Debugging GPU-Accelerated Applications with NVIDIA Developer Tools

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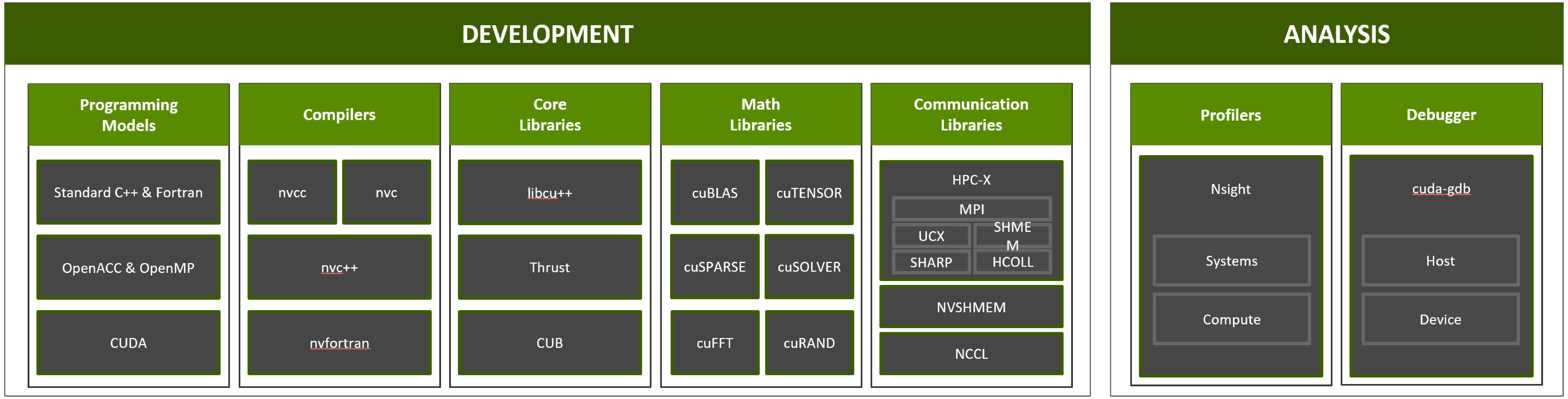
Introduction to the NVIDIA debugging toolchest

Overview

- NVIDIA HPC SDK
  - A comprehensive suite of compilers, libraries and tools for HPC
    - More info: https://developer.nvidia.com/hpc-sdk
  - Provided by nvhpc module
    - nvhpc/21.9 is default on Polaris

- Bundled with the HPC SDK is a debugging toolchest
  - CUDA-GDB
    - Interactive thread-based debugger
  - Compute Sanitizer
    - Functional correctness checking suite



DEVELOPMENT

Programming Models
Standard C++ & Fortran
OpenACC & OpenMP
CUDA

Compilers
nvcc
nvc
nvc++
nvfortran

Core Libraries
libcu++
Thrust
CUB

Math Libraries
cuBLAS
cuTENSOR
cuSPARSE
cuSOLVER
cuFFT
cuRAND

Communication Libraries
HPC-X
MPI
UCX
SHME
M
SHARP
HCOLL
NVSHMEM
NCCL

ANALYSIS

Profilers
Nsight
Systems
Compute

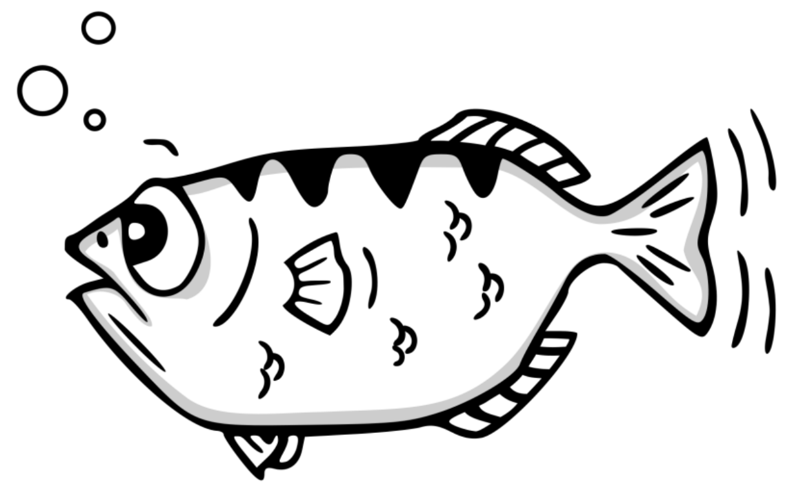
Debugger
cuda-gdb
Host
Device

Overview: CUDA-GDB

Overview: CUDA-GDB

What is it?

- Built on the familiar GDB debugger!
  - Ease-of-use: Users already familiar with gdb
  - GPU debugging provides a similar logical experience
  - Existing C/C++/Fortran support
  - Seamless experience between host (CPU) and device (GPU) debugging
  - Support for CUDA/OptiX/OpenACC/OpenMP/etc source level device code
  - Support for SASS disassembly
  - Various command extensions unique to CUDA-GDB



- Interactive CLI based tool
- Provides reactive debugging of CUDA kernels
  - CUDA Runtime errors
  - Debugging when exceptions occur
  - Logic errors producing incorrect answers
- Post-mortem debugging with corefiles
  - Coredump capture enabled via environment variables

Overview: CUDA-GDB

Quickstart

- On Polaris
  - Provided by PATH from module nvhpc/21.9 (default)

```
agontarek@polaris-login-01:~> which cuda-gdb
/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/compilers/bin/cuda-gdb
```

- Latest documentation: https://docs.nvidia.com/cuda/cuda-gdb/index.html
- Tips and Tricks: https://docs.nvidia.com/cuda/cuda-gdb/index.html#advanced-settings
- Getting help: https://forums.developer.nvidia.com/c/development-tools/cuda-developer-tools/cuda-gdb/

Overview: CUDA-GDB

Quickstart

- Recompile application for debugging
  - When compiling with nvcc:
    - Provide –g for host (CPU) debugging
    - Provide –G for device (GPU) debugging

    ```
    $ nvcc -g -G -o foo foo.cu
    ```
  - Using `–lineinfo` will allow debugging of optimized code
    - Lacks `.debug_info` sections
      - No symbolic debugging
    - Debugging optimized code can be a challenging experience
  - Check your compiler manual!
    - Command line arguments can vary by compiler
- Pascal+ GPUs have an improved debugging experience
  - Out of scope for this presentation
  - Feature support listed in the CUDA-GDB manual
- HPC features of interest
  - Mutli-GPU debugging is supported on same node
  - Multiple CUDA-GDB instances can debug multiple processes running on same node
- HPC features of interest (cont.)
  - Limited CUDA-GDB support for CUDA Multi Process Server (MPS)
    - https://docs.nvidia.com/deploy/mps/index.html#topic_3_3_6_1
  - Use `CUDA_VISIBLE_DEVICES` env var to select which GPUs are available to the application
  - CUDA Lazy Loading feature can speed up debugging times significantly (10x or more)

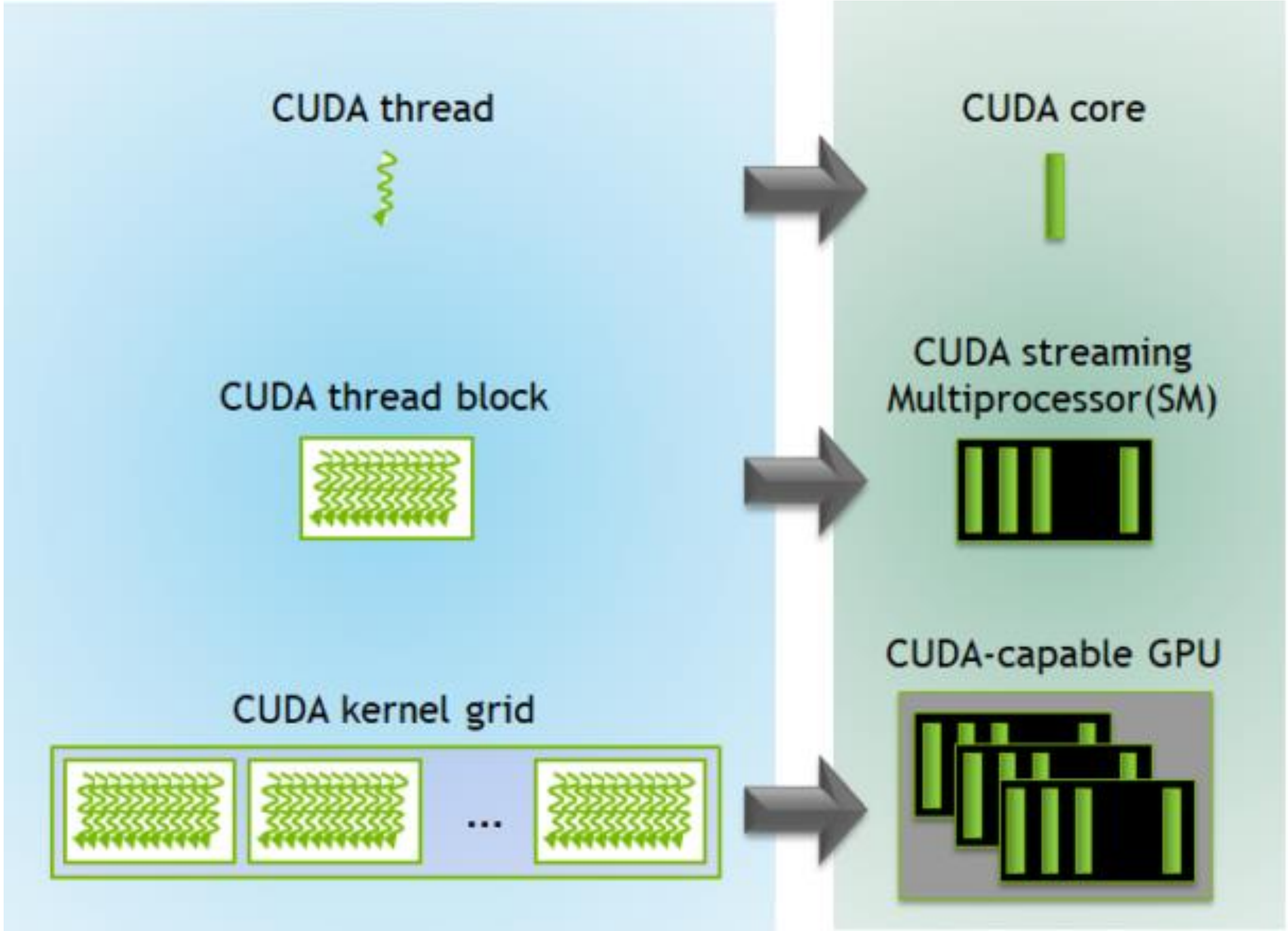
    ```
    $ export CUDA_MODULE_LOADING=lazy
    ```
    - Requires CUDA Toolkit 11.8+ and CUDA driver r520+
    - Defers loading cubins until first use
    - Especially helpful for applications linked against large math libs
    - See for more info: https://docs.nvidia.com/cuda/cuda-c-programming-guide/index.html#lazy-loading
  - CUDA-GDB uses `TMPDIR` to write temporary files
    - Defaults to `/tmp` if `TMPDIR` unset
    - Directory required to be writeable
    - Needs to be the same for both application and CUDA-GDB

