctapersm`
- `.maxnctapersm` (deprecated)
- `.pragma`

The `.maxnreg` directive specifies the maximum number of registers to be allocated to a single thread; the `.maxntid` directive specifies the maximum number of threads in a thread block (CTA); the `.reqntid` directive specifies the required number of threads in a thread block (CTA); and the `.minnctapersm` directive specifies a minimum number of thread blocks to be scheduled on a single multiprocessor (SM). These can be used, for example, to throttle the resource requirements (e.g., registers) to increase total thread count and provide a greater opportunity to hide memory latency. The `.minnctapersm` directive can be used together with either the `.maxntid` or `.reqntid` directive to trade-off registers-per-thread against multiprocessor utilization without needed to directly specify a maximum number of registers. This may achieve better performance when compiling PTX for multiple devices having different numbers of registers per SM.

Currently, the `.maxnreg`, `.maxntid`, `.reqntid`, and `.minnctapersm` directives may be applied per-entry and must appear between an `.entry` directive and its body. The directives take precedence over any module-level constraints passed to the optimizing backend. A warning message is generated if the directives' constraints are inconsistent or cannot be met for the specified target device.

A general `.pragma` directive is supported for passing information to the PTX backend. The directive passes a list of strings to the backend, and the strings have no semantics within the PTX virtual machine model. The interpretation of `.pragma` values is determined by the backend implementation and is beyond the scope of the PTX ISA. Note that `.pragma` directives may appear at module (file) scope, at entry-scope, or as statements within a kernel or device function body.

11.4.1. Performance-Tuning Directives: `.maxnreg`

`.maxnreg`

Maximum number of registers that can be allocated per thread.

Syntax

```
.maxnreg n
```

Description

Declare the maximum number of registers per thread in a CTA.

Semantics

The compiler guarantees that this limit will not be exceeded. The actual number of registers used may be less; for example, the backend may be able to compile to fewer registers, or the maximum number of registers may be further constrained by `.maxntid` and `.maxctapersm`.

PTX ISA Notes

Introduced in PTX ISA version 1.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry foo .maxnreg 16 { ... }  // max regs per thread = 16
```

11.4.2. Performance-Tuning Directives: `.maxntid`

`.maxntid`

Maximum number of threads in the thread block (CTA).

Syntax

```
.maxntid nx
.maxntid nx, ny
.maxntid nx, ny, nz
```

Description

Declare the maximum number of threads in the thread block (CTA). This maximum is specified by giving the maximum extent of each dimension of the 1D, 2D, or 3D CTA. The maximum number of threads is the product of the maximum extent in each dimension.

Semantics

The maximum number of threads in the thread block, computed as the product of the maximum extent specified for each dimension, is guaranteed not to be exceeded in any invocation of the kernel in which this directive appears. Exceeding the maximum number of threads results in a runtime error or kernel launch failure.

Note that this directive guarantees that the *total* number of threads does not exceed the maximum, but does not guarantee that the limit in any particular dimension is not exceeded.

PTX ISA Notes

Introduced in PTX ISA version 1.3.

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry foo .maxntid 256       { ... }  // max threads = 256
.entry bar .maxntid 16,16,4   { ... }  // max threads = 1024
```

11.4.3. Performance-Tuning Directives: `.reqntid`

`.reqntid`

Number of threads in the thread block (CTA).

Syntax

```
.reqntid nx
.reqntid nx, ny
.reqntid nx, ny, nz
```

Description

Declare the number of threads in the thread block (CTA) by specifying the extent of each dimension of the 1D, 2D, or 3D CTA. The total number of threads is the product of the number of threads in each dimension.

Semantics

The size of each CTA dimension specified in any invocation of the kernel is required to be equal to that specified in this directive. Specifying a different CTA dimension at launch will result in a runtime error or kernel launch failure.

Notes

The `.reqntid` directive cannot be used in conjunction with the `.maxntid` directive.

PTX ISA Notes

Introduced in PTX ISA version 2.1.

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry foo .reqntid 256       { ... }  // num threads = 256
.entry bar .reqntid 16,16,4   { ... }  // num threads = 1024
```

11.4.4. Performance-Tuning Directives: `.minnctapersm`

`.minnctapersm`

Minimum number of CTAs per SM.

Syntax

```
.minnctapersm ncta
```

Description

Declare the minimum number of CTAs from the kernel's grid to be mapped to a single multiprocessor (SM).

Notes

Optimizations based on `.minnctapersm` need either `.maxntid` or `.reqntid` to be specified as well.

If the total number of threads on a single SM resulting from `.minnctapersm` and `.maxntid` / `.reqntid` exceed maximum number of threads supported by an SM then directive `.minnctapersm` will be ignored.

In PTX ISA version 2.1 or higher, a warning is generated if `.minnctapersm` is specified without specifying either `.maxntid` or `.reqntid`.

PTX ISA Notes

Introduced in PTX ISA version 2.0 as a replacement for `.maxnctapersm`.

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry foo .maxntid 256 .minnctapersm 4 { ... }
```

11.4.5. Performance-Tuning Directives: `.maxnctapersm` (deprecated)

`.maxnctapersm`

Maximum number of CTAs per SM.

Syntax

```
.maxnctapersm ncta
```

Description

Declare the maximum number of CTAs from the kernel's grid that may be mapped to a single multiprocessor (SM).

Notes

Optimizations based on .maxnctapersm generally need `.maxntid` to be specified as well. The optimizing backend compiler uses `.maxntid` and `.maxnctapersm` to compute an upper-bound on per-thread register usage so that the specified number of CTAs can be mapped to a single multiprocessor. However, if the number of registers used by the backend is sufficiently lower than this bound, additional CTAs may be mapped to a single multiprocessor. For this reason, `.maxnctapersm` has been renamed to .minnctapersm in PTX ISA version 2.0.

PTX ISA Notes

Introduced in PTX ISA version 1.3. Deprecated in PTX ISA version 2.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
.entry foo .maxntid 256 .maxnctapersm 4 { ... }
```

11.4.6. Performance-Tuning Directives: `.noreturn`

`.noreturn`

Indicate that the function does not return to its caller function.

Syntax

```
.noreturn
```

Description

Indicate that the function does not return to its caller function.

Semantics

An optional `.noreturn` directive indicates that the function does not return to caller function. `.noreturn` directive can only be specified on device functions and must appear between a `.func` directive and its body.

The directive cannot be specified on functions which have return parameters.

If a function with `.noreturn` directive returns to the caller function at runtime, then the behavior is undefined.

PTX ISA Notes

Introduced in PTX ISA version 6.4.

Target ISA Notes

Requires `sm_30` or higher.

Examples

```
.func foo .noreturn { ... }
```

11.4.7. Performance-Tuning Directives: `.pragma`

`.pragma`

Pass directives to PTX backend compiler.

Syntax

```
.pragma list-of-strings ;
```

Description

Pass module-scoped, entry-scoped, or statement-level directives to the PTX backend compiler.

The `.pragma` directive may occur at module-scope, at entry-scope, or at statement-level.

Semantics

The interpretation of `.pragma` directive strings is implementation-specific and has no impact on PTX semantics. See *Descriptions of .pragma Strings* for descriptions of the pragma strings defined in `ptxas`.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
.pragma "nounroll";    // disable unrolling in backend

// disable unrolling for current kernel
.entry foo .pragma "nounroll"; { ... }
```

11.5. Debugging Directives

DWARF-format debug information is passed through PTX modules using the following directives:

- `@@DWARF`
- `.section`
- `.file`
- `.loc`

The `.section` directive was introduced in PTX ISA version 2.0 and replaces the `@@DWARF` syntax. The `@@DWARF` syntax was deprecated in PTX ISA version 2.0 but is supported for legacy PTX ISA version 1.x code.

Beginning with PTX ISA version 3.0, PTX files containing DWARF debug information should include the `.target debug` platform option. This forward declaration directs PTX compilation to retain mappings for source-level debugging.

11.5.1. Debugging Directives: @@dwarf

@@dwarf

DWARF-format information.

Syntax

```
@@DWARF dwarf-string

dwarf-string may have one of the
.byte   byte-list   // comma-separated hexadecimal byte values
.4byte  int32-list  // comma-separated hexadecimal integers in range [0..2^32-1]
.quad   int64-list  // comma-separated hexadecimal integers in range [0..2^64-1]
.4byte  label
.quad   label
```

PTX ISA Notes

Introduced in PTX ISA version 1.2. Deprecated as of PTX ISA version 2.0, replaced by `.section` directive.

Target ISA Notes

Supported on all target architectures.

