Debugging oneAPI applications with The Intel® Distribution for GDB*

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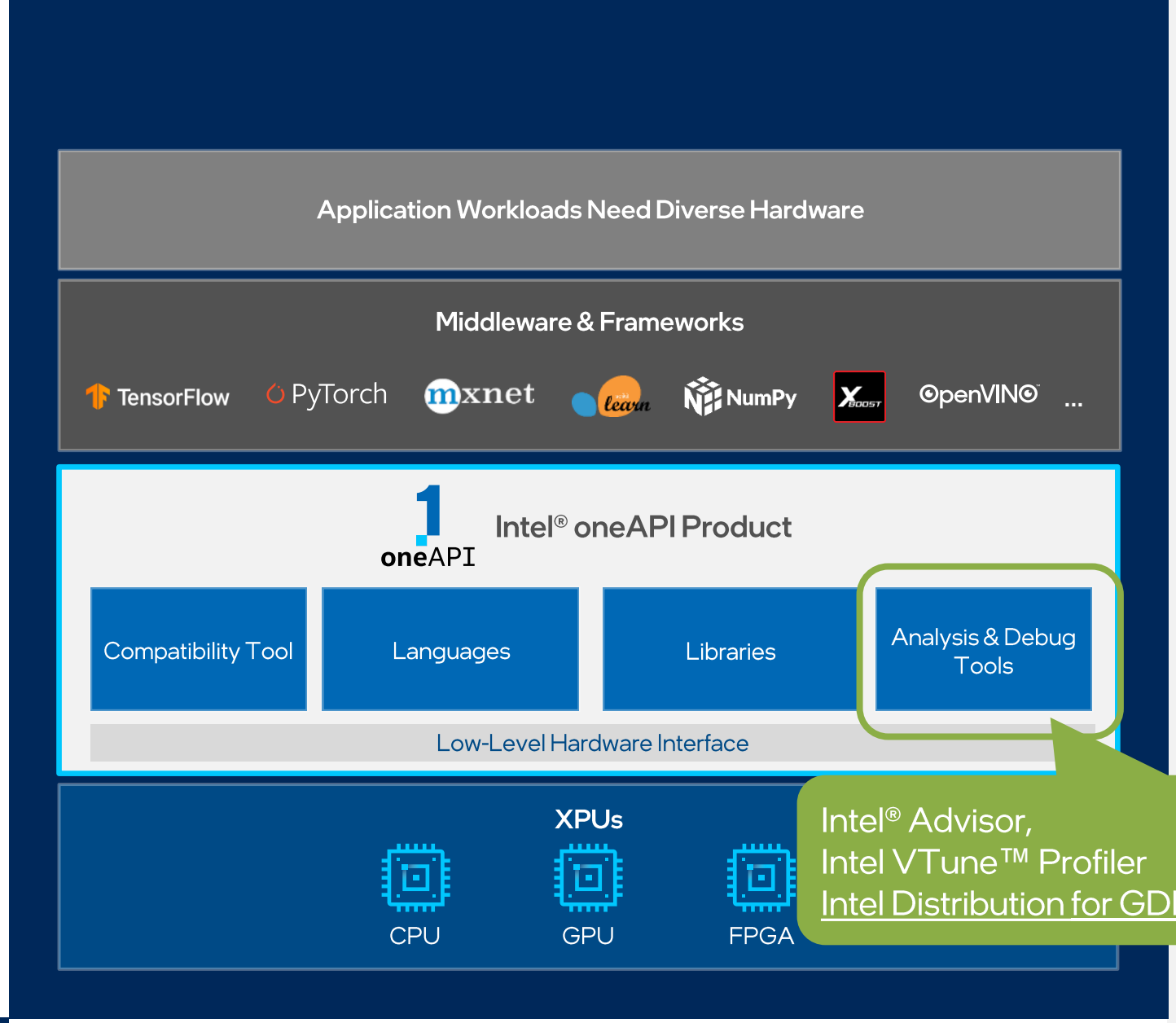
Intel® oneAPI Product

Built on Intel's Rich Heritage of CPU Tools Expanded to XPUs

A complete set of advanced compilers, libraries, and porting, analysis and debugger tools