Overview: CUDA-GDB

Terminology

- Assume: familiarity with the CUDA programming model
- Exposes both logical and physical concepts to user
- Logical
  - Kernel
    - A function executed in parallel on the device
    - Executed as a grid of blocks of threads
      - Specified by the <<<…>>> syntax
  - Block
    - Consists of threads – 1024 threads max
    - 3-dimensional coordinate
      - `dim3` named `blockIdx`
      - Bounded by `gridDim`
  - Thread
    - Smallest unit of work
    - 3-dimensional coordinate
      - `dim3` named `threadIdx`
      - Bounded by `blockDim`

- Physical
  - Device
    - CUDA capable GPUs
    - Comprised of many SMs
  - SM
    - Streaming multiprocessor
    - Executes block(s) in warp sized chunks
  - Warp
    - Group of 32 lanes
  - Lane
    - Core that executes CUDA thread



Overview: CUDA-GDB

Terminology

- CUDA focus
  - Most CUDA-GDB commands apply to a single thread in focus
    - Focus can be host **or** device thread
  - Breakpoints or exceptions inside a CUDA kernel will automatically switch to device focus

```
[Switching focus to CUDA kernel 0, grid 1, block
(0,0,0), thread (0,0,0), device 0, sm 0, warp 0, lane 0]
```

  - Kernel identifier (logical)
    - Assigned sequentially by CUDA-GDB
    - Unique across devices
    - Begins at index 0
  - Grid identifier (logical)
    - Assigned by CUDA
    - Unique per device
    - Begins at index 1
    - CUDA dynamic parallelism can have negative grid offsets
  - Block identifier (logical)
- CUDA focus (cont.)
  - Thread identifier (logical)
  - Device identifier (physical)
  - SM identifier (physical)
  - Warp identifier (physical)
  - Lane identifier (physical)
- Divergent thread behavior
  - Consider: two or more threads in the same warp execute different instructions
    - Example: if else body
  - Active lane mask
    - Threads that are currently executing device code at $pc
  - Divergent lane mask
    - Threads that are waiting or have completed at $pc

Overview: CUDA-GDB

Device information

- Use `info cuda` commands to query CUDA enabled GPU activities

```
(cuda-gdb) help info cuda
Print information about the current CUDA activities. Available options:
         devices : information about all the devices
             sms : information about all the SMs in the current device
           warps : information about all the warps in the current SM
           lanes : information about all the lanes in the current warp
         kernels : information about all the active kernels
        contexts : information about all the contexts
          blocks : information about all the active blocks in the current kernel
         threads : information about all the active threads in the current kernel
    launch trace : information about the parent kernels of the kernel in focus
 launch children : information about the kernels launched by the kernels in focus
         managed : information about global managed variables
            line : information about the filename and linenumber for a given $pc
```

- Output from `info cuda` marked with a * indicates that the range contains the focused CUDA thread

Overview: CUDA-GDB

Device information

- info cuda kernels
    - Displays the list of kernels

```
(cuda-gdb) info cuda kernels
  Kernel Parent Dev Grid Status       SMs Mask   GridDim  BlockDim Invocation
*      0      -   0    1 Active 0x3fffffffffff (20,10,1) (32,32,1) MatrixMulCUDA<32>()
```

- info cuda blocks
    - Displays the list of active blocks in the focused kernel

```
(cuda-gdb) info cuda blocks
  BlockIdx To BlockIdx Count   State
Kernel 0
   (0,0,0)     (0,2,0)     3 running
*  (1,0,0)     (1,2,0)     3 running
   (2,0,0)     (2,2,0)     3 running
   (3,0,0)     (3,2,0)     3 running
```

Overview: CUDA-GDB

Device information

- `info cuda threads`
    - Displays the active threads in the focused kernel

```
(cuda-gdb) info cuda threads
  BlockIdx ThreadIdx To BlockIdx To ThreadIdx Count         Virtual PC     Filename  Line
Kernel 0
   (0,0,0)   (0,0,0)     (0,2,0)    (31,31,0)  3072 0x00007fffc385e230 matrixMul.cu    62
*  (1,0,0)   (0,0,0)     (1,2,0)    (31,31,0)  3072 0x00007fffc385e230 matrixMul.cu    62
   (2,0,0)   (0,0,0)     (2,2,0)    (31,31,0)  3072 0x00007fffc385e230 matrixMul.cu    62
```

- Obtain current focus with `cuda` commands

```
(cuda-gdb) cuda kernel block thread
kernel 0, block (1,0,0), thread (3,0,0)
```

Overview: CUDA-GDB

CUDA thread focus

- CUDA thread focus is controlled with *cuda* commands
  - Sets focus to single CUDA thread
  - Some commands apply only to thread in focus
    - Printing local or shared variables
    - Printing registers
    - Printing stack contents
- Examples
  - Set focus to specified CUDA thread

```
(cuda-gdb) cuda thread 5
[Switching focus to CUDA kernel 0, grid 1, block (2,0,0), thread (5,0,0), device 0, sm 4, warp 0, lane 5]
```

  - Set focus based on block and thread

```
(cuda-gdb) cuda block 2 thread 6
[Switching focus to CUDA kernel 0, grid 1, block (2,0,0), thread (6,0,0), device 0, sm 4, warp 0, lane 6]
```

  - Set focus based on kernel, dim3 block, dim3 thread

```
(cuda-gdb) cuda kernel 0 block 1,0,0 thread 3,0,0
[Switching focus to CUDA kernel 0, grid 1, block (1,0,0), thread (3,0,0), device 0, sm 2, warp 0, lane 3]
```

Overview: CUDA-GDB

Execution Control Basics

- Two ways to get control
  - `run`

```
$ cuda-gdb --quiet my_application
Reading symbols from my_application...
(cuda-gdb) run
```

  - `attach`

```
$ cuda-gdb --quiet
(cuda-gdb) attach 261230
```

- Exit debugger with `quit`
  - Applications `run` are killed
  - Applications `attach` are detached

- Resume application execution

```
(cuda-gdb) continue
```

  - Resumes both host and device threads

- Interrupt execution with `ctrl-c`
  - Application is executing
  - No `(cuda-gdb)` prompt
  - `Ctrl-C` halts both host and device threads

Overview: CUDA-GDB

Stepping

- Single stepping
  - Source vs assembly level
  - Over vs into function calls
  - Device behavior is like host
    - Source level – following source line in kernel
    - Assembly level – following SASS instruction

Stepping mode	Source level command	Assembly level command
Over functions	`next`	`nexti`
Into functions	`step`	`stepi`

- Stepping behaviors
  - Single stepping advances every active thread in the warp
    - Divergent inactive threads do not make forward progress
  - kernel launch is asynchronous
    - Cannot step into launched kernel from host code
    - Set a breakpoint or use `break_on_launch`

- Stepping behaviors (cont.)
  - Stepping over barriers
    - Example: `__syncthreads()`
    - Resumes execution of all warps executing the same block
    - Required to make forward progress past barrier

Overview: CUDA-GDB

Breakpoints

- Symbolic breakpoints

```
(cuda-gdb) break my_function
(cuda-gdb) break my_class::my_method
```

- Line breakpoints

```
(cuda-gdb) break my_file.cu:185
```

- Address breakpoints

```
(cuda-gdb) break *0x1afe34d0
```

- Conditional breakpoints
  - Executed on the host every time breakpoint is hit
  - Can be slow

```
(cuda-gdb) break foo.cu:23 if threadIdx.x == 1 && i < 5
```

- Kernel entry breakpoints
  - Used to automatically break on kernel launches
  - Good first step if you don’t know where to start

```
(cuda-gdb) set cuda break_on_launch application
```

Overview: CUDA-GDB

Breakpoints

- `info break`
  - View the status of breakpoints
  - Breakpoints can be pending
  - Breakpoints can be set at multiple addresses
  - Breakpoint locations may change during runtime

```
(cuda-gdb) break main
Breakpoint 1 at 0xbdaa: file matrixMul.cu, line 296.
(cuda-gdb) info break
Num     Type           Disp Enb Address            What
1       breakpoint     keep y   0x000000000000bdaa in main(int, char**) at matrixMul.cu:296
```

- Breakpoint resolution
  - Breakpoints inserted as pending until CUDA cubins are loaded
    - Missing most CUDA symbols
      - Host side shadow breakpoints can be inserted on named kernel
      - Automatically resolved to device location after cubin load
    - Missing line info
  - Similar debugging experience to `dlopen`
  - C++ templates may result in multiple breakpoint locations

Overview: CUDA-GDB

Breakpoints

- Pending breakpoint examples

```
(cuda-gdb) break MatrixMulCUDA
Breakpoint 2 at 0x555555561535: MatrixMulCUDA. (2 locations)
(cuda-gdb) info break 2
Num     Type           Disp Enb Address            What
2       breakpoint     keep y   <MULTIPLE>
2.1                         n   0x0000555555561535 in MatrixMulCUDA<16>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:60
2.2                         n   0x0000555555561576 in MatrixMulCUDA<32>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:60
```

```
(cuda-gdb) info break 2
Num     Type           Disp Enb Address            What
2       breakpoint     keep y   <MULTIPLE>
 breakpoint already hit 1 time
2.1                         n   0x0000555555561535 in MatrixMulCUDA<16>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:60
2.2                         n   0x0000555555561576 in MatrixMulCUDA<32>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:60
2.3                         y   0x00007fffc385c130 in MatrixMulCUDA<16>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:62
2.4                         y   0x00007fffc385e230 in MatrixMulCUDA<32>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:62
```