Examples

```
@@DWARF .section .debug_pubnames, "", @progbits
@@DWARF .byte   0x2b, 0x00, 0x00, 0x00, 0x02, 0x00
@@DWARF .4byte  .debug_info
@@DWARF .4byte  0x000006b5, 0x00000364, 0x61395a5f, 0x5f736f63
@@DWARF .4byte  0x6e69616d, 0x63613031, 0x6150736f, 0x736d6172
@@DWARF .byte   0x00, 0x00, 0x00, 0x00, 0x00
```

11.5.2. Debugging Directives: .section

.section

PTX section definition.

Syntax

```
.section section_name { dwarf-lines }

dwarf-lines have the following formats:
  .b8    byte-list       // comma-separated list of integers
                         // in range [-128..255]
  .b16   int16-list      // comma-separated list of integers
                         // in range [-2^15..2^16-1]
  .b32   int32-list      // comma-separated list of integers
                         // in range [-2^31..2^32-1]
  label:                 // Define label inside the debug section
  .b64   int64-list      // comma-separated list of integers
                         // in range [-2^63..2^64-1]
  .b32   label
  .b64   label
  .b32   label+imm       // a sum of label address plus a constant integer byte
                         // offset(signed, 32bit)
  .b64   label+imm       // a sum of label address plus a constant integer byte
                         // offset(signed, 64bit)
  .b32   label1-label2   // a difference in label addresses between labels in
                         // the same dwarf section (32bit)
  .b64   label3-label4   // a difference in label addresses between labels in
                         // the same dwarf section (64bit)
```

PTX ISA Notes

Introduced in PTX ISA version 2.0, replaces `@@DWARF` syntax.

label+imm expression introduced in PTX ISA version 3.2.

Support for `.b16` integers in dwarf-lines introduced in PTX ISA version 6.0.

Support for defining `label` inside the DWARF section is introduced in PTX ISA version 7.2.

`label1-label2` expression introduced in PTX ISA version 7.5.

Negative numbers in dwarf lines introduced in PTX ISA version 7.5.

Target ISA Notes

Supported on all target architectures.

Examples

```
.section .debug_pubnames
{
    .b32    LpubNames_end0-LpubNames_begin0
  LpubNames_begin0:
    .b8     0x2b, 0x00, 0x00, 0x00, 0x02, 0x00
    .b32    .debug_info
  info_label1:
    .b32    0x000006b5, 0x00000364, 0x61395a5f, 0x5f736f63
    .b32    0x6e69616d, 0x63613031, 0x6150736f, 0x736d6172
```

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```
    .b8     0x00, 0x00, 0x00, 0x00, 0x00
  LpubNames_end0:
}

.section .debug_info
{
    .b32 11430
    .b8 2, 0
    .b32 .debug_abbrev
    .b8 8, 1, 108, 103, 101, 110, 102, 101, 58, 32, 69, 68, 71, 32, 52, 46, 49
    .b8 0
    .b32 3, 37, 176, -99
    .b32 info_label1
    .b32 .debug_loc+0x4
    .b8 -11, 11, 112, 97
    .b32 info_label1+12
    .b64 -1
    .b16 -5, -65535
}
```

11.5.3. Debugging Directives: `.file`

`.file`

Source file name.

Syntax

```
.file file_index "filename" {, timestamp, file_size}
```

Description

Associates a source filename with an integer index. `.loc` directives reference source files by index.

`.file` directive allows optionally specifying an unsigned number representing time of last modification and an unsigned integer representing size in bytes of source file. `timestamp` and `file_size` value can be 0 to indicate this information is not available.

`timestamp` value is in format of C and C++ data type `time_t`.

`file_size` is an unsigned 64-bit integer.

The `.file` directive is allowed only in the outermost scope, i.e., at the same level as kernel and device function declarations.

Semantics

If timestamp and file size are not specified, they default to 0.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Timestamp and file size introduced in PTX ISA version 3.2.

Target ISA Notes

Supported on all target architectures.

Examples

```
.file 1 "example.cu"
.file 2 "kernel.cu"
.file 1 "kernel.cu", 1339013327, 64118
```

11.5.4. Debugging Directives: .loc

.loc

Source file location.

Syntax

```
.loc file_index line_number column_position
.loc file_index line_number column_position,function_name label {+ immediate },
↪inlined_at file_index2 line_number2 column_position2
```

Description

Declares the source file location (source file, line number, and column position) to be associated with lexically subsequent PTX instructions. `.loc` refers to `file_index` which is defined by a `.file` directive.

To indicate PTX instructions that are generated from a function that got inlined, additional attribute `.inlined_at` can be specified as part of the `.loc` directive. `.inlined_at` attribute specifies source location at which the specified function is inlined. `file_index2`, `line_number2`, and `column_position2` specify the location at which function is inlined. Source location specified as part of `.inlined_at` directive must lexically precede as source location in `.loc` directive.

The `function_name` attribute specifies an offset in the DWARF section named `.debug_str`. Offset is specified as `label` expression or `label + immediate` expression where `label` is defined in `.debug_str` section. DWARF section `.debug_str` contains ASCII null-terminated strings that specify the name of the function that is inlined.

Note that a PTX instruction may have a single associated source location, determined by the nearest lexically preceding .loc directive, or no associated source location if there is no preceding .loc directive. Labels in PTX inherit the location of the closest lexically following instruction. A label with no following PTX instruction has no associated source location.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

`function_name` and `inlined_at` attributes are introduced in PTX ISA version 7.2.

Target ISA Notes

Supported on all target architectures.

Examples

```
    .loc 2 4237 0
L1:                         // line 4237, col 0 of file #2,
                            // inherited from mov
    mov.u32  %r1,%r2;       // line 4237, col 0 of file #2
    add.u32  %r2,%r1,%r3;   // line 4237, col 0 of file #2
...
L2:                         // line 4239, col 5 of file #2,
                            // inherited from sub
    .loc 2 4239 5
    sub.u32  %r2,%r1,%r3;   // line 4239, col 5 of file #2
    .loc 1 21 3
    .loc 1 9 3, function_name info_string0, inlined_at 1 21 3
    ld.global.u32   %r1, [gg]; // Function at line 9
    setp.lt.s32 %p1, %r1, 8;   // inlined at line 21
    .loc 1 27 3
    .loc 1 10 5, function_name info_string1, inlined_at 1 27 3
    .loc 1 15 3, function_name .debug_str+16, inlined_at 1 10 5
    setp.ne.s32 %p2, %r1, 18;
    @%p2 bra    BB2_3;

    .section .debug_str {
    info_string0:
     .b8 95  // _
     .b8 90  // z
     .b8 51  // 3
     .b8 102 // f
     .b8 111 // o
     .b8 111 // o
     .b8 118 // v
     .b8 0
```

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```
    info_string1:
     .b8 95  // _
     .b8 90  // z
     .b8 51  // 3
     .b8 98  // b
     .b8 97  // a
     .b8 114 // r
     .b8 118 // v
     .b8 0
     .b8 95  // _
     .b8 90  // z
     .b8 51  // 3
     .b8 99  // c
     .b8 97  // a
     .b8 114 // r
     .b8 118 // v
     .b8 0
    }
```

11.6. Linking Directives

- `.extern`
- `.visible`
- `.weak`

11.6.1. Linking Directives: `.extern`

`.extern`

External symbol declaration.

Syntax

```
.extern identifier
```

Description

Declares identifier to be defined external to the current module. The module defining such identifier must define it as `.weak` or `.visible` only once in a single object file. Extern declaration of symbol may appear multiple times and references to that get resolved against the single definition of that symbol.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
.extern .global .b32 foo;  // foo is defined in another module
```

11.6.2. Linking Directives: `.visible`

`.visible`

Visible (externally) symbol declaration.

Syntax

```
.visible identifier
```

Description

Declares identifier to be globally visible. Unlike C, where identifiers are globally visible unless declared static, PTX identifiers are visible only within the current module unless declared `.visible` outside the current.

PTX ISA Notes

Introduced in PTX ISA version 1.0.

Target ISA Notes

Supported on all target architectures.

Examples

```
.visible .global .b32 foo;  // foo will be externally visible
```

11.6.3. Linking Directives: .weak

.weak

Visible (externally) symbol declaration.

Syntax

```
.weak identifier
```

Description

Declares identifier to be globally visible but *weak*. Weak symbols are similar to globally visible symbols, except during linking, weak symbols are only chosen after globally visible symbols during symbol resolution. Unlike globally visible symbols, multiple object files may declare the same weak symbol, and references to a symbol get resolved against a weak symbol only if no global symbols have the same name.

PTX ISA Notes

Introduced in PTX ISA version 3.1.

Target ISA Notes

Supported on all target architectures.

Examples

```
.weak .func (.reg .b32 val) foo;  // foo will be externally visible
```

11.6.4. Linking Directives: .common

.common

Visible (externally) symbol declaration.

Syntax