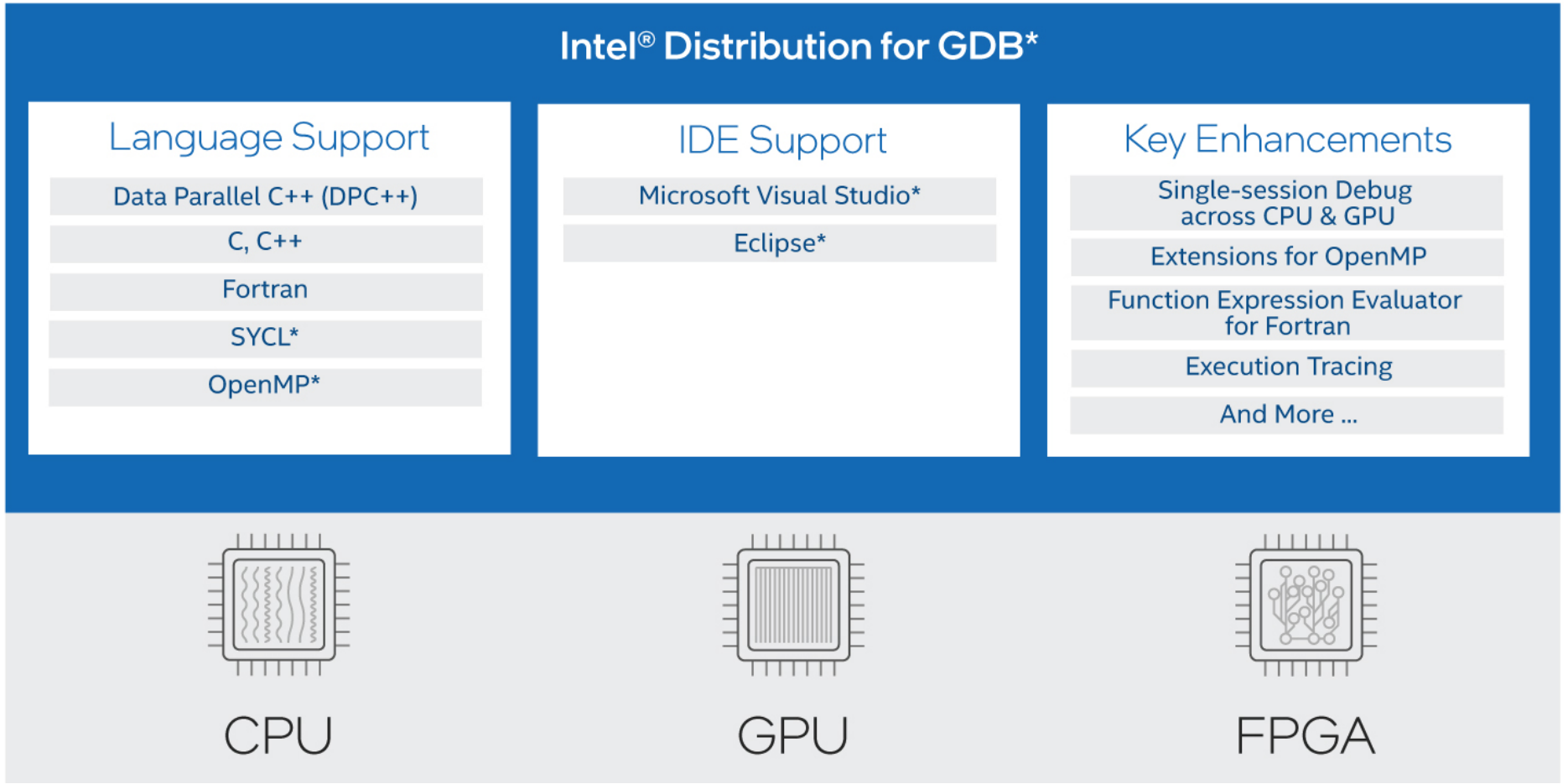
- Accelerates compute by exploiting cutting-edge hardware features
- Interoperable with existing programming models and code bases (C++, Fortran, Python, OpenMP, etc.), developers can be confident that existing applications work seamlessly with oneAPI
- Eases transitions to new systems and accelerators—using a single code base frees developers to invest more time on innovation



Available Now

Visit software.intel.com/oneapi for more details
Some capabilities may differ per architecture and custom-tuning will still be required. Other accelerators to be supported in the future.