Overview: CUDA-GDB

Breakpoints

- Pending breakpoint examples (cont.)

```
(cuda-gdb) break matrixMul.cu:104
Breakpoint 3 at 0x555555561554: matrixMul.cu:104. (2 locations)
(cuda-gdb) info break 3
Num     Type           Disp Enb Address            What
3       breakpoint     keep y   <MULTIPLE>
3.1                         n   0x0000555555561554 in MatrixMulCUDA<16>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:129
3.2                         n   0x0000555555561595 in MatrixMulCUDA<32>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:129
```

```
(cuda-gdb) info break 3
Num     Type           Disp Enb Address            What
3       breakpoint     keep y   <MULTIPLE>
3.1                         y   0x00007fffc385c4a0 in MatrixMulCUDA<16>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:104
3.2                         y   0x00007fffc385e5a0 in MatrixMulCUDA<32>(float*, float*, float*, int, int)
                                                   at matrixMul.cu:104
```

Overview: CUDA-GDB

Stacktrace

- Same commands as used in gdb
  - `where`, `bt`, `info stack`
- Applies to the thread in focus
- CUDA threads have first source line of kernel as outermost frame

```
(cuda-gdb) bt
#0  recursive_function (i=1) at calldepth_function.cu:4
#1  0x00007fffc385b690 in recursive_function (i=2) at calldepth_function.cu:7
#2  0x00007fffc385b690 in recursive_function (i=3) at calldepth_function.cu:7
#3  0x00007fffc385a890 in calldepth<<<(1,1,1),(2,1,1)>>> (input=3, output=0x7fffc1e00000) at calldepth_kernel.cu:7
```

Overview: CUDA-GDB

Examining state

- `info locals`
  - Displays local variables in the current stack frame
  - Value printed or hint as to why the variable is not valid

```
(cuda-gdb) info locals
by = <unavailable>
tx = <unavailable>
aStep = <unavailable>
bx = <unavailable>
ty = <unavailable>
aBegin = <unavailable>
aEnd = <unavailable>
bBegin = <unavailable>
bStep = <unavailable>
Csub = <optimized out>
c = <unavailable>
```

```
(cuda-gdb) n
63    int by = blockIdx.y;
(cuda-gdb) n
66    int tx = threadIdx.x;
(cuda-gdb) n
67    int ty = threadIdx.y;
(cuda-gdb) n
70    int aBegin = wA * BLOCK_SIZE * by;
(cuda-gdb) n
73    int aEnd   = aBegin + wA - 1;
(cuda-gdb) n
76    int aStep  = BLOCK_SIZE;
(cuda-gdb) n
79    int bBegin = BLOCK_SIZE * bx;
```

```
(cuda-gdb) info locals
by = 0
tx = 0
aStep = 32
bx = 0
ty = 0
aBegin = 0
aEnd = 319
bBegin = 32
bStep = <unavailable>
Csub = <optimized out>
c = <unavailable>
```

Overview: CUDA-GDB

Examining state

- `print`
    - Read a source variable
    - Variable must be in scope
        - Local or global scope

```
(cuda-gdb) print A[1]
$1 = 1
(cuda-gdb) print &A[1]
$2 = (@generic float *) 0x7fffc3a00004
```

- `set variable`
    - Write to a source variable
    - Address space must have write permissions

```
(cuda-gdb) print bx
$3 = 0
(cuda-gdb) set variable bx = 3
(cuda-gdb) print bx
$4 = 3
```

- Supply address space identifier when storage class is ambiguous
    - `@code, @constant, @generic, @global, @managed_global, @parameter, @shared, @register, @local, @uniform_register`
- `info registers`
    - Inspect device registers
    - Pseudo names
        - $R<num>
            - Regular register
        - $UR<num>
            - Uniform register
        - $UP<num>
            - Uniform predicate
        - $PC
            - Program counter
            - Unassignable

Overview: CUDA-GDB

API Errors

- `set cuda api_failures`
  - Allows automatic checks of any CUDA driver or runtime API call
  - Three modes
    - `hide`
      - Do not report error of any kind
    - `ignore`
      - Emit warning, but continue execution
      - Default
    - `stop`
      - Emit an error and stop execution

```
(cuda-gdb) set cuda api_failures stop
(cuda-gdb) continue
Continuing.
Cuda API error detected: cudaMalloc returned (0x1)
(cuda-gdb)
```

Overview: CUDA-GDB

GPU Exceptions

- GPU device exceptions
  - Always caught
  - Fatal – unable to continue device execution
  - Most exceptions are precise
    - View address causing exception with `$errorpc`
    - CUDA cluster (CUDA 11.8+) exceptions are imprecise
      - Use `autostep` to determine exact block and instruction causing error
  - CUDA_EXCEPTION_0 through CUDA_EXCEPTION_18
    - See link for table of exceptions and descriptions: https://docs.nvidia.com/cuda/cuda-gdb/index.html#gpu-error-reporting