```
.common identifier
```

Description

Declares identifier to be globally visible but “common”.

Common symbols are similar to globally visible symbols. However multiple object files may declare the same common symbol and they may have different types and sizes and references to a symbol get resolved against a common symbol with the largest size.

Only one object file can initialize a common symbol and that must have the largest size among all other definitions of that common symbol from different object files.

`.common` linking directive can be used only on variables with `.global` storage. It cannot be used on function symbols or on symbols with opaque type.

PTX ISA Notes

Introduced in PTX ISA version 5.0.

Target ISA Notes

`.common` directive requires `sm_20` or higher.

Examples

```
.common .global .u32 gbl;
```

11.7. Cluster Dimension Directives

The following directives specify information about clusters:

- `.reqnctapercluster`
- `.explicitcluster`
- `.maxclusterrank`

The `.reqnctapercluster` directive specifies the number of CTAs in the cluster. The `.explicitcluster` directive specifies that the kernel should be launched with explicit cluster details. The `.maxclusterrank` directive specifies the maximum number of CTAs in the cluster.

The cluster dimension directives can be applied only on kernel functions.

11.7.1. Cluster Dimension Directives: .reqnctapercluster

.reqnctapercluster

Declare the number of CTAs in the cluster.

Syntax

```
.reqnctapercluster nx
.reqnctapercluster nx, ny
.reqnctapercluster nx, ny, nz
```

Description

Set the number of thread blocks (CTAs) in the cluster by specifying the extent of each dimension of the 1D, 2D, or 3D cluster. The total number of CTAs is the product of the number of CTAs in each dimension. For kernels with `.reqnctapercluster` directive specified, runtime will use the specified values for configuring the launch if the same are not specified at launch time.

Semantics

If cluster dimension is explicitly specified at launch time, it should be equal to the values specified in this directive. Specifying a different cluster dimension at launch will result in a runtime error or kernel launch failure.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.entry foo .reqnctapercluster 2         { . . . }
.entry bar .reqnctapercluster 2, 2, 1   { . . . }
.entry ker .reqnctapercluster 3, 2      { . . . }
```

11.7.2. Cluster Dimension Directives: .explicitcluster

.explicitcluster

Declare that Kernel must be launched with cluster dimensions explicitly specified.

Syntax

```
.explicitcluster
```

Description

Declares that this Kernel should be launched with cluster dimension explicitly specified.

Semantics

Kernels with `.explicitcluster` directive must be launched with cluster dimension explicitly specified (either at launch time or via `.reqnctapercluster`), otherwise program will fail with runtime error or kernel launch failure.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.entry foo .explicitcluster         { . . . }
```

11.7.3. Cluster Dimension Directives: .maxclusterrank

.maxclusterrank

Declare the maximum number of CTAs that can be part of the cluster.

Syntax

```
.maxclusterrank n
```

Description

Declare the maximum number of thread blocks (CTAs) allowed to be part of the cluster.

Semantics

Product of the number of CTAs in each cluster dimension specified in any invocation of the kernel is required to be less or equal to that specified in this directive. Otherwise invocation will result in a runtime error or kernel launch failure.

The `.maxclusterrank` directive cannot be used in conjunction with the `.reqnctapercluster` directive.

PTX ISA Notes

Introduced in PTX ISA version 7.8.

Target ISA Notes

Requires `sm_90` or higher.

Examples

```
.entry foo ..maxclusterrank 8         { . . . }
```

Chapter 12. Descriptions of .pragma Strings

This section describes the .pragma strings defined by ptxas.

12.1. Pragma Strings: "nounroll"

"nounroll"

Disable loop unrolling in optimizing the backend compiler.

Syntax

```
.pragma "nounroll";
```

Description

The "nounroll" pragma is a directive to disable loop unrolling in the optimizing backend compiler.

The "nounroll" pragma is allowed at module, entry-function, and statement levels, with the following meanings:

module scope
: disables unrolling for all loops in module, including loops preceding the .pragma.

entry-function scope
: disables unrolling for all loops in the entry function body.

statement-level pragma
: disables unrolling of the loop for which the current block is the loop header.

Note that in order to have the desired effect at statement level, the "nounroll" directive must appear before any instruction statements in the loop header basic block for the desired loop. The loop header block is defined as the block that dominates all blocks in the loop body and is the target of the loop backedge. Statement-level "nounroll" directives appearing outside of loop header blocks are silently ignored.

PTX ISA Notes

Introduced in PTX ISA version 2.0.

Target ISA Notes

Requires `sm_20` or higher. Ignored for `sm_1x` targets.

Examples

```
.entry foo (...)
.pragma "nounroll";  // do not unroll any loop in this function
{
...
}

.func bar (...)
{
...
L1_head:
     .pragma "nounroll";  // do not unroll this loop
     ...
@p   bra L1_end;
L1_body:
     ...
L1_continue:
     bra L1_head;
L1_end:
     ...
}
```

12.2. Pragma Strings: "used_bytes_mask"

"used_bytes_mask"

Mask for indicating used bytes in data of ld operation.

Syntax

```
.pragma "used_bytes_mask mask";
```

Description

The `"used_bytes_mask" pragma` is a directive that specifies used bytes in a load operation based on the mask provided.

`"used_bytes_mask" pragma` needs to be specified prior to a load instruction for which information about bytes used from the load operation is needed. Pragma is ignored if instruction following it is not a load instruction.

For a load instruction without this pragma, all bytes from the load operation are assumed to be used.

Operand `mask` is a 32-bit integer with set bits indicating the used bytes in data of load operation.

Semantics

```
Each bit in mask operand corresponds to a byte data where each set bit represents the
↪used byte.
Most-significant bit corresponds to most-significant byte of data.

// For 4 bytes load with only lower 3 bytes used
.pragma "used_bytes_mask 0x7";
ld.global.u32 %r0, [gbl];     // Higher 1 byte from %r0 is unused

// For vector load of 16 bytes with lower 12 bytes used
.pragma "used_bytes_mask 0xfff";
ld.global.v4.u32 {%r0, %r1, %r2, %r3}, [gbl];  // %r3 unused
```

PTX ISA Notes

Introduced in PTX ISA version 8.3.

Target ISA Notes

Requires `sm_50` or higher.

Examples