Overview of Intel® Distribution of GDB



- Focus of this workshop is on debugging DPC++ GPU kernels

Setup for GPU (Linux)

Install the debug companion driver (DCD)

```
$ tree /opt/intel/oneapi/debugger/latest/
├── dep
│   └── lib
├── documentation
│   ├── gdb.pdf
│   ├── info
│   └── man
├── env
│   └── vars.sh
├── gdb
│   └── intel64
├── igfxdcd-1.8.0-Linux.deb
├── igfxdcd-1.8.0-Linux.rpm
├── …
```

User Manual

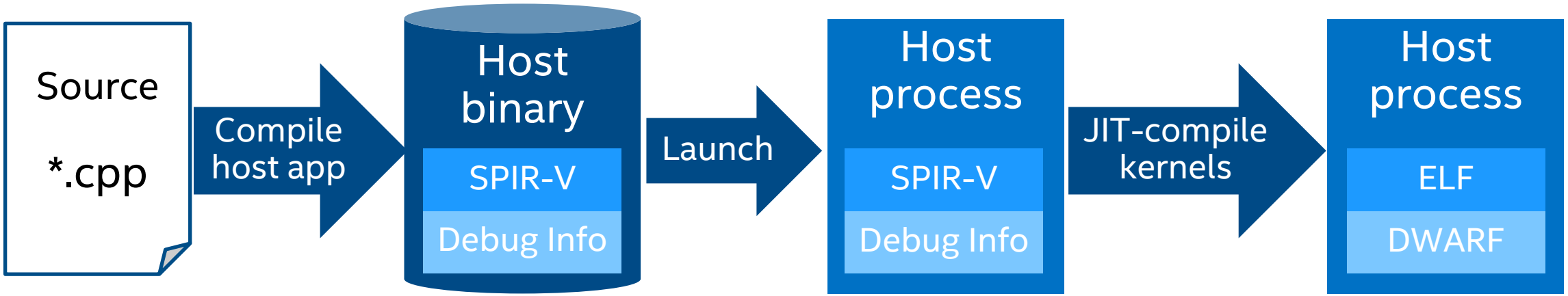
Debug driver

```
$ sudo dpkg -i path/to/igfxdcd-1.8.0-Linux.deb
$ sudo modprobe igfxdcd
```

Additional setup steps maybe necessary, see Get Started guide

Application Compilation (JIT)