Overview: CUDA-GDB

GPU Exceptions

- Table of exception codes

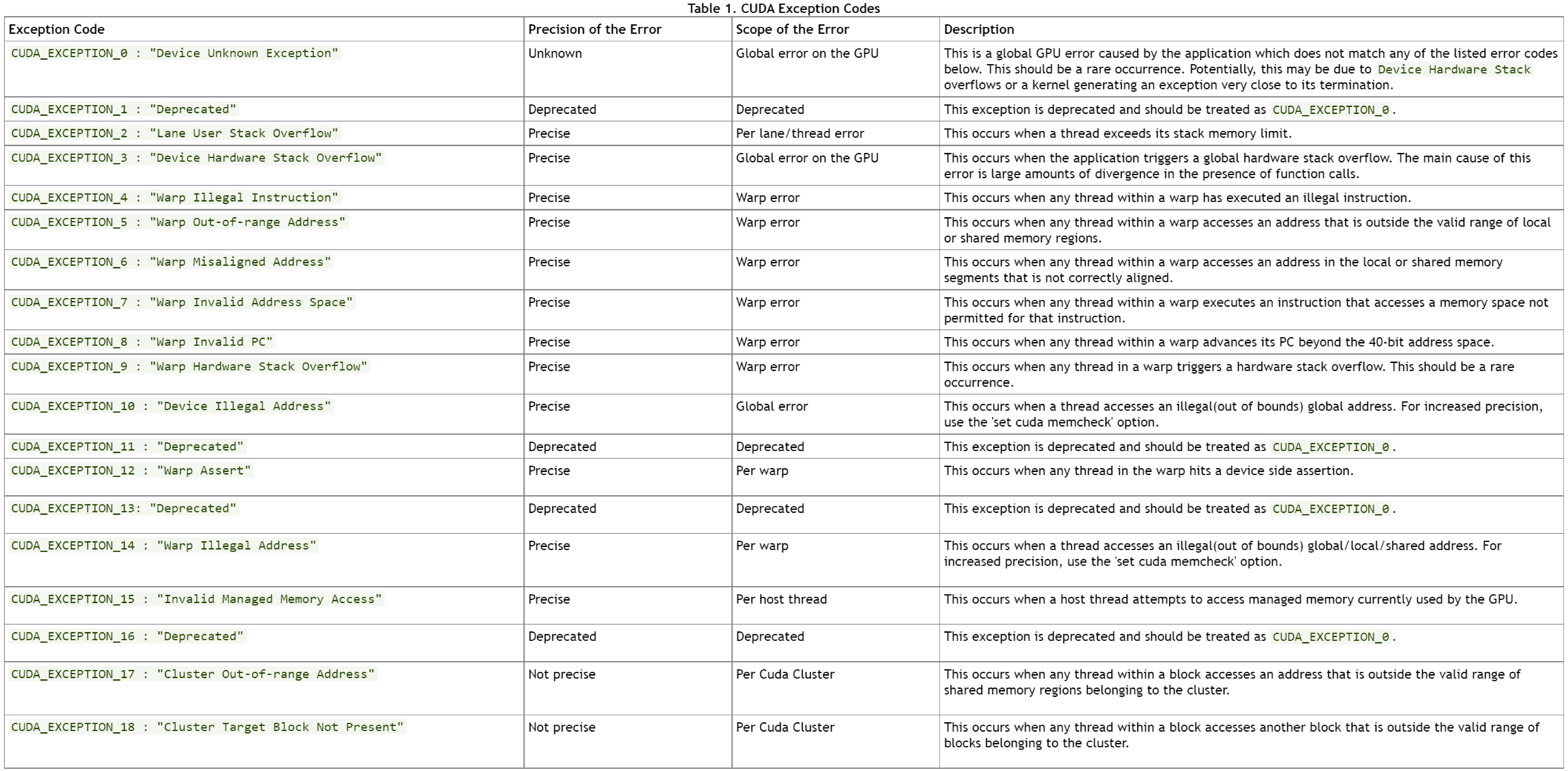


Table 1. CUDA Exception Codes

Exception Code	Precision of the Error	Scope of the Error	Description
`CUDA_EXCEPTION_0 : "Device Unknown Exception"`	Unknown	Global error on the GPU	This is a global GPU error caused by the application which does not match any of the listed error codes below. This should be a rare occurrence. Potentially, this may be due to `Device Hardware Stack` overflows or a kernel generating an exception very close to its termination.
`CUDA_EXCEPTION_1 : "Deprecated"`	Deprecated	Deprecated	This exception is deprecated and should be treated as `CUDA_EXCEPTION_0`.
`CUDA_EXCEPTION_2 : "Lane User Stack Overflow"`	Precise	Per lane/thread error	This occurs when a thread exceeds its stack memory limit.
`CUDA_EXCEPTION_3 : "Device Hardware Stack Overflow"`	Precise	Global error on the GPU	This occurs when the application triggers a global hardware stack overflow. The main cause of this error is large amounts of divergence in the presence of function calls.
`CUDA_EXCEPTION_4 : "Warp Illegal Instruction"`	Precise	Warp error	This occurs when any thread within a warp has executed an illegal instruction.
`CUDA_EXCEPTION_5 : "Warp Out-of-range Address"`	Precise	Warp error	This occurs when any thread within a warp accesses an address that is outside the valid range of local or shared memory regions.
`CUDA_EXCEPTION_6 : "Warp Misaligned Address"`	Precise	Warp error	This occurs when any thread within a warp accesses an address in the local or shared memory segments that is not correctly aligned.
`CUDA_EXCEPTION_7 : "Warp Invalid Address Space"`	Precise	Warp error	This occurs when any thread within a warp executes an instruction that accesses a memory space not permitted for that instruction.
`CUDA_EXCEPTION_8 : "Warp Invalid PC"`	Precise	Warp error	This occurs when any thread within a warp advances its PC beyond the 40-bit address space.
`CUDA_EXCEPTION_9 : "Warp Hardware Stack Overflow"`	Precise	Warp error	This occurs when any thread in a warp triggers a hardware stack overflow. This should be a rare occurrence.
`CUDA_EXCEPTION_10 : "Device Illegal Address"`	Precise	Global error	This occurs when a thread accesses an illegal(out of bounds) global address. For increased precision, use the 'set cuda memcheck' option.
`CUDA_EXCEPTION_11 : "Deprecated"`	Deprecated	Deprecated	This exception is deprecated and should be treated as `CUDA_EXCEPTION_0`.
`CUDA_EXCEPTION_12 : "Warp Assert"`	Precise	Per warp	This occurs when any thread in the warp hits a device side assertion.
`CUDA_EXCEPTION_13: "Deprecated"`	Deprecated	Deprecated	This exception is deprecated and should be treated as `CUDA_EXCEPTION_0`.
`CUDA_EXCEPTION_14 : "Warp Illegal Address"`	Precise	Per warp	This occurs when a thread accesses an illegal(out of bounds) global/local/shared address. For increased precision, use the 'set cuda memcheck' option.
`CUDA_EXCEPTION_15 : "Invalid Managed Memory Access"`	Precise	Per host thread	This occurs when a host thread attempts to access managed memory currently used by the GPU.
`CUDA_EXCEPTION_16 : "Deprecated"`	Deprecated	Deprecated	This exception is deprecated and should be treated as `CUDA_EXCEPTION_0`.
`CUDA_EXCEPTION_17 : "Cluster Out-of-range Address"`	Not precise	Per Cuda Cluster	This occurs when any thread within a block accesses an address that is outside the valid range of shared memory regions belonging to the cluster.
`CUDA_EXCEPTION_18 : "Cluster Target Block Not Present"`	Not precise	Per Cuda Cluster	This occurs when any thread within a block accesses another block that is outside the valid range of blocks belonging to the cluster.

Overview: CUDA-GDB

GPU Exceptions

- GPU exception example

```
CUDA Exception: Warp Out-of-range Address
The exception was triggered at PC 0x7fffc385acd0 (memexceptions_kernel.cu:21)

Thread 1 "memexceptions" received signal CUDA_EXCEPTION_5, Warp Out-of-range Address.
[Switching focus to CUDA kernel 1, grid 1, block (0,0,0), thread (0,0,0), device 0, sm 0, warp 0, lane 0]
exception_kernel<<<(1,1,1),(1,1,1)>>> (data=0x7fffc1e00000, exception=OOR_SHARED) at memexceptions_kernel.cu:44
44      *sdata = *ldata;
```

```
(cuda-gdb) print $errorpc
$1 = (void (*)(void)) 0x7fffc385acd0 <exception_kernel(void*, exception_t)+1488>
```

```
(cuda-gdb) print $pc
$2 = (void (*)(void)) 0x7fffc385b1d0 <exception_kernel(void*, exception_t)+2768>
```

```
(cuda-gdb) list *$errorpc
0x7fffc385acd0 is in exception_kernel(void*, exception_t) (memexceptions_kernel.cu:21).
16          case MMU_FAULT:
17              *(volatile unsigned char *)0 = exception;
18              // Above line causes an MMU fault (global page not mapped for writing)
19              break;
20          case OOR_SHARED:
21              *(volatile unsigned char *)(sdata + gridDim.x*MAX_SHARED) = exception;
22              // Above line causes an out-of-range access (shared)
23              break;
24          case OOR_LOCAL:
25              *(volatile unsigned char *)(ldata + gridDim.x*MAX_LOCAL) = exception;
```

Overview: CUDA-GDB

Disassembly

- disassemble
  - View disassembly of sass instructions
  - Current pc prefixed with =>
  - Instruction triggering exception (errorpc) prefixed with *>
    - If errorpc and pc match, prefixed with *=>

```
(cuda-gdb) disas $pc,+32
Dump of assembler code from 0x7fffc385b4b0 to 0x7fffc385b4d0:
=>0x00007fffc385b4b0 <_Z16exception_kernelPv11exception_t+3504>: ERRBAR
  0x00007fffc385b4c0 <_Z16exception_kernelPv11exception_t+3520>: EXIT
End of assembler dump.
```

```
(cuda-gdb) disas $errorpc,+64
Dump of assembler code from 0x7fffc385ab20 to 0x7fffc385ab60:
*> 0x00007fffc385ab20 <_Z16exception_kernelPv11exception_t+1056>: ST.E.U8.STRONG.SYS desc[UR4][R6.64], R5
   0x00007fffc385ab30 <_Z16exception_kernelPv11exception_t+1072>: BRA 0xad0
   0x00007fffc385ab40 <_Z16exception_kernelPv11exception_t+1088>: PRMT R5, R5, 0x7610, R5
   0x00007fffc385ab50 <_Z16exception_kernelPv11exception_t+1104>: MOV R6, c[0x0][0xc]
End of assembler dump.
```

Overview: CUDA-GDB

Coredumps

- GPU coredump support
  - Disabled by default
  - Set `CUDA_ENABLE_COREDUMP_ON_EXCEPTION` env var to 1
  - Generated when a GPU exception is encountered

```
$ ./memexceptions 1
SM version: 86, Min version: 35, Max version: 999
Aborted (core dumped)
$ ls | grep core
core_1669651659_agontarek-dt_612954.nvcudmp
```

- GPU coredump name
  - `core_%t_%h_%p.nvcudmp`
    - `%t` is seconds since Epoch
    - %h is hostname of system running the CUDA application
    - %p is the process identifier of the CUDA application
  - Written into the applications `$PWD` by default
  - User defined with `CUDA_COREDUMP_FILE` env var
    - Recognizes `%t`, %h, %p specifiers

```
$ export CUDA_COREDUMP_FILE=“/lus/grand/projects/alcf_training/$USER/core.gpu.%h.%p”
```

Overview: CUDA-GDB

Coredumps

- Lightweight coredumps
  - Set `CUDA_ENABLE_LIGHTWEIGHT_COREDUMP` env var to 1
  - GPU coredumps will forego dumping memory
    - Local
    - Shared
    - Global
  - Size of coredump reduced significantly
  - Backtrace only

Overview: CUDA-GDB

Coredumps

- User induced GPU coredump
  - Set CUDA_ENABLE_USER_TRIGGERED_COREDUMP env var to 1
  - Opens a communication pipe for each CUDA process
  - Write to pipe to induce a GPU coredump

```
$ export CUDA_ENABLE_USER_TRIGGERED_COREDUMP=1
$ ./matrixMul > output &
[1] 619157
$ ls | grep corepipe
corepipe_agontarek-dt_619157
$ echo "1" > corepipe_agontarek-dt_619157
[1]+  Aborted                 (core dumped) ./matrixMul > output
$ ls | grep 619157
core_1669654018_agontarek-dt_619157.nvcudmp
```

- GPU corepipe name
  - `corepipe_%h_%p`
  - Same %t, %h, %p specifiers
  - User defined with CUDA_COREDUMP_PIPE env var

Overview: CUDA-GDB

Coredumps

- `target cudacore`
  - Loads GPU core dump into the debugger
  - Can load both CPU and GPU coredumps
    - CPU coredump is optional
  - Examining coredumps with CUDA-GDB does not require a GPU be installed on the system

```
(cuda-gdb) target cudacore core_1669651659_agontarek-dt_612954.nvcudmp
Opening GPU coredump: core_1669651659_agontarek-dt_612954.nvcudmp

CUDA Exception: Warp Illegal Address
The exception was triggered at PC 0x7f2823859620 (memexceptions_kernel.cu:17)
[Current focus set to CUDA kernel 0, grid 1, block (0,0,0), thread (0,0,0), device 0, sm 0, warp 0, lane 0]
#0  0x00007f2823859fb0 in exception_kernel<<<(1,1,1),(1,1,1)>>> (data=0x7f2820c00000, exception=MMU_FAULT) at
memexceptions_kernel.cu:50
50 }
(cuda-gdb) print $errorpc
$1 = (void (*)(void)) 0x7f2823859620 <exception_kernel(void*, exception_t)+1056>
(cuda-gdb) print $pc
$2 = (void (*)(void)) 0x7f2823859fb0 <exception_kernel(void*, exception_t)+3504>
```

Overview: Compute Sanitizer

Overview: Compute Sanitizer

What is it?