```
.pragma "used_bytes_mask 0xfff";
ld.global.v4.u32 {%r0, %r1, %r2, %r3}, [gbl]; // Only lower 12 bytes used
```

Chapter 13. Release Notes

This section describes the history of change in the PTX ISA and implementation. The first section describes ISA and implementation changes in the current release of PTX ISA version 8.8, and the remaining sections provide a record of changes in previous releases of PTX ISA versions back to PTX ISA version 2.0.

Table 62 shows the PTX release history.

Table 62: PTX Release History

PTX ISA Version	CUDA Release	Supported Targets
PTX ISA 1.0	CUDA 1.0	sm_{10,11}
PTX ISA 1.1	CUDA 1.1	sm_{10,11}
PTX ISA 1.2	CUDA 2.0	sm_{10,11,12,13}
PTX ISA 1.3	CUDA 2.1	sm_{10,11,12,13}
PTX ISA 1.4	CUDA 2.2	sm_{10,11,12,13}
PTX ISA 1.5	driver r190	sm_{10,11,12,13}
PTX ISA 2.0	CUDA 3.0, driver r195	sm_{10,11,12,13}, sm_20
PTX ISA 2.1	CUDA 3.1, driver r256	sm_{10,11,12,13}, sm_20
PTX ISA 2.2	CUDA 3.2, driver r260	sm_{10,11,12,13}, sm_20
PTX ISA 2.3	CUDA 4.0, driver r270	sm_{10,11,12,13}, sm_20
PTX ISA 3.0	CUDA 4.1, driver r285	sm_{10,11,12,13}, sm_20
	CUDA 4.2, driver r295	sm_{10,11,12,13}, sm_20, sm_30
PTX ISA 3.1	CUDA 5.0, driver r302	sm_{10,11,12,13}, sm_20, sm_{30,35}
PTX ISA 3.2	CUDA 5.5, driver r319	sm_{10,11,12,13}, sm_20, sm_{30,35}
PTX ISA 4.0	CUDA 6.0, driver r331	sm_{10,11,12,13}, sm_20, sm_{30,32,35}, sm_50
PTX ISA 4.1	CUDA 6.5, driver r340	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52}
PTX ISA 4.2	CUDA 7.0, driver r346	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}

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Table 62 – continued from previous page

PTX ISA Version	CUDA Release	Supported Targets
PTX ISA 4.3	CUDA 7.5, driver r352	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}
PTX ISA 5.0	CUDA 8.0, driver r361	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}
PTX ISA 6.0	CUDA 9.0, driver r384	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70
PTX ISA 6.1	CUDA 9.1, driver r387	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70, sm_72
PTX ISA 6.2	CUDA 9.2, driver r396	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70, sm_72
PTX ISA 6.3	CUDA 10.0, driver r400	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70, sm_72, sm_75
PTX ISA 6.4	CUDA 10.1, driver r418	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70, sm_72, sm_75
PTX ISA 6.5	CUDA 10.2, driver r440	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_70, sm_72, sm_75
PTX ISA 7.0	CUDA 11.0, driver r445	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_80
PTX ISA 7.1	CUDA 11.1, driver r455	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86}
PTX ISA 7.2	CUDA 11.2, driver r460	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86}
PTX ISA 7.3	CUDA 11.3, driver r465	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86}
PTX ISA 7.4	CUDA 11.4, driver r470	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87}
PTX ISA 7.5	CUDA 11.5, driver r495	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87}
PTX ISA 7.6	CUDA 11.6, driver r510	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87}

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PTX ISA Version	CUDA Release	Supported Targets
PTX ISA 7.7	CUDA 11.7, driver r515	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87}
PTX ISA 7.8	CUDA 11.8, driver r520	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_90
PTX ISA 8.0	CUDA 12.0, driver r525	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
PTX ISA 8.1	CUDA 12.1, driver r530	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
PTX ISA 8.2	CUDA 12.2, driver r535	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
PTX ISA 8.3	CUDA 12.3, driver r545	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
PTX ISA 8.4	CUDA 12.4, driver r550	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
PTX ISA 8.5	CUDA 12.5, driver r555	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}
	CUDA 12.6, driver r560	
PTX ISA 8.6	CUDA 12.7, driver r565	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}, sm_{100,100a,101,101a}
PTX ISA 8.7	CUDA 12.8, driver r570	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}, sm_{100,100,101,101a}, sm_{120,120a}
PTX ISA 8.8	CUDA 12.9, driver r575	sm_{10,11,12,13}, sm_20, sm_{30,32,35,37}, sm_{50,52,53}, sm_{60,61,62}, sm_{70,72,75}, sm_{80,86,87,89}, sm_{90,90a}, sm_{100,100f,100a,101,101f,101a,103,103f,103a}, sm_{120,120f,120a,121,121f,121a}

13.1. Changes in PTX ISA Version 8.8

New Features

PTX ISA version 8.8 introduces the following new features:

- Adds support for `sm_103` target architecture.
- Adds support for target `sm_103a` that supports architecture-specific features.
- Adds support for `sm_121` target architecture.
- Adds support for target `sm_121a` that supports architecture-specific features.
- Introduces family-specific target architectures that are represented with “f” suffix. PTX for family-specific targets is compatible with all subsequent targets in same family. Adds support for `sm_100f`, `sm_101f`, `sm_103f`, `sm_120f`, `sm_121f`.
- Extends `min` and `max` instructions to support three input arguments.
- Extends `tcgen05.mma` instruction to add support for new `scale_vectorsize` qualifiers `.block16` and `.block32` and K dimension 96.
- Extends `.field3` of `tensormap.replace` instruction to support 96B swizzle mode.
- Adds support for `tcgen05.ld.red` instruction.
- Extends `ld`, `ld.global.nc` and `st` instructions to support 256b load/store operations.
- Following table shows the list of features that are supported on family-specific targets:

Table 63: List of features promoted to family-specific architecture

Feature	Supported targets
.m16n8, .m16n16, .m8n16 shapes and .b8 type for ldmatrix/stmatrix	sm_100f, sm_101f, sm_120f
Shapes for tcgen05 .16x64b .16x128b, .16x256b, .16x32bx2, .32x32b, .4x256b, .32x128b, .64x128b, .128x256b, .128x128b, .31x256b	sm_100f, sm_101f
setmaxnreg	sm_100f, sm_101f, sm_120f
.cta_group modifier	sm_100f, sm_101f
cvt with .e2m1x2, .e3m2x2, .e2m3x2, .ue8m0x2	sm_100f, sm_101f, sm_120f
multimem with .acc::f16 and .e5m2, .e5m2x2, .e5m2x4, .e4m3, .e4m3x2, .e4m3x4 types	sm_100f, sm_101f
tensormap.replace	sm_100f, sm_101f, sm_120f
tcgen05.ld.red	sm_101f, sm_103f
tcgen05.ld/st/fence/ wait/commit/cp/ alloc/dealloc/ relinquish_alloc_permit	sm_100f, sm_101f
tcgen05.mma{.ws}{.sp} (except kind::mxf4/ kind::mxf4nvf4 for .sp)	sm_100f, sm_101f
tcgen05 .kind::mxf4nvf4, .kind::mxf4, .kind::mxf8f6f4, .kind::f16, .kind::tf32, .kind::f8f6f4	sm_100f, sm_101f
.ashift, .collector_usage modifiers for tcgen05	sm_100f, sm_101f
Modifiers .b8x16, .b6x16_p32, .b4x16_p64	sm_100f, sm_101f, sm_120f
.block_scale modifier	sm_100f, sm_101f, sm_120f
mma{.sp} with .e3m2, .e2m3, .e2m1 types and .kind, .block_scale, .scale_vec_size modifiers (except .sp with mxf4/ mxf4nvf4)	sm_120f
.scale_vec::1X/2X/4X modifiers	sm_120f
.block16/.block32 modifiers (alias to scale_vec)	sm_100f, sm_101f
.warpx2::02_13, .warpx2::01_23, .warpx4, .pack::16b, .unpack::16b modifiers for tcgen05	sm_100f, sm_101f
clusterlaunchcontrol.try_cancel multicast::cluster::all	sm_100f, sm_101f, sm_120f
.tile::scatter4, .tile::gather4, .im2col::w, .im2col::w::128	sm_100f, sm_101f
redux.f32	sm_100f
scale-input-d for tcgen05	sm_100f

Semantic Changes and Clarifications

- Clarified the behavior of float-to-integer conversions for `NaN` input.

13.2. Changes in PTX ISA Version 8.7

New Features

PTX ISA version 8.7 introduces the following new features:

- Adds support for `sm_120` target architecture.
- Adds support for target `sm_120a` that supports architecture-specific features.
- Extends `tcgen05.mma` instruction to add support for `.kind::mxf4nvf4` and `.scale_vec::4X` qualifiers.
- Extends `mma` instructions to support `.f16` type accumulator and shape `.m16n8k16` with FP8 types `.e4m3` and `.e5m2`.
- Extends `cvt` instruction to add support for `.rs` rounding mode and destination types `.e2m1x4`, `.e4m3x4`, `.e5m2x4`, `.e3m2x4`, `.e2m3x4`.
- Extends support for `st.async` and `red.async` instructions to add support for `.mmio`, `.release`, `.global` and `.scope` qualifiers.
- Extends `tensormap.replace` instruction to add support for values 13 to 15 for `.elemtype` qualifier.
- Extends `mma` and `mma.sp::ordered_metadata` instructions to add support for types `.e3m2`/`.e2m3`/ `.e2m1` and qualifiers `.kind`, `.block_scale`, `.scale_vec_size`.

Semantic Changes and Clarifications

- Clarified that in `.tile::gather4`, `.tile::scatter4` modes, tensor coordinates need to be specified as {col_idx, row_idx0, row_idx1, row_idx2, row_idx3} i.e. {x, y0, y1, y2, y3} instead of {x0, x1, x2, x3, y}.
- Updated *Instruction descriptor* of `tcgen05.mma` instruction to clarify the bits that are reserved for future use.

13.3. Changes in PTX ISA Version 8.6

New Features

PTX ISA version 8.6 introduces the following new features:

- Adds support for `sm_100` target architecture.
- Adds support for target `sm_100a` that supports architecture-specific features.
- Adds support for `sm_101` target architecture.

- Adds support for target `sm_101a` that supports architecture-specific features.
- Extends `cp.async.bulk` and `cp.async.bulk.tensor` instructions to add `.shared::cta` as destination state space.
- Extends `fence` instruction to add support for `.acquire` and `.release` qualifiers.
- Extends `fence` and `fence.proxy` instructions to add support for `.sync_restrict` qualifier.
- Extends `ldmatrix` instruction to support `.m16n16`, `.m8n16` shapes and `.b8` type.
- Extends `ldmatrix` instruction to support `.src_fmt`, `.dst_fmt` qualifiers.