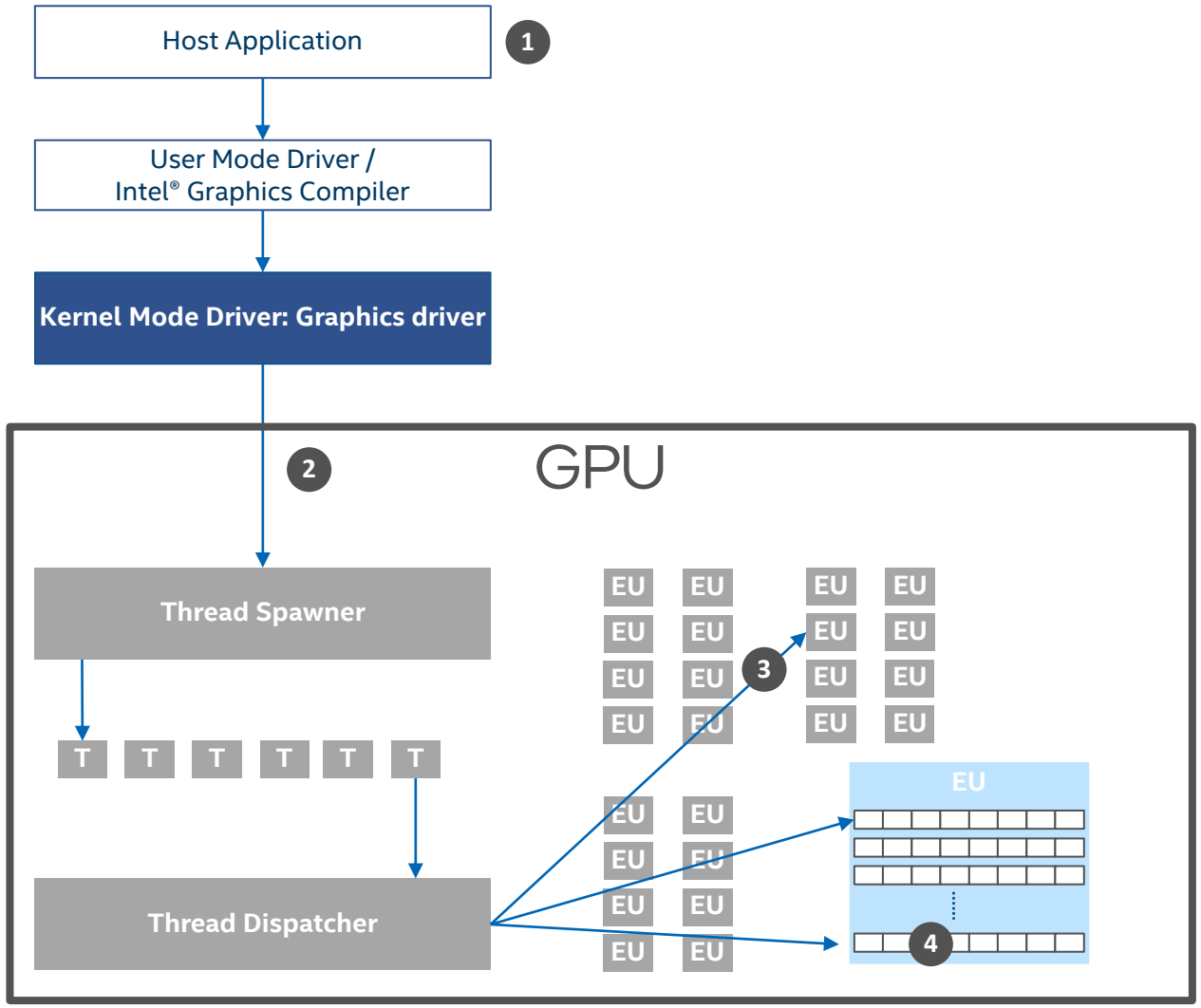
Legend: Debug | Device | Host



Kernels are translated to SPIR-V IR

- Compile with -g (generate debug information) and -O0 (disable optimization) to debug.
  - May use –O2 to debug at assembly level
  - Use same optimization level when linking
- Debug also works with ahead-of-time (AOT) compilation

GPU Debug Model



1. Host inferior*
2. Device inferior*, one per Device / Tile
3. Device thread, one per EU thread
4. SIMD lanes, depending on SIMD width (1/8/16/32)

- *inferior ≈ debuggee process

Fundamental GDB Commands

Command	Description
`help <cmd>`	Print help info
`run [arg1, … argN]`	Start the program, optionally with arguments
`break <file>:<line>`	Define a breakpoint at a specified line
`info break`	Show defined breakpoints
`delete <N>`	Remove Nth breakpoint
`step / next`	Single-step a source line, stepping into / over function calls
`info args/locals`	Show the arguments / local variables of the current function
`print <exp>`	Print value of expression
`x/<format> <addr>`	Examine the memory at <addr>
`up, down`	Go one level up/down in the function call stack
`disassemble`	Disassemble the current function
`backtrace`	Show the function call stack

GPU-Relevant GDB Commands

Command	Description
`info inferiors`	Display information about the inferiors. GPU Debugging will display additional inferior(s) (gdbserver-gt)
`info threads <thread>`	Display information about threads, including their active SIMD lanes
`thread <thread>:<lane>`	Switch context to the SIMD lane of the specified thread
`thread apply <thread>:<lane> <cmd>`	Apply <cmd> to specified lane of the thread
`set scheduler-locking on/step/off`	Lock the thread scheduler. Keep other threads stopped while current thread is stepping (step) or resumed (on) to avoid interference. Default (off)
`set nonstop on/off`	Enable/disable nonstop mode. Set before program starts. (off) : When a thread stops, all other threads stop. Default. (on) : When a thread stops, other threads keep running.
`print/t $emask`	Inspect the execution mask to show active lanes

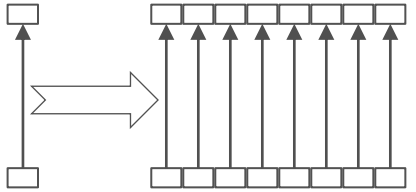
Inferiors

GDB uses *inferior* objects to represent states of program execution (usually a process)