- Suite of dynamic analysis tools to catch common programming errors
  - Memcheck
    - Report invalid memory accesses
  - Initcheck
    - Report uninitialized memory reads
  - Racecheck
    - Report invalid concurrent accesses to shared memory
  - Synccheck
    - Report invalid barrier usage
- Non-interactive CLI based tool
- Provides proactive debugging of CUDA kernels
  - Discover common programming errors up front

- Supports CUDA/OptiX/OpenACC/OpenMP/etc
- Replaces CUDA-MEMCHECK tool
  - Deprecated since CUDA 11.5
  - Removed in next major version
  - CUDA-GDB memcheck support removed
    - Sanitizer coredumps

Overview: Compute Sanitizer

Quickstart

- On Polaris
  - Missing from PATH by module nvhpc/21.9 (default)

```
agontarek@polaris-login-01:~> $NVIDIA_PATH/cuda/11.4/compute-sanitizer/compute-sanitizer
```

  - Provided by path from module nvhpc/22.7 (non-default)

```
agontarek@polaris-login-01:~> which compute-sanitizer
/soft/ecp/ParaTools/E4S/22.08/mvapich2/spack/opt/spack/cray-sles15-zen3/gcc-11.2.0/nvhpc-
22.7-bpsppgyo3xpzqdblytyxlkyjyzbmld57/Linux_x86_64/22.7/compilers/bin/compute-sanitizer
```

- Recompile for debugging
  - When compiling with nvcc:
    - Provide –g for host (CPU) debugging
    - Provide –G for device (GPU) debugging
  - Using `–lineinfo` will allow checking of optimized code
    - Reduced quality of output messages
- Latest documentation: https://docs.nvidia.com/compute-sanitizer/index.html
- Getting help: https://forums.developer.nvidia.com/c/development-tools/cuda-developer-tools/compute-sanitizer/
- Compute sanitizer examples: https://github.com/NVIDIA/compute-sanitizer-samples

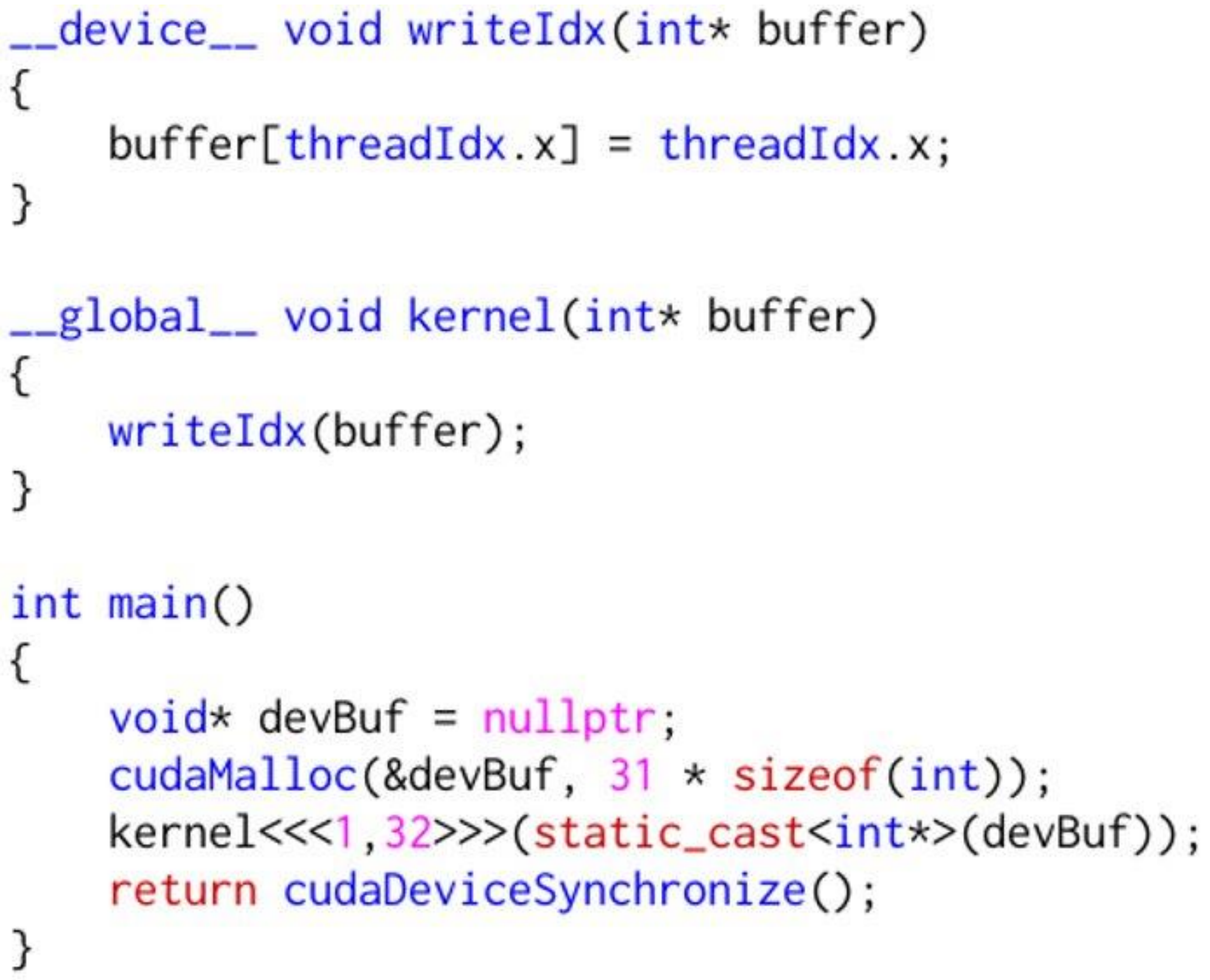
Overview: Compute Sanitizer

Memcheck

- Memcheck is used to report invalid memory accesses
  - Out of bounds or misaligned read/write/atomic accesses
    - Local, shared, or global memory
  - Stack overflows
  - Invalid system-scoped atomic accesses
    - NVLINK peer access
- Reports CUDA API errors
- Hardware exceptions
- Invalid device-side malloc/free usage
- Default tool for compute-sanitizer

Overview: Compute Sanitizer

Memcheck



```
__device__ void writeIdx(int* buffer)
{
    buffer[threadIdx.x] = threadIdx.x;
}

__global__ void kernel(int* buffer)
{
    writeIdx(buffer);
}

int main()
{
    void* devBuf = nullptr;
    cudaMalloc(&devBuf, 31 * sizeof(int));
    kernel<<<1,32>>>(static_cast<int*>(devBuf));
    return cudaDeviceSynchronize();
}
```

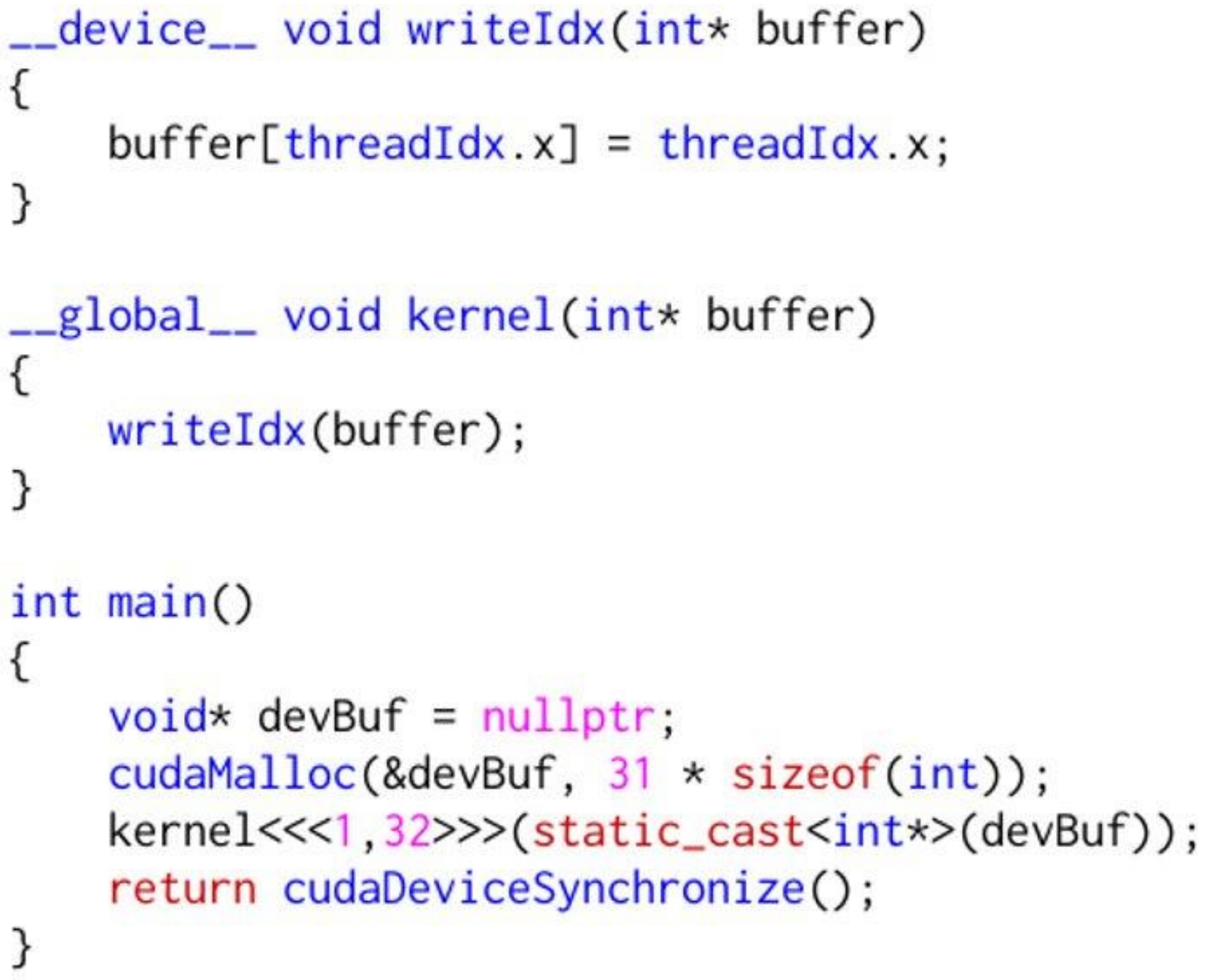
- When first error is encountered
  - Destroy the CUDA context by default
  - Controllable with args
    - `--destroy-on-device-error=<context|kernel>`