- Extends `stmatrix` instruction to support `.m16n8` shape and `.b8` type.
- Adds support for `clusterlaunchcontrol` instruction.
- Extends `add`, `sub` and `fma` instructions to support mixed precision floating point operations with `.f32` as destaination operand type and `.f16`/`.bf16` as source operand types.
- Extends `add`, `sub`, `mul` and `fma` instructions to support `.f32x2` type.
- Extends `cvt` instruction with `.tf32` type to support `.satfinite` qualifier for `.rn`/`.rz` rounding modes.
- Extends `cp.async.bulk` instruction to support `.cp_mask` qualifier and `byteMask` operand.
- Extends `multimem.ld_reduce` and `multimem.st` instructions to support `.e5m2`, `.e5m2x2`, `.e5m2x4`, `.e4m3`, `.e4m3x2` and `.e4m3x4` types.
- Extends `cvt` instruction to support conversions to/from `.e2m1x2`, `.e3m2x2`, `.e2m3x2` and `.ue8m0x2` types.
- Extends `cp.async.bulk.tensor` and `cp.async.bulk.prefetch.tensor` instructions to support new load_mode qualifiers `.tile::scatter4` and `.tile::gather4`.
- Extends `tensormap.replace` instruction to add support for new qualifier `.swizzle_atomicity` for supporting new swizzle modes.
- Extends `mbarrier.arrive`, `mbarrier.arrive_drop`, `.mbarrier.test_wait` and `.mbarrier.try_wait` instructions to support `.relaxed` qualifier.
- Extends `cp.async.bulk.tensor` and `cp.async.bulk.prefetch.tensor` instructions to support new load_mode qualifiers `.im2col::w` and `.im2col::w::128`.
- Extends `cp.async.bulk.tensor` instruction to support new qualifier `.cta_group`.
- Add support for `st.bulk` instruction.
- Adds support for tcgen05 features and related instructions: `tcgen05.alloc`, `tcgen05.dealloc`, `tcgen05.relinquish_alloc_permit`, `tcgen05.ld`, `tcgen05.st`, `tcgen05.wait`, `tcgen05.cp`, `tcgen05.shift`, `tcgen05.mma`, `tcgen05.mma.sp`, `tcgen05.mma.ws`, `tcgen05.mma.ws.sp`, `tcgen05.fence` and `tcgen05.commit`.
- Extends `redux.sync` instruction to add support for `.f32` type with qualifiers `.abs` and `.NaN`.

Semantic Changes and Clarifications

None.

13.4. Changes in PTX ISA Version 8.5

New Features

PTX ISA version 8.5 introduces the following new features:

- Adds support for `mma.sp::ordered_metadata` instruction.

Semantic Changes and Clarifications

- Values `0b0000`, `0b0101`, `0b1010`, `0b1111` for sparsity metadata (operand e) of instruction `mma.sp` are invalid and their usage results in undefined behavior.

13.5. Changes in PTX ISA Version 8.4

New Features

PTX ISA version 8.4 introduces the following new features:

- Extends `ld`, `st` and `atom` instructions with `.b128` type to support `.sys` scope.
- Extends integer `wgmma.mma_async` instruction to support `.u8.s8` and `.s8.u8` as `.atype` and `.btype` respectively.
- Extends `mma`, `mma.sp` instructions to support FP8 types `.e4m3` and `.e5m2`.

Semantic Changes and Clarifications

None.

13.6. Changes in PTX ISA Version 8.3

New Features

PTX ISA version 8.3 introduces the following new features:

- Adds support for pragma `used_bytes_mask` that is used to specify mask for used bytes for a load operation.
- Extends `isspacep`, `cvta.to`, `ld` and `st` instructions to accept `::entry` and `::func` sub-qualifiers with `.param` state space qualifier.

- Adds support for `.b128` type on instructions `ld`, `ld.global.nc`, `ldu`, `st`, `mov` and `atom`.
- Add support for instructions `tensormap.replace`, `tensormap.cp_fenceproxy` and support for qualifier `.to_proxykind::from_proxykind` on instruction `fence.proxy` to support modifying `tensor-map`.

Semantic Changes and Clarifications

None.

13.7. Changes in PTX ISA Version 8.2

New Features

PTX ISA version 8.2 introduces the following new features:

- Adds support for `.mmio` qualifier on `ld` and `st` instructions.
- Extends `lop3` instruction to allow predicate destination.
- Extends `multimem.ld_reduce` instruction to support `.acc::f32` qualifer to allow `.f32` precision of the intermediate accumulation.
- Extends the asynchronous warpgroup-level matrix multiply-and-accumulate operation `wgmma.mma_async` to support `.sp` modifier that allows matrix multiply-accumulate operation when input matrix A is sparse.

Semantic Changes and Clarifications

The `.multicast::cluster` qualifier on `cp.async.bulk` and `cp.async.bulk.tensor` instructions is optimized for target architecture `sm_90a` and may have substantially reduced performance on other targets and hence `.multicast::cluster` is advised to be used with `sm_90a`.

13.8. Changes in PTX ISA Version 8.1

New Features

PTX ISA version 8.1 introduces the following new features:

- Adds support for `st.async` and `red.async` instructions for asynchronous store and asynchronous reduction operations respectively on shared memory.
- Adds support for `.oob` modifier on half-precision `fma` instruction.
- Adds support for `.satfinite` saturation modifer on `cvt` instruction for `.f16`, `.bf16` and `.tf32` formats.
- Extends support for `cvt` with `.e4m3`/`.e5m2` to `sm_89`.
- Extends `atom` and `red` instructions to support vector types.

- Adds support for special register `%aggr_smem_size`.
- Extends `sured` instruction with 64-bit `min`/`max` operations.
- Adds support for increased kernel parameter size of 32764 bytes.
- Adds support for multimem addresses in memory consistency model.
- Adds support for `multimem.ld_reduce`, `multimem.st` and `multimem.red` instructions to perform memory operations on multimem addresses.

Semantic Changes and Clarifications

None.

13.9. Changes in PTX ISA Version 8.0

New Features

PTX ISA version 8.0 introduces the following new features:

- Adds support for target `sm_90a` that supports architecture-specific features.
- Adds support for asynchronous warpgroup-level matrix multiply-and-accumulate operation `wgmma`.
- Extends the asynchronous copy operations with bulk operations that operate on large data, including tensor data.
- Introduces packed integer types `.u16x2` and `.s16x2`.
- Extends integer arithmetic instruction `add` to allow packed integer types `.u16x2` and `.s16x2`.
- Extends integer arithmetic instructions `min` and `max` to allow packed integer types `.u16x2` and `.s16x2`, as well as saturation modifier `.relu` on `.s16x2` and `.s32` types.
- Adds support for special register `%current_graph_exec` that identifies the currently executing CUDA device graph.
- Adds support for `elect.sync` instruction.
- Adds support for `.unified` attribute on functions and variables.
- Adds support for `setmaxnreg` instruction.
- Adds support for `.sem` qualifier on `barrier.cluster` instruction.
- Extends the `fence` instruction to allow opcode-specific synchronizaion using `op_restrict` qualifier.
- Adds support for `.cluster` scope on `mbarrier.arrive`, `mbarrier.arrive_drop`, `mbarrier.test_wait` and `mbarrier.try_wait` operations.
- Adds support for transaction count operations on `mbarrier` objects, specified with `.expect_tx` and `.complete_tx` qualifiers.

Semantic Changes and Clarifications

None.

13.10. Changes in PTX ISA Version 7.8

New Features

PTX ISA version 7.8 introduces the following new features:

- Adds support for `sm_89` target architecture.
- Adds support for `sm_90` target architecture.
- Extends `bar` and `barrier` instructions to accept optional scope qualifier `.cta`.
- Extends `.shared` state space qualifier with optional sub-qualifier `::cta`.
- Adds support for `movmatrix` instruction which transposes a matrix in registers across a warp.
- Adds support for `stmatrix` instruction which stores one or more matrices to shared memory.
- Extends the `.f64` floating point type `mma` operation with shapes `.m16n8k4`, `.m16n8k8`, and `.m16n8k16`.
- Extends `add`, `sub`, `mul`, `set`, `setp`, `cvt`, `tanh`, `ex2`, `atom` and `red` instructions with `bf16` alternate floating point data format.
- Adds support for new alternate floating-point data formats `.e4m3` and `.e5m2`.
- Extends `cvt` instruction to convert `.e4m3` and `.e5m2` alternate floating point data formats.
- Adds support for `griddepcontrol` instruction as a communication mechanism to control the execution of dependent grids.
- Extends `mbarrier` instruction to allow a new phase completion check operation *try_wait*.
- Adds support for new thread scope `.cluster` which is a set of Cooperative Thread Arrays (CTAs).
- Extends `fence/membar`, `ld`, `st`, `atom`, and `red` instructions to accept `.cluster` scope.
- Adds support for extended visibility of shared state space to all threads within a cluster.
- Extends `.shared` state space qualifier with `::cluster` sub-qualifier for cluster-level visibility of shared memory.
- Extends `isspacep`, `cvta`, `ld`, `st`, `atom`, and `red` instructions to accept `::cluster` sub-qualifier with `.shared` state space qualifier.
- Adds support for `mapa` instruction to map a shared memory address to the corresponding address in a different CTA within the cluster.
- Adds support for `getctarank` instruction to query the rank of the CTA that contains a given address.
- Adds support for new barrier synchronization instruction `barrier.cluster`.
- Extends the memory consistency model to include the new cluster scope.
- Adds support for special registers related to cluster information: `%is_explicit_cluster`, `%clusterid`, `%nclusterid`, `%cluster_ctaid`, `%cluster_nctaid`, `%cluster_ctarank`, `%cluster_nctarank`.

- Adds support for cluster dimension directives `.reqnctapercluster`, `.explicitcluster`, and `.maxclusterrank`.

Semantic Changes and Clarifications

None.

13.11. Changes in PTX ISA Version 7.7

New Features