- Debugger create inferior(s) that attaches to GPU(s) to receive events and control the GPU


```
$ dpcpp -g -O0 array-transform.cpp -o array-transform
$ gdb-oneaopi -q -args ./array-transform gpu
Reading symbols from ./array-transform...
(gdb) b 59
Breakpoint 1 at 0x406f34: file array-transform.cpp, line 59.
(gdb) r
…
intelgt: gdbserver-gt started for process 28986.
…
(gdb) info inferiors
 Num  Description   Connection                                          Executable
   1  process 9463  1 (native)                                          <path_to_program>
* 2  device 1       2 (extended-remote gdbserver-gt --multi --hostpid=9463 -)
```

Debugging Threaded GPU SIMD Code

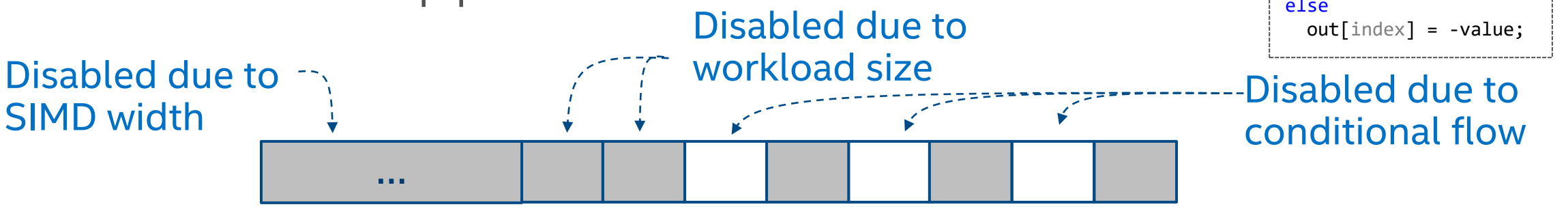


- Kernel code written for single work-item
- Code implicitly threaded and widened to vectors of work-items
- Variable locations expressed as functions of the SIMD lane
  - Lane field added to thread representation <inferior>.<thread>:<lane>
  - Applies to `info threads`, `thread`, `thread apply` …

```
(gdb) info thread 2.*
  Id           Target Id           Frame
* 2.1:0        Thread 1.1073741824 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lambo
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
  2.1:[2 4 6]  Thread 1.1073741824 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lambo
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
  2.2:[0 2 4 6] Thread 1.1073742400 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lamb
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
  2.3:[0 2 4 6] Thread 1.1073742336 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lamb
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
  2.4:[0 2 4 6] Thread 1.1073742144 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lamb
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
```

SIMD Lanes Support

```
if (index % 2 == 0)
  out[index] = value;
else
  out[index] = -value;
```



- Only enabled SIMD lanes displayed
- SIMD width is not fixed
- A user can switch only between enabled SIMD lanes
- After a stop, GDB switches to an enabled SIMD lane
- If target architecture does not support SIMD or thread SIMD width is 1, GDB behavior is unchanged

A thread might switch between different kernels with different SIMD widths

A Sample GDB Session

```
$ gdb -q sycl-if
Reading symbols from sycl-if...
(gdb) set print thread-events off
(gdb) break 21
Breakpoint 1 at 0x40497b: file src/sycl-if.cpp, line 21.
(gdb) ignore 1 41
Will ignore next 41 crossings of breakpoint 1.
(gdb) run
Starting program: .../sycl-if
[...]
intelgt: attached to device with id 0x3ea5 (Gen9)
intelgt: inferior 2 (gdbserver-gt) created for process 1555133.
[Switching to Thread 1073746465 lane 1]

Thread 2.43 hit Breakpoint 1,  with SIMD lanes [1 3 5 7], compute(int*, int*)::$_0::operator()(cl::sycl::handler&)
const::{lambda(cl::sycl::id<1>)#1}::operator()(cl::sycl::id<1>) const (this=0x2dfff00, index=...) at sycl-if.cpp:21
21          out[index] = -value;
(gdb) list
16      cgh.parallel_for<class kernel>(range, [=](sycl::id<1> index) {
17        int value = in[index];
18        if (index % 2 == 0)
19          out[index] = value;
20        else
21          out[index] = -value;
22      });
23    });
24  }
25
(gdb) print index
$1 = {<cl::sycl::detail::array<1>> = {common_array = {617}}, <No data fields>}
(gdb)
```

Multi-Device Debugging

- A program can offload a kernel to all or subset of GPU devices
- Intel® Distribution for GDB* can debug the CPU and GPUs in the same debug session
- User can switch to the context of a thread on a GPU or the CPU
- Each GPU device appears as a separate inferior (i.e. process)
- Inferior for a device does not appear if not used
- Threads of the GPUs can be independently resumed; thread state can be examined.