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer memcheck-test
========= COMPUTE-SANITIZER
========= Invalid __global__ write of size 4 bytes
=========     at 0x1b0 in /home/agontarek/sanitizer_demos/memcheck.cu:3:writeIdx(int *)
=========     by thread (31,0,0) in block (0,0,0)
=========     Address 0x14efb380007c is out of bounds
=========     and is 1 bytes after the nearest allocation at 0x14efb3800000 of size 124 bytes
=========     Device Frame:/home/agontarek/sanitizer_demos/memcheck.cu:8:kernel(int *) [0xd0]
=========     Saved host backtrace up to driver entry point at kernel launch time
=========     Host Frame: [0x20d4ea]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart802 [0x881b]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:cudaLaunchKernel [0x5ee58]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/cuda/11.4/include/cuda_runtime.h:211:cudaError
cudaLaunchKernel<char>(char const*, dim3, dim3, void**, unsigned long, CUstream_st*) [0x40c0]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/var/tmp/pbs.357595.polaris-pbs-01.hsn.cm.polaris.alcf.anl.gov/tmpxft_0000d0fc_00000000-
6_memcheck.cudafe1.stub.c:13:__device_stub__Z6kernelPi(int*) [0x3fa1]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/memcheck.cu:9:kernel(int*) [0x3fc9]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/memcheck.cu:16:main [0x3e4f]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3cca]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========
========= Program hit cudaErrorLaunchFailure (error 719) due to "unspecified launch failure" on CUDA API call to
cudaDeviceSynchronize.
=========     Saved host backtrace up to driver entry point at error
=========     Host Frame: [0x3dc143]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:cudaDeviceSynchronize [0x3a217]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/memcheck.cu:16:main [0x3e54]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3cca]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========
========= Target application returned an error
========= ERROR SUMMARY: 2 errors
```

Overview: Compute Sanitizer

Memcheck

- Report device side memory leaks
  - `--leak-check=full`



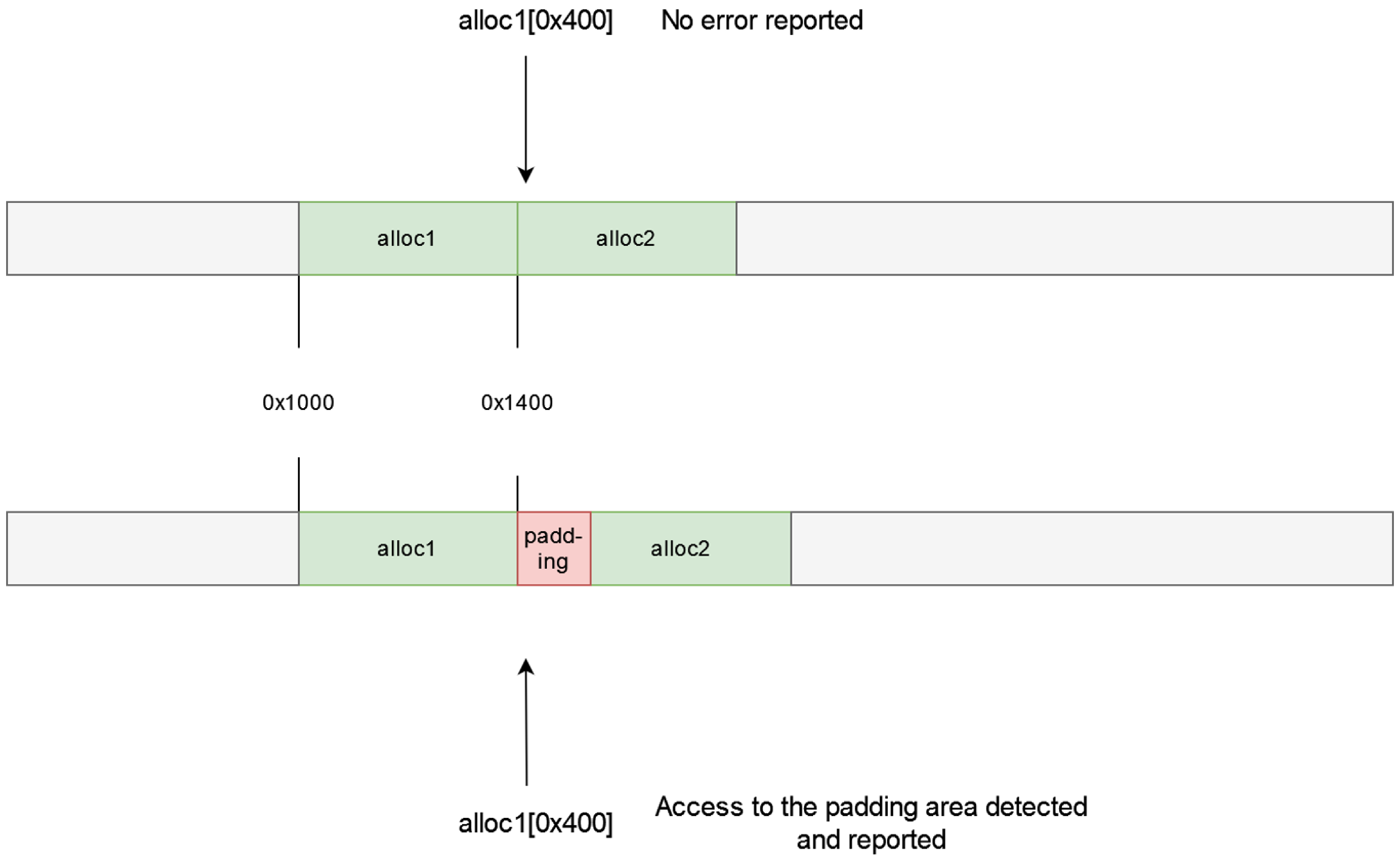
```
__device__ void writeIdx(int* buffer)
{
    buffer[threadIdx.x] = threadIdx.x;
}

__global__ void kernel(int* buffer)
{
    writeIdx(buffer);
}

int main()
{
    void* devBuf = nullptr;
    cudaMalloc(&devBuf, 31 * sizeof(int));
    kernel<<<1,32>>>(static_cast<int*>(devBuf));
    return cudaDeviceSynchronize();
}
```

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --leak-check=full memcheck-test
========= COMPUTE-SANITIZER
========= Leaked 128 bytes at 0x149a43800000
=========     Saved host backtrace up to driver entry point at allocation time
=========     Host Frame: [0x2410e7]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart611 [0x3743e]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:__cudart617 [0x935b]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:cudaMalloc [0x4440f]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/memcheck.cu:16:main [0x3de1]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3cca]
=========                in /home/agontarek/sanitizer_demos/memcheck-test
=========
========= LEAK SUMMARY: 128 bytes leaked in 1 allocations
========= ERROR SUMMARY: 1 error
```

Overview: Compute Sanitizer

Memcheck

- Avoid false negative invalid memory accesses with padding
  - Adds a padding buffer at the end of each allocation
  - Ensures out-of-bounds access doesn't access adjacent memory allocation
  - `--padding=<bytes>`



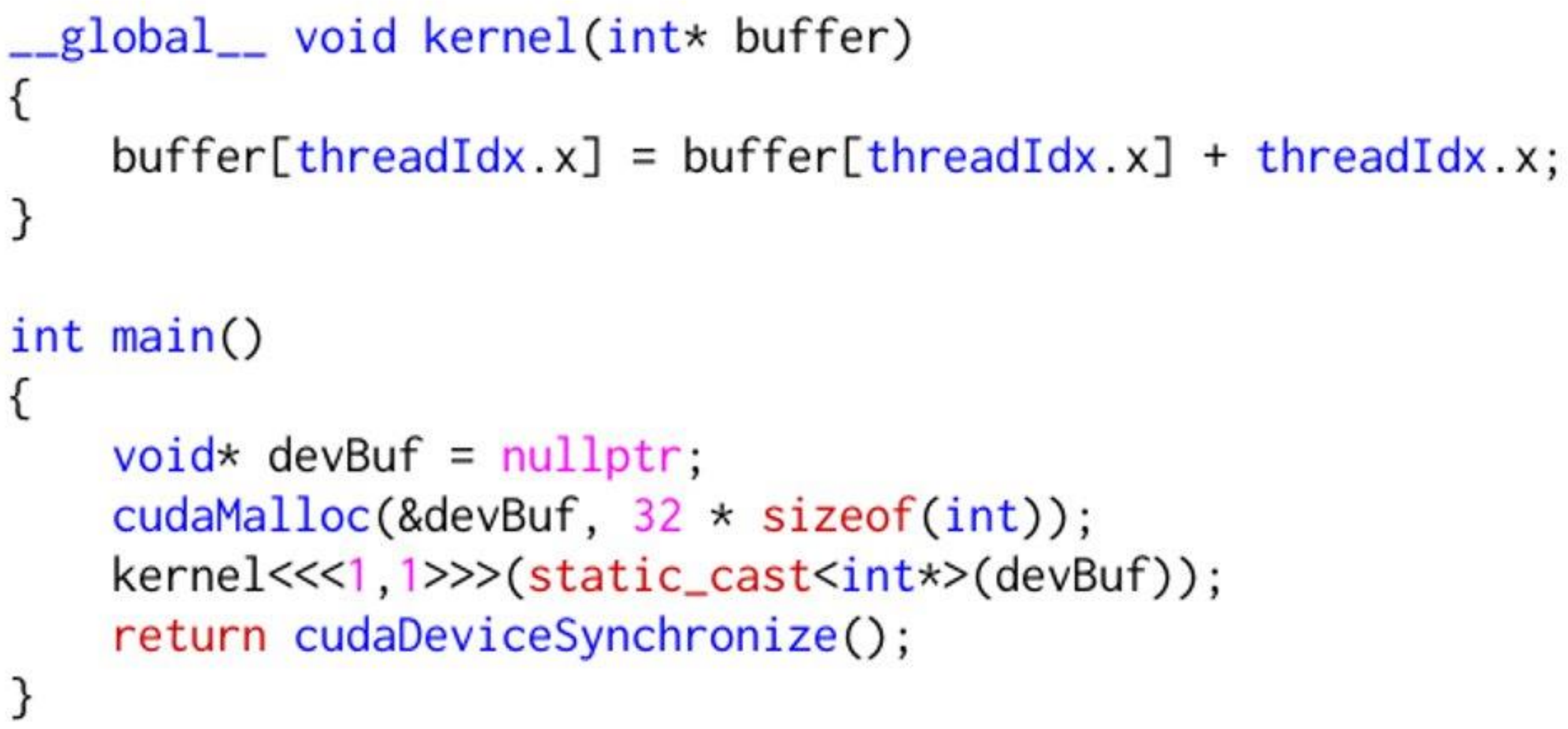
Overview: Compute Sanitizer

Initcheck

- Initcheck is used to report uninitialized memory reads
  - Kernel
  - Memory passed to CUDA API calls
- Global memory supported
  - Shared and local memory untracked
- Can track peer GPU allocations