PTX ISA version 7.7 introduces the following new features:

- Extends `isspacep` and `cvta` instructions to include the `.param` state space for kernel function parameters.

Semantic Changes and Clarifications

None.

13.12. Changes in PTX ISA Version 7.6

New Features

PTX ISA version 7.6 introduces the following new features:

- Support for `szext` instruction which performs sign-extension or zero-extension on a specified value.
- Support for `bmsk` instruction which creates a bitmask of the specified width starting at the specified bit position.
- Support for special registers `%reserved_smem_offset_begin`, `%reserved_smem_offset_end`, `%reserved_smem_offset_cap`, `%reserved_smem_offset<2>`.

Semantic Changes and Clarifications

None.

13.13. Changes in PTX ISA Version 7.5

New Features

PTX ISA version 7.5 introduces the following new features:

- Debug information enhancements to support label difference and negative values in the `.section` debugging directive.
- Support for `ignore-src` operand on `cp.async` instruction.
- Extensions to the memory consistency model to introduce the following new concepts:
  - A *memory proxy* as an abstract label for different methods of memory access.
  - Virtual aliases as distinct memory addresses accessing the same physical memory location.
- Support for new `fence.proxy` and `membar.proxy` instructions to allow synchronization of memory accesses performed via virtual aliases.

Semantic Changes and Clarifications

None.

13.14. Changes in PTX ISA Version 7.4

New Features

PTX ISA version 7.4 introduces the following new features:

- Support for `sm_87` target architecture.
- Support for `.level::eviction_priority` qualifier which allows specifying cache eviction priority hints on `ld`, `ld.global.nc`, `st`, and `prefetch` instructions.
- Support for `.level::prefetch_size` qualifier which allows specifying data prefetch hints on `ld` and `cp.async` instructions.
- Support for `createpolicy` instruction which allows construction of different types of cache eviction policies.
- Support for `.level::cache_hint` qualifier which allows the use of cache eviction policies with `ld`, `ld.global.nc`, `st`, `atom`, `red` and `cp.async` instructions.
- Support for `applypriority` and `discard` operations on cached data.

Semantic Changes and Clarifications

None.

13.15. Changes in PTX ISA Version 7.3

New Features

PTX ISA version 7.3 introduces the following new features:

- Extends `mask()` operator used in initializers to also support integer constant expression.
- Adds support for stack manpulation instructions that allow manipulating stack using `stacksave` and `stackrestore` instructions and allocation of per-thread stack using `alloca` instruction.

Semantic Changes and Clarifications

The unimplemented version of `alloca` from the older PTX ISA specification has been replaced with new stack manipulation instructions in PTX ISA version 7.3.

13.16. Changes in PTX ISA Version 7.2

New Features

PTX ISA version 7.2 introduces the following new features:

- Enhances `.loc` directive to represent inline function information.
- Adds support to define labels inside the debug sections.
- Extends `min` and `max` instructions to support `.xorsign` and `.abs` modifiers.

Semantic Changes and Clarifications

None.

13.17. Changes in PTX ISA Version 7.1

New Features

PTX ISA version 7.1 introduces the following new features:

- Support for `sm_86` target architecture.
- Adds a new operator, `mask()`, to extract a specific byte from variable's address used in initializers.

- Extends `tex` and `tld4` instructions to return an optional predicate that indicates if data at specified coordinates is resident in memory.
- Extends single-bit `wmma` and `mma` instructions to support `.and` operation.
- Extends `mma` instruction to support `.sp` modifier that allows matrix multiply-accumulate operation when input matrix A is sparse.
- Extends `mbarrier.test_wait` instruction to test the completion of specific phase parity.

Semantic Changes and Clarifications

None.

13.18. Changes in PTX ISA Version 7.0

New Features

PTX ISA version 7.0 introduces the following new features:

- Support for `sm_80` target architecture.
- Adds support for asynchronous copy instructions that allow copying of data asynchronously from one state space to another.
- Adds support for `mbarrier` instructions that allow creation of *mbarrier objects* in memory and use of these objects to synchronize threads and asynchronous copy operations initiated by threads.
- Adds support for `redux.sync` instruction which allows reduction operation across threads in a warp.
- Adds support for new alternate floating-point data formats `.bf16` and `.tf32`.
- Extends `wmma` instruction to support `.f64` type with shape `.m8n8k4`.
- Extends `wmma` instruction to support `.bf16` data format.
- Extends `wmma` instruction to support `.tf32` data format with shape `.m16n16k8`.
- Extends `mma` instruction to support `.f64` type with shape `.m8n8k4`.
- Extends `mma` instruction to support `.bf16` and `.tf32` data formats with shape `.m16n8k8`.
- Extends `mma` instruction to support new shapes `.m8n8k128`, `.m16n8k4`, `.m16n8k16`, `.m16n8k32`, `.m16n8k64`, `.m16n8k128` and `.m16n8k256`.
- Extends `abs` and `neg` instructions to support `.bf16` and `.bf16x2` data formats.
- Extends `min` and `max` instructions to support `.NaN` modifier and `.f16`, `.f16x2`, `.bf16` and `.bf16x2` data formats.
- Extends `fma` instruction to support `.relu` saturation mode and `.bf16` and `.bf16x2` data formats.
- Extends `cvt` instruction to support `.relu` saturation mode and `.f16`, `.f16x2`, `.bf16`, `.bf16x2` and `.tf32` destination formats.
- Adds support for `tanh` instruction that computes hyperbolic-tangent.

- Extends ex2 instruction to support `.f16` and `.f16x2` types.

Semantic Changes and Clarifications

None.

13.19. Changes in PTX ISA Version 6.5

New Features

PTX ISA version 6.5 introduces the following new features:

- Adds support for integer destination types for half precision comparison instruction `set`.
- Extends `abs` instruction to support `.f16` and `.f16x2` types.
- Adds support for `cvt.pack` instruction which allows converting two integer values and packing the results together.
- Adds new shapes `.m16n8k8`, `.m8n8k16` and `.m8n8k32` on the `mma` instruction.
- Adds support for `ldmatrix` instruction which loads one or more matrices from shared memory for `mma` instruction.

Removed Features

PTX ISA version 6.5 removes the following features:

- Support for `.satfinite` qualifier on floating point `wmma.mma` instruction has been removed. This support was deprecated since PTX ISA version 6.4.

Semantic Changes and Clarifications

None.

13.20. Changes in PTX ISA Version 6.4

New Features

PTX ISA version 6.4 introduces the following new features:

- Adds support for `.noreturn` directive which can be used to indicate a function does not return to it's caller function.
- Adds support for `mma` instruction which allows performing matrix multiply-and-accumulate operation.

Deprecated Features

PTX ISA version 6.4 deprecates the following features:

- Support for `.satfinite` qualifier on floating point `wmma.mma` instruction.

Removed Features

PTX ISA version 6.4 removes the following features:

- Support for `shfl` and `vote` instructions without the `.sync` qualifier has been removed for `.targetsm_70` and higher. This support was deprecated since PTX ISA version 6.0 as documented in PTX ISA version 6.2.

Semantic Changes and Clarifications

- Clarified that resolving references of a `.weak` symbol considers only `.weak` or `.visible` symbols with the same name and does not consider local symbols with the same name.
- Clarified that in `cvt` instruction, modifier `.ftz` can only be specified when either `.atype` or `.dtype` is `.f32`.

13.21. Changes in PTX ISA Version 6.3

New Features

PTX ISA version 6.3 introduces the following new features:

- Support for `sm_75` target architecture.
- Adds support for a new instruction `nanosleep` that suspends a thread for a specified duration.
- Adds support for `.alias` directive which allows defininig alias to function symbol.
- Extends `atom` instruction to perform `.f16` addition operation and `.cas.b16` operation.
- Extends `red` instruction to perform `.f16` addition operation.
- The `wmma` instructions are extended to support multiplicand matrices of type `.s8`, `.u8`, `.s4`, `.u4`, `.b1` and accumulator matrices of type `.s32`.

Semantic Changes and Clarifications

- Introduced the mandatory `.aligned` qualifier for all `wmma` instructions.
- Specified the alignment required for the base address and stride parameters passed to `wmma.load` and `wmma.store`.
- Clarified that layout of fragment returned by `wmma` operation is architecture dependent and passing `wmma` fragments around functions compiled for different link compatible SM architectures may not work as expected.
- Clarified that atomicity for `{atom/red}.f16x2}` operations is guranteed separately for each of the two `.f16` elements but not guranteed to be atomic as single 32-bit access.

13.22. Changes in PTX ISA Version 6.2

New Features

PTX ISA version 6.2 introduces the following new features:

- A new instruction `activemask` for querying active threads in a warp.
- Extends atomic and reduction instructions to perform `.f16x2` addition operation with mandatory `.noftz` qualifier.

Deprecated Features

PTX ISA version 6.2 deprecates the following features:

- The use of `shfl` and `vote` instructions without the `.sync` is deprecated retrospectively from PTX ISA version 6.0, which introduced the `sm_70` architecture that implements *Independent Thread Scheduling*.

Semantic Changes and Clarifications

- Clarified that `wmma` instructions can be used in conditionally executed code only if it is known that all threads in the warp evaluate the condition identically, otherwise behavior is undefined.
- In the memory consistency model, the definition of *morally strong operations* was updated to exclude fences from the requirement of *complete overlap* since fences do not access memory.

13.23. Changes in PTX ISA Version 6.1

New Features

PTX ISA version 6.1 introduces the following new features:

- Support for `sm_72` target architecture.
- Support for new matrix shapes `32x8x16` and `8x32x16` in `wmma` instruction.

Semantic Changes and Clarifications

None.

13.24. Changes in PTX ISA Version 6.0

New Features

PTX ISA version 6.0 introduces the following new features:

- Support for `sm_70` target architecture.
- Specifies the memory consistency model for programs running on `sm_70` and later architectures.
- Various extensions to memory instructions to specify memory synchronization semantics and scopes at which such synchronization can be observed.
- New instruction `wmma` for matrix operations which allows loading matrices from memory, performing multiply-and-accumulate on them and storing result in memory.
- Support for new `barrier` instruction.
- Extends `neg` instruction to support `.f16` and `.f16x2` types.
- A new instruction `fns` which allows finding n-th set bit in integer.
- A new instruction `bar.warp.sync` which allows synchronizing threads in warp.
- Extends `vote` and `shfl` instructions with `.sync` modifier which waits for specified threads before executing the `vote` and `shfl` operation respectively.
- A new instruction `match.sync` which allows broadcasting and comparing a value across threads in warp.
- A new instruction `brx.idx` which allows branching to a label indexed from list of potential targets.
- Support for unsized array parameter for `.func` which can be used to implement variadic functions.
- Support for `.b16` integer type in dwarf-lines.
- Support for taking address of device function return parameters using `mov` instruction.

Semantic Changes and Clarifications

- Semantics of `bar` instruction were updated to indicate that executing thread waits for other non-exited threads from it's warp.
- Support for indirect branch introduced in PTX 2.1 which was unimplemented has been removed from the spec.
- Support for taking address of labels, using labels in initializers which was unimplemented has been removed from the spec.
- Support for variadic functions which was unimplemented has been removed from the spec.

13.25. Changes in PTX ISA Version 5.0

New Features

PTX ISA version 5.0 introduces the following new features:

- Support for `sm_60`, `sm_61`, `sm_62` target architecture.
- Extends atomic and reduction instructions to perform double-precision add operation.
- Extends atomic and reduction instructions to specify `scope` modifier.
- A new `.common` directive to permit linking multiple object files containing declarations of the same symbol with different size.
- A new `dp4a` instruction which allows 4-way dot product with accumulate operation.
- A new `dp2a` instruction which allows 2-way dot product with accumulate operation.
- Support for special register `%clock_hi`.

Semantic Changes and Clarifications

Semantics of cache modifiers on `ld` and `st` instructions were clarified to reflect cache operations are treated as performance hint only and do not change memory consistency behavior of the program.

Semantics of `volatile` operations on `ld` and `st` instructions were clarified to reflect how `volatile` operations are handled by optimizing compiler.

13.26. Changes in PTX ISA Version 4.3

New Features

PTX ISA version 4.3 introduces the following new features:

- A new `lop3` instruction which allows arbitrary logical operation on 3 inputs.
- Adds support for 64-bit computations in extended precision arithmetic instructions.
- Extends `tex.grad` instruction to support `cube` and `acube` geometries.
- Extends `tld4` instruction to support `a2d`, `cube` and `acube` geometries.
- Extends `tex` and `tld4` instructions to support optional operands for offset vector and depth compare.
- Extends `txq` instruction to support querying texture fields from specific LOD.

Semantic Changes and Clarifications

None.

13.27. Changes in PTX ISA Version 4.2

New Features

PTX ISA version 4.2 introduces the following new features:

- Support for `sm_53` target architecture.
- Support for arithmetic, comparsion and texture instructions for `.f16` and `.f16x2` types.
- Support for `memory_layout` field for surfaces and `suq` instruction support for querying this field.

Semantic Changes and Clarifications

Semantics for parameter passing under ABI were updated to indicate `ld.param` and `st.param` instructions used for argument passing cannot be predicated.

Semantics of `{atom/red}.add.f32` were updated to indicate subnormal inputs and results are flushed to sign-preserving zero for atomic operations on global memory; whereas atomic operations on shared memory preserve subnormal inputs and results and don't flush them to zero.

13.28. Changes in PTX ISA Version 4.1

New Features

PTX ISA version 4.1 introduces the following new features:

- Support for `sm_37` and `sm_52` target architectures.
- Support for new fields `array_size`, `num_mipmap_levels` and `num_samples` for Textures, and the `txq` instruction support for querying these fields.
- Support for new field `array_size` for Surfaces, and the `suq` instruction support for querying this field.
- Support for special registers `%total_smem_size` and `%dynamic_smem_size`.

Semantic Changes and Clarifications

None.

13.29. Changes in PTX ISA Version 4.0

New Features

PTX ISA version 4.0 introduces the following new features:

- Support for `sm_32` and `sm_50` target architectures.
- Support for 64bit performance counter special registers `%pm0_64,..,%pm7_64`.
- A new `istypep` instruction.
- A new instruction, `rsqrt.approx.ftz.f64` has been added to compute a fast approximation of the square root reciprocal of a value.
- Support for a new directive `.attribute` for specifying special attributes of a variable.
- Support for `.managed` variable attribute.

Semantic Changes and Clarifications

The `vote` instruction semantics were updated to clearly indicate that an inactive thread in a warp contributes a 0 for its entry when participating in `vote.ballot.b32`.

13.30. Changes in PTX ISA Version 3.2

New Features

PTX ISA version 3.2 introduces the following new features:

- The texture instruction supports reads from multi-sample and multisample array textures.
- Extends `.section` debugging directive to include label + immediate expressions.
- Extends `.file` directive to include timestamp and file size information.

Semantic Changes and Clarifications

The `vavrg2` and `vavrg4` instruction semantics were updated to indicate that instruction adds 1 only if Va[i] + Vb[i] is non-negative, and that the addition result is shifted by 1 (rather than being divided by 2).

13.31. Changes in PTX ISA Version 3.1

New Features

PTX ISA version 3.1 introduces the following new features:

- Support for `sm_35` target architecture.
- Support for CUDA Dynamic Parallelism, which enables a kernel to create and synchronize new work.
- `ld.global.nc` for loading read-only global data though the non-coherent texture cache.
- A new funnel shift instruction, `shf`.
- Extends atomic and reduction instructions to perform 64-bit `{and, or, xor}` operations, and 64-bit integer `{min, max}` operations.
- Adds support for `mipmaps`.
- Adds support for indirect access to textures and surfaces.
- Extends support for generic addressing to include the `.const` state space, and adds a new operator, `generic()`, to form a generic address for `.global` or `.const` variables used in initializers.
- A new `.weak` directive to permit linking multiple object files containing declarations of the same symbol.

Semantic Changes and Clarifications

PTX 3.1 redefines the default addressing for global variables in initializers, from generic addresses to offsets in the global state space. Legacy PTX code is treated as having an implicit `generic()` operator for each global variable used in an initializer. PTX 3.1 code should either include explicit `generic()` operators in initializers, use `cvta.global` to form generic addresses at runtime, or load from the non-generic address using `ld.global`.

Instruction `mad.f32` requires a rounding modifier for `sm_20` and higher targets. However for PTX ISA version 3.0 and earlier, ptxas does not enforce this requirement and `mad.f32` silently defaults to `mad.rn.f32`. For PTX ISA version 3.1, ptxas generates a warning and defaults to `mad.rn.f32`, and in subsequent releases ptxas will enforce the requirement for PTX ISA version 3.2 and later.

13.32. Changes in PTX ISA Version 3.0

New Features

PTX ISA version 3.0 introduces the following new features:

- Support for `sm_30` target architectures.
- SIMD video instructions.
- A new warp shuffle instruction.
- Instructions `mad.cc` and `madc` for efficient, extended-precision integer multiplication.
- Surface instructions with 3D and array geometries.

- The texture instruction supports reads from cubemap and cubemap array textures.