Multi-Device Debugging

```
multi-gpu.cpp
   31            cl::sycl::device device = devices[device_index];
   32            print_device ("Found", device);
   33
   34            return cl::sycl::queue {device}; /* return-sycl-queue */
   35          }
   36
   37          static void
   38          compute (cl::sycl::id<1> index)
   39          {
   40            int point = index[0];
B+ 41            int a = 33; /* kernel-line-1 */
   42            int b = 44;
B+>43            int c = 55; /* kernel-line-3 */
   44          }
   45
   46          static void
```

```
extended-r Thread 3.1073741824 In: _ZTSZZL3runRN2cl4sycl5queueEENKUlRNS0_7handlerEE54_24clES4_EUlNS0_2idILi1EEEE* L43   PC: 0xffde3640
(gdb) info threads
  Id           Target Id                                    Frame
  1.1          Thread 0x7ffff6e37000 (LWP 401277) "multi-gpu" 0x00007ffff725f89b in sched_yield ()
   from /lib/x86_64-linux-gnu/libc.so.6
  1.2          Thread 0x5ffff37c5700 (LWP 401281) "multi-gpu" 0x00007ffff727150b in ioctl () from /lib/x86_64-linux-gnu/libc.so.6
  2.1:[0-7]    Thread 2.1073741824                          compute (index=cl::sycl::id<1> = {...}) at multi-gpu.cpp:43
  2.2:[0-7]    Thread 2.1073741888                          compute (index=cl::sycl::id<1> = {...}) at multi-gpu.cpp:43
* 3.1:0        Thread 3.1073741824                          compute (index=cl::sycl::id<1> = {...}) at multi-gpu.cpp:43
  3.1:[1-7]    Thread 3.1073741824                          compute (index=cl::sycl::id<1> = {...}) at multi-gpu.cpp:43
  3.2:[0-7]    Thread 3.1073741888                          compute (index=cl::sycl::id<1> = {...}) at multi-gpu.cpp:43
(gdb)
```

- Second GPU's threads
- First GPU's threads
- Host application threads (CPU)

Limitations

- If a bug occurs on both CPU and GPU, debug on the CPU
- Breakpoint must be set inside kernel to debug GPU
  - Unable to step into the kernel, separate inferiors
- Debug process state on hardware (not on CPU)
  - Restricts GPU to single context (unable to perform other tasks)
  - Display interruption for rendering GPU
- CPU polls status of debug process state through MMIO
  - Increases load on host
- See Release Notes for complete list

Case Study: Using Intel® Distribution of GDB* to Debug SYCL ZFP Compression Library

- ZFP: open-source library for compressed floating-point and integer arrays
  - Supports high-throughput random access read and write to individual elements
- Intel® DPC++ Compatibility Tool used to assist the migration of the CUDA source to DPC++
  - Unit test failures for 1D double, 2D float, 2D double, and all 3D cases.
- Intel® Distribution for GDB* used to identify the bug

Debugging ZFP

1. Identify indices of the array that was failing
   - Incorrect encoding due to overflow was happening for certain indices
2. Start debugger
3. Set conditional breakpoint in kernel
   - `b encode1.dp.hpp:64 if block_idx==65534`
4. After stepping through kernel code, an unnecessary typecast from double to float was discovered, causing overflow

References

- Intel® Distribution for GDB* Get Started Guide
  - Linux, Windows
- Debugging with Intel® Distribution for GDB Tutorial
  - Linux, Windows
- Intel® Distribution for GDB* Release Notes
- Intel® Distribution for GDB* Reference Sheet
- Debugger Samples on GitHub

Summary

- Intel® Distribution for GDB* can be used to debug host and device for oneAPI applications written in various languages
- Traditional GDB commands have been extended to accommodate GPU execution model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