Overview: Compute Sanitizer

Initcheck



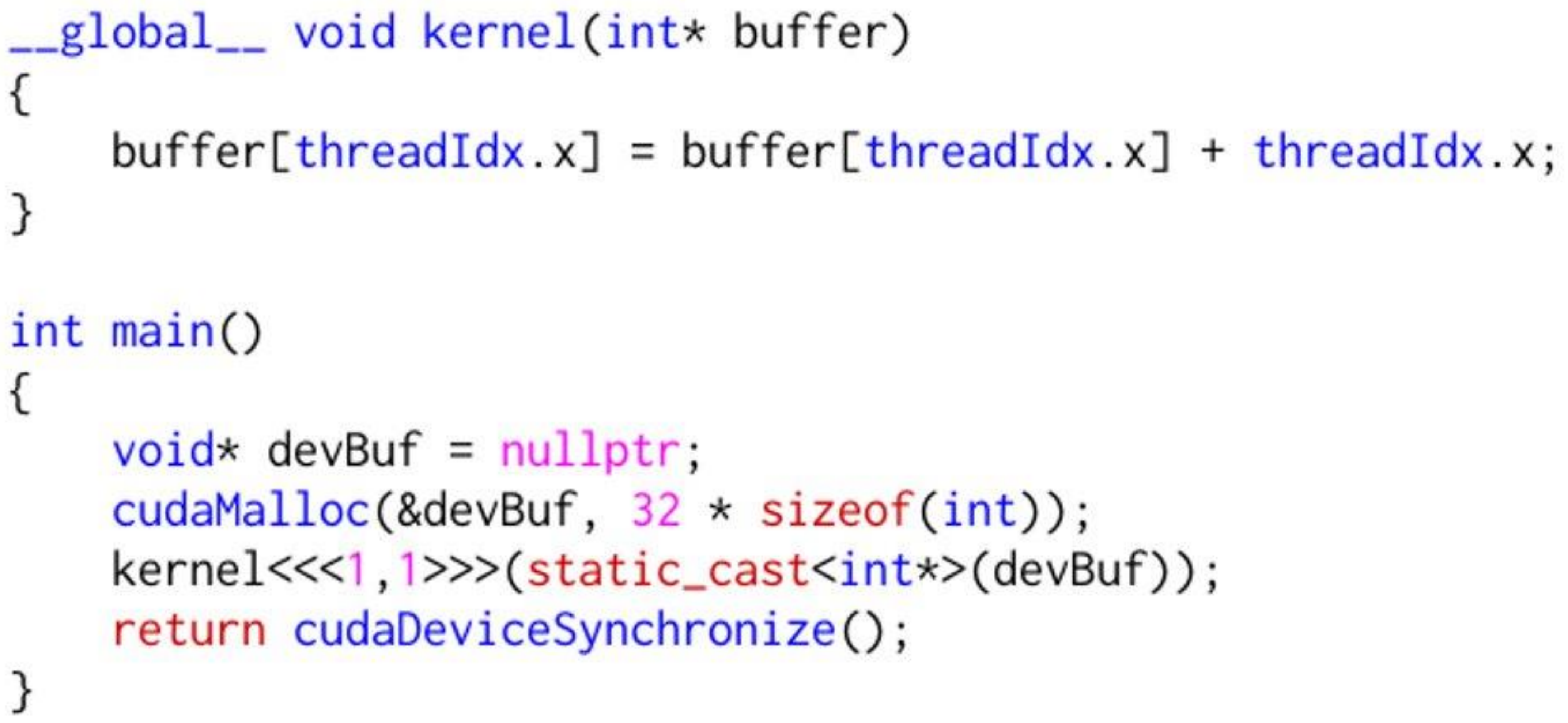
```
__global__ void kernel(int* buffer)
{
    buffer[threadIdx.x] = buffer[threadIdx.x] + threadIdx.x;
}

int main()
{
    void* devBuf = nullptr;
    cudaMalloc(&devBuf, 32 * sizeof(int));
    kernel<<<1,1>>>(static_cast<int*>(devBuf));
    return cudaDeviceSynchronize();
}
```

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --tool=initcheck ./initcheck-test
========= COMPUTE-SANITIZER
========= Uninitialized __global__ memory read of size 4 bytes
=========     at 0x1a0 in /home/agontarek/sanitizer_demos/initcheck.cu:3:kernel(int *)
=========     by thread (0,0,0) in block (0,0,0)
=========     Address 0x152063000000
=========     Saved host backtrace up to driver entry point at kernel launch time
=========     Host Frame: [0x20d4ea]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart802 [0x87ab]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:cudaLaunchKernel [0x5ede8]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/cuda/11.4/include/cuda_runtime.h:211:cudaError
cudaLaunchKernel<char>(char const*, dim3, dim3, void**, unsigned long, CUstream_st*) [0x4053]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:/var/tmp/pbs.357595.polaris-pbs-01.hsn.cm.polaris.alcf.anl.gov/tmpxft_0000d4b6_00000000-
6_initcheck.cudafe1.stub.c:13:__device_stub__Z6kernelPi(int*) [0x3f34]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/initcheck.cu:4:kernel(int*) [0x3f5c]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/initcheck.cu:11:main [0x3de2]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3c7a]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========
========= ERROR SUMMARY: 1 error
```

Overview: Compute Sanitizer

Initcheck

- Initcheck can track unused memory
  - Global memory allocated but never written
  - `--track-unused-memory=yes`



```
__global__ void kernel(int* buffer)
{
    buffer[threadIdx.x] = buffer[threadIdx.x] + threadIdx.x;
}

int main()
{
    void* devBuf = nullptr;
    cudaMalloc(&devBuf, 32 * sizeof(int));
    kernel<<<1,1>>>(static_cast<int*>(devBuf));
    return cudaDeviceSynchronize();
}
```

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --tool=initcheck --track-unused-memory=yes
./initcheck-test
========= COMPUTE-SANITIZER
=========  Unused memory in allocation 0x14e3eb000000 of size 128
=========     Not written 124 bytes at 4 (0x14e3eb000004)
=========     96.875% of allocation were unused.
=========     Saved host backtrace up to driver entry point at allocation time
=========     Host Frame: [0x2410e7]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart611 [0x373ce]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:__cudart617 [0x92eb]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:cudaMalloc [0x4439f]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/initcheck.cu:10:main [0x3d74]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3c7a]
=========                in /home/agontarek/sanitizer_demos/./initcheck-test
=========
========= ERROR SUMMARY: 1 error
```

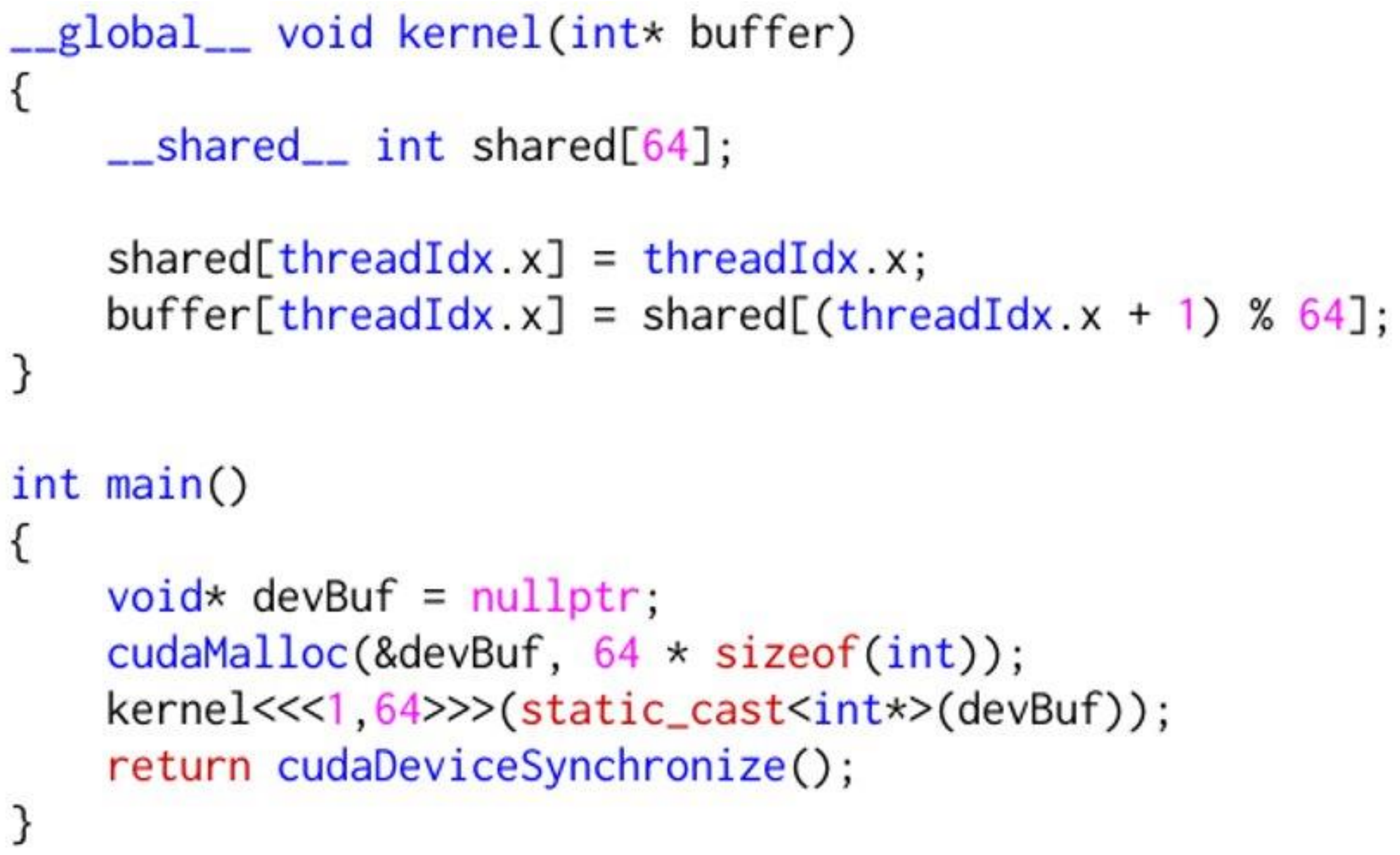
Overview: Compute Sanitizer

Racecheck

- Racecheck is used to detect potential race conditions
  - WAW, WAR, RAW accesses to shared memory
  - Lack of valid synchronization primitive
    - Warp/block level etc
- Shared memory supported
  - Global and local memory untracked
- Two reporting modes
  - Analysis
    - Aggregated report
  - Hazard
    - Every detected error with details
    - Verbose