- Platform option `.target` debug to declare that a PTX module contains DWARF debug information.
- `pmevent.mask`, for triggering multiple performance monitor events.
- Performance monitor counter special registers `%pm4..%pm7`.

Semantic Changes and Clarifications

Special register `%gridid` has been extended from 32-bits to 64-bits.

PTX ISA version 3.0 deprecates module-scoped `.reg` and `.local` variables when compiling to the Application Binary Interface (ABI). When compiling without use of the ABI, module-scoped `.reg` and `.local` variables are supported as before. When compiling legacy PTX code (ISA versions prior to 3.0) containing module-scoped `.reg` or `.local` variables, the compiler silently disables use of the ABI.

The `shfl` instruction semantics were updated to clearly indicate that value of source operand `a` is unpredictable for inactive and predicated-off threads within the warp.

PTX modules no longer allow duplicate `.version` directives. This feature was unimplemented, so there is no semantic change.

Unimplemented instructions `suld.p` and `sust.p.{u32,s32,f32}` have been removed.

13.33. Changes in PTX ISA Version 2.3

New Features

PTX 2.3 adds support for texture arrays. The texture array feature supports access to an array of 1D or 2D textures, where an integer indexes into the array of textures, and then one or two single-precision floating point coordinates are used to address within the selected 1D or 2D texture.

PTX 2.3 adds a new directive, `.address_size`, for specifying the size of addresses.

Variables in `.const` and `.global` state spaces are initialized to zero by default.

Semantic Changes and Clarifications

The semantics of the `.maxntid` directive have been updated to match the current implementation. Specifically, `.maxntid` only guarantees that the total number of threads in a thread block does not exceed the maximum. Previously, the semantics indicated that the maximum was enforced separately in each dimension, which is not the case.

Bit field extract and insert instructions BFE and BFI now indicate that the `len` and `pos` operands are restricted to the value range `0..255`.

Unimplemented instructions `{atom,red}.{min,max}.f32` have been removed.

13.34. Changes in PTX ISA Version 2.2

New Features

PTX 2.2 adds a new directive for specifying kernel parameter attributes; specifically, there is a new directives for specifying that a kernel parameter is a pointer, for specifying to which state space the parameter points, and for optionally specifying the alignment of the memory to which the parameter points.

PTX 2.2 adds a new field named `force_unnormalized_coords` to the `.samplerref` opaque type. This field is used in the independent texturing mode to override the `normalized_coords` field in the texture header. This field is needed to support languages such as OpenCL, which represent the property of normalized/unnormalized coordinates in the sampler header rather than in the texture header.

PTX 2.2 deprecates explicit constant banks and supports a large, flat address space for the `.const` state space. Legacy PTX that uses explicit constant banks is still supported.

PTX 2.2 adds a new `tld4` instruction for loading a component (`r`, `g`, `b`, or `a`) from the four texels compising the bilinear interpolation footprint of a given texture location. This instruction may be used to compute higher-precision bilerp results in software, or for performing higher-bandwidth texture loads.

Semantic Changes and Clarifications

None.

13.35. Changes in PTX ISA Version 2.1

New Features

The underlying, stack-based ABI is supported in PTX ISA version 2.1 for `sm_2x` targets.

Support for indirect calls has been implemented for `sm_2x` targets.

New directives, `.branchtargets` and `.calltargets`, have been added for specifying potential targets for indirect branches and indirect function calls. A `.callprototype` directive has been added for declaring the type signatures for indirect function calls.

The names of `.global` and `.const` variables can now be specified in variable initializers to represent their addresses.

A set of thirty-two driver-specific execution environment special registers has been added. These are named `%envreg0..%envreg31`.

Textures and surfaces have new fields for channel data type and channel order, and the `txq` and `suq` instructions support queries for these fields.

Directive `.minnctapersm` has replaced the `.maxnctapersm` directive.

Directive `.reqntid` has been added to allow specification of exact CTA dimensions.

A new instruction, `rcp.approx.ftz.f64`, has been added to compute a fast, gross approximate reciprocal.

Semantic Changes and Clarifications

A warning is emitted if `.minnctapersm` is specified without also specifying `.maxntid`.

13.36. Changes in PTX ISA Version 2.0

New Features

Floating Point Extensions

This section describes the floating-point changes in PTX ISA version 2.0 for `sm_20` targets. The goal is to achieve IEEE 754 compliance wherever possible, while maximizing backward compatibility with legacy PTX ISA version 1.x code and `sm_1x` targets.

The changes from PTX ISA version 1.x are as follows:

- Single-precision instructions support subnormal numbers by default for `sm_20` targets. The `.ftz` modifier may be used to enforce backward compatibility with `sm_1x`.
- Single-precision `add`, `sub`, and `mul` now support `.rm` and `.rp` rounding modifiers for `sm_20` targets.
- A single-precision fused multiply-add (fma) instruction has been added, with support for IEEE 754 compliant rounding modifiers and support for subnormal numbers. The `fma.f32` instruction also supports `.ftz` and `.sat` modifiers. `fma.f32` requires `sm_20`. The `mad.f32` instruction has been extended with rounding modifiers so that it's synonymous with `fma.f32` for `sm_20` targets. Both `fma.f32` and `mad.f32` require a rounding modifier for `sm_20` targets.
- The `mad.f32` instruction *without rounding* is retained so that compilers can generate code for `sm_1x` targets. When code compiled for `sm_1x` is executed on `sm_20` devices, `mad.f32` maps to `fma.rn.f32`.
- Single- and double-precision `div`, `rcp`, and `sqrt` with IEEE 754 compliant rounding have been added. These are indicated by the use of a rounding modifier and require `sm_20`.
- Instructions `testp` and `copysign` have been added.

New Instructions

A *load uniform* instruction, `ldu`, has been added.

Surface instructions support additional `.clamp` modifiers, `.clamp` and `.zero`.

Instruction `sust` now supports formatted surface stores.

A *count leading zeros* instruction, `clz`, has been added.

A *find leading non-sign bit instruction*, `bfind`, has been added.

A *bit reversal* instruction, `brev`, has been added.

Bit field extract and insert instructions, `bfe` and `bfi`, have been added.

A *population count* instruction, `popc`, has been added.

A *vote ballot* instruction, `vote.ballot.b32`, has been added.

Instructions `{atom,red}.add.f32` have been implemented.

Instructions {atom,red}.shared have been extended to handle 64-bit data types for sm_20 targets.

A system-level membar instruction, membar.sys, has been added.

The bar instruction has been extended as follows:

- A bar.arrive instruction has been added.
- Instructions bar.red.popc.u32 and bar.red.{and,or}.pred have been added.
- bar now supports optional thread count and register operands.

Scalar video instructions (includes prmt) have been added.

Instruction isspacep for querying whether a generic address falls within a specified state space window has been added.

Instruction cvta for converting global, local, and shared addresses to generic address and vice-versa has been added.

Other New Features

Instructions ld, ldu, st, prefetch, prefetchu, isspacep, cvta, atom, and red now support generic addressing.

New special registers %nwarpid, %nsmid, %clock64, %lanemask_{eq,le,lt,ge,gt} have been added.

Cache operations have been added to instructions ld, st, suld, and sust, e.g., for prefetching to specified level of memory hierarchy. Instructions prefetch and prefetchu have also been added.

The .maxnctapersm directive was deprecated and replaced with .minnctapersm to better match its behavior and usage.

A new directive, .section, has been added to replace the @@DWARF syntax for passing DWARF-format debugging information through PTX.

A new directive, .pragma nounroll, has been added to allow users to disable loop unrolling.

Semantic Changes and Clarifications

The errata in cvt.ftz for PTX ISA versions 1.4 and earlier, where single-precision subnormal inputs and results were not flushed to zero if either source or destination type size was 64-bits, has been fixed. In PTX ISA version 1.5 and later, cvt.ftz (and cvt for .target sm_1x, where .ftz is implied) instructions flush single-precision subnormal inputs and results to sign-preserving zero for all combinations of floating-point instruction types. To maintain compatibility with legacy PTX code, if .version is 1.4 or earlier, single-precision subnormal inputs and results are flushed to sign-preserving zero only when neither source nor destination type size is 64-bits.

Components of special registers %tid, %ntid, %ctaid, and %nctaid have been extended from 16-bits to 32-bits. These registers now have type .v4.u32.

The number of samplers available in independent texturing mode was incorrectly listed as thirty-two in PTX ISA version 1.5; the correct number is sixteen.

Chapter 14. Notices

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