Overview: Compute Sanitizer

Racecheck



```
__global__ void kernel(int* buffer)
{
    __shared__ int shared[64];

    shared[threadIdx.x] = threadIdx.x;
    buffer[threadIdx.x] = shared[(threadIdx.x + 1) % 64];
}

int main()
{
    void* devBuf = nullptr;
    cudaMalloc(&devBuf, 64 * sizeof(int));
    kernel<<<1,64>>>(static_cast<int*>(devBuf));
    return cudaDeviceSynchronize();
}
```

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --tool=racecheck ./racecheck-test
========= COMPUTE-SANITIZER
========= Error: Race reported between Write access at 0x250 in /home/agontarek/sanitizer_demos/racecheck.cu:5:kernel(int *)
=========     and Read access at 0x5d0 in /home/agontarek/sanitizer_demos/racecheck.cu:6:kernel(int *) [256 hazards]
=========
========= RACECHECK SUMMARY: 1 hazard displayed (1 error, 0 warnings)
```

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --tool=racecheck --racecheck-report=hazard ./racecheck-test | head -n 25
========= COMPUTE-SANITIZER
========= Warning: (Warp Level Programming) Potential RAW hazard detected at __shared__ 0x84 in block (0,0,0) :
=========     Write Thread (33,0,0) at 0x250 in /home/agontarek/sanitizer_demos/racecheck.cu:5:kernel(int *)
=========     Read Thread (32,0,0) at 0x5d0 in /home/agontarek/sanitizer_demos/racecheck.cu:6:kernel(int *)
=========     Current Value : 33
=========     Saved host backtrace up to driver entry point at kernel launch time
=========     Host Frame: [0x20d4ea]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart802 [0x87ab]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:cudaLaunchKernel [0x5ede8]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/cuda/11.4/include/cuda_runtime.h:211:cudaError cudaLaunchKernel<char>(char
const*, dim3, dim3, void**, unsigned long, CUstream_st*) [0x4053]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:/var/tmp/pbs.357595.polaris-pbs-01.hsn.cm.polaris.alcf.anl.gov/tmpxft_0000d332_00000000-
6_racecheck.cudafe1.stub.c:13:__device_stub__Z6kernelPi(int*) [0x3f34]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/racecheck.cu:7:kernel(int*) [0x3f5c]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/racecheck.cu:14:main [0x3de2]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3c7a]
=========                in /home/agontarek/sanitizer_demos/./racecheck-test
=========
```

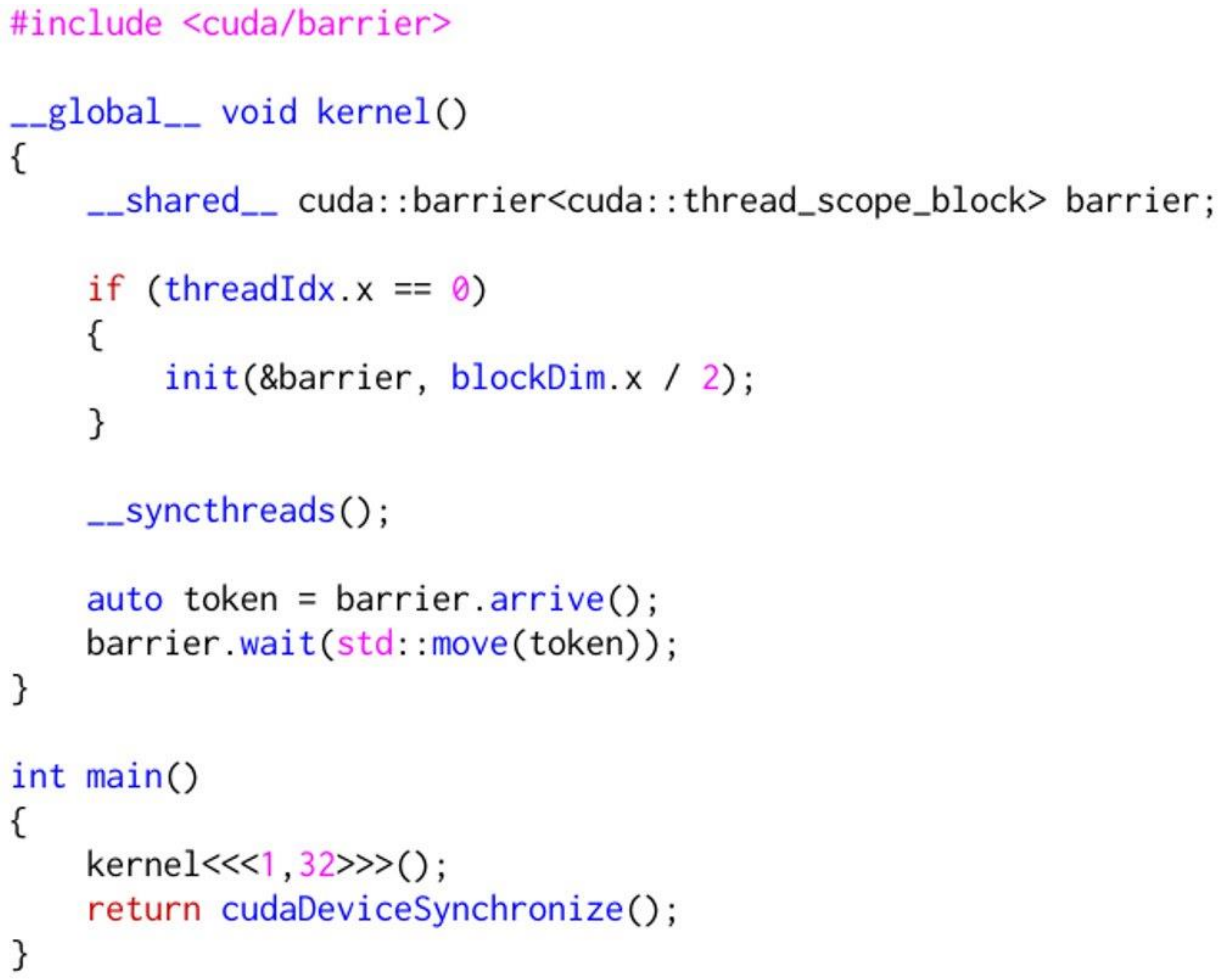
Overview: Compute Sanitizer

Synccheck

- Synccheck is used to detect invalid use of CUDA synchronization primitives
- Behavior depends on architecture
  - Divergent threads in warp/block
  - Invalid barrier arguments

Overview: Compute Sanitizer

Synccheck



```
#include <cuda/barrier>

__global__ void kernel()
{
    __shared__ cuda::barrier<cuda::thread_scope_block> barrier;

    if (threadIdx.x == 0)
    {
        init(&barrier, blockDim.x / 2);
    }

    __syncthreads();

    auto token = barrier.arrive();
    barrier.wait(std::move(token));
}

int main()
{
    kernel<<<1,32>>>();
    return cudaDeviceSynchronize();
}
```

Overview: Compute Sanitizer

Synccheck

```
agontarek@x3204c0s13b0n0:~/sanitizer_demos> compute-sanitizer --tool=synccheck ./synccheck-test
========= COMPUTE-SANITIZER
========= Barrier error detected. Barrier overflow
=========     at 0x540 in
/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/cuda/11.4/include/cuda/std/barrier:189:cuda::__3::barrier<(cuda::__3::thread_scope)2,
cuda::std::__3::__empty_completion>::arrive(long)
=========     by thread (31,0,0) in block (0,0,0)
=========     Device Frame:/home/agontarek/sanitizer_demos/synccheck.cu:14:kernel() [0x6f0]
=========     Saved host backtrace up to driver entry point at kernel launch time
=========     Host Frame: [0x20d4ea]
=========                in /usr/lib64/libcuda.so.1
=========     Host Frame:__cudart802 [0x876b]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:cudaLaunchKernel [0x5eda8]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:/opt/nvidia/hpc_sdk/Linux_x86_64/21.9/cuda/11.4/include/cuda_runtime.h:211:cudaError cudaLaunchKernel<char>(char
const*, dim3, dim3, void**, unsigned long, CUstream_st*) [0x400e]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:/var/tmp/pbs.357595.polaris-pbs-01.hsn.cm.polaris.alcf.anl.gov/tmpxft_0000d43f_00000000-
6_synccheck.cudafe1.stub.c:13:__device_stub__Z6kernelv() [0x3ecc]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/synccheck.cu:16:kernel() [0x3f17]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:/home/agontarek/sanitizer_demos/synccheck.cu:21:main [0x3dc2]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========     Host Frame:__libc_start_main [0x2534d]
=========                in /lib64/libc.so.6
=========     Host Frame:../sysdeps/x86_64/start.S:122:_start [0x3c7a]
=========                in /home/agontarek/sanitizer_demos/./synccheck-test
=========
========= Target application returned an error
========= ERROR SUMMARY: 1 error
```

Overview: Compute Sanitizer

Useful options

- Track all child processes
  - `--target-processes=all`
- Filter desired kernel launches to be tracked
  - `--kernel-regex`
  - `--kernel-regex-exclude`
- Track/ignore n kernel launches
  - `--launch-count=n`
  - `--launch-skip=n`
- Force stream synchronization every n launches
  - `--force-synchronization-limit`
- XML output for error reports
  - `--xml=yes`
- Generate coredump on first error
  - `--generate-coredump=yes`
  - Debug with CUDA-GDB
  - Unsupported with racecheck
- Support for custom memory allocators with NVIDIA Tools Extension (NVTX)

Questions/Comments?