Intel® Distribution for GDB*

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Agenda

- Intel® Distribution for GDB* Overview
- Debugging GPU Offloaded Code
  - Compilation flow and debug information
  - GPU debug model
  - Compute kernel debugging
  - SIMD lanes
  - Multi-device debugging
  - GDB commands relevant for GDB debugging
- GDB Demo
- Summary and References

Intel® Distribution for GDB* Overview

Intel® Distribution for GDB* Overview

- Intel® oneAPI
  - Set of toolkits that include software development tools and libraries
  - Advanced compilers, including C++ compiler with SYCL support
  - The goal is to enable developers to write code for heterogeneous and offload processors
- Intel® Distribution for GDB*
  - All standard GDB* features
    - Intel GDB team works with the GDB project to contribute back
  - Support for C, C++, SYCL, Fortran, OpenMP for both C/C++ and Fortran
  - Multi-target/GPU: debug “host” and “kernel” in the same session
    - Auto-attach: automatically create inferior to debug GPU
      - Automatically detect JIT-compiled, or dynamically loaded, kernel code
    - SIMD lanes: display lane information and switch among lanes

Fundamental GDB Commands

Command	Description
`help [cmd|cmd-class]`	Print help for the given command or command class
`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

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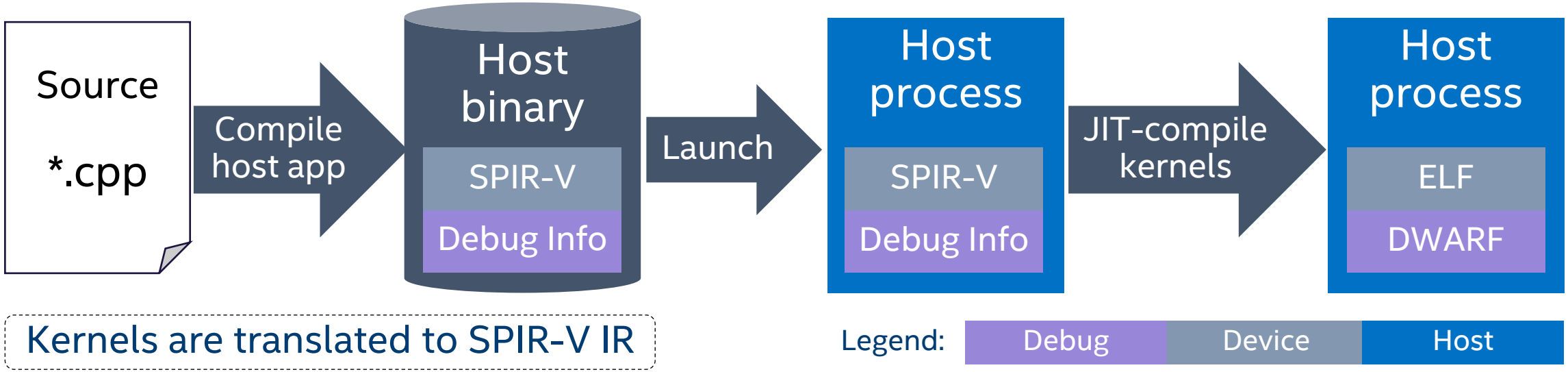
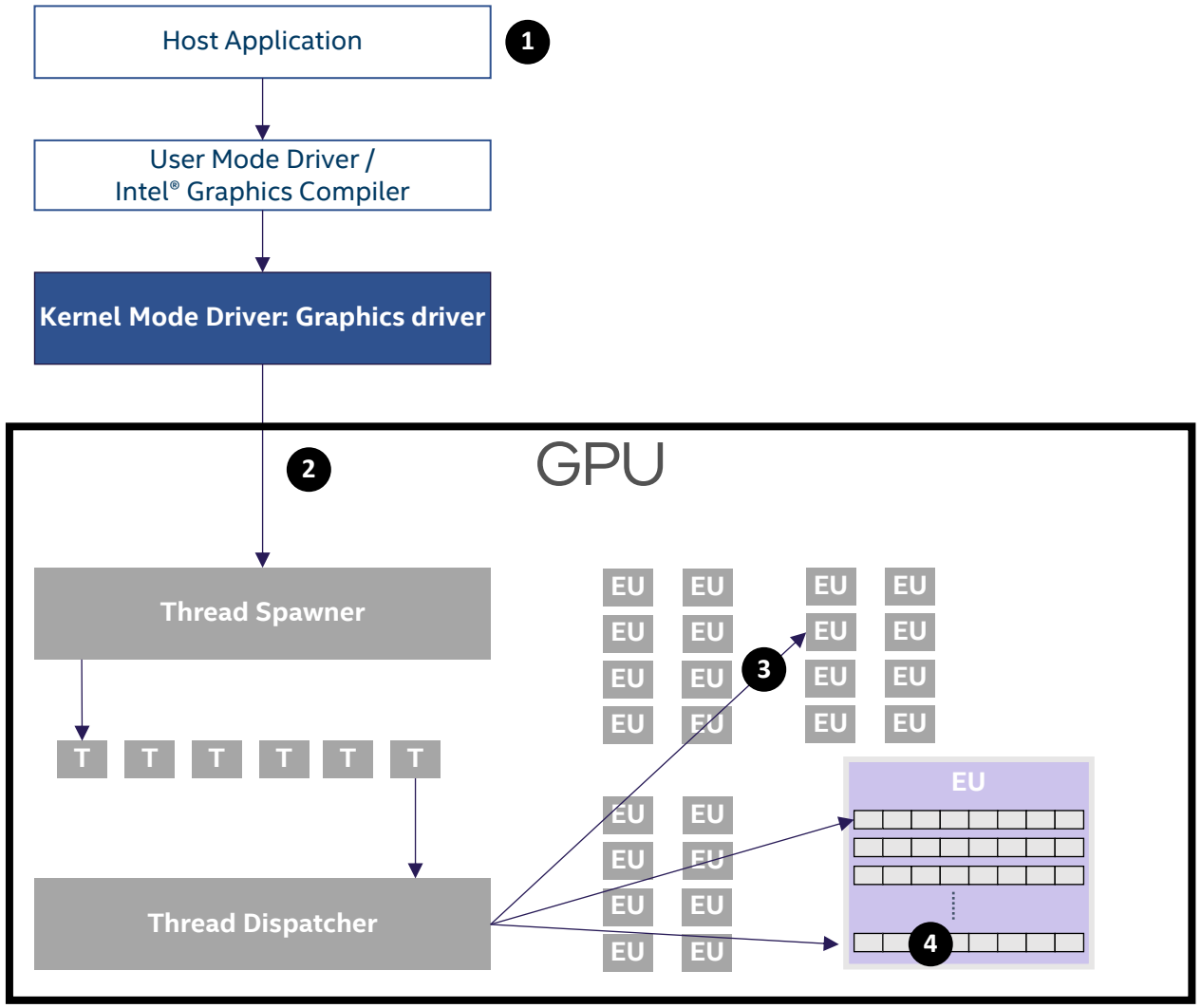
Debugging GPU Offloaded Code

Application Compilation (JIT)



- Compile with -g (generate debug information) and -O0 (disable optimizations) 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

Kernel Debugging, CPU vs GPU

- Behavior and commands are very similar to standard GDB*.
- CPU and GPU debugging experience is similar except:
- SIMD Lane Support
  - CPU: Cannot switch context to non-default SIMD lane.
  - GPU: May switch to a particular SIMD lane during debugging.
- Debugger calls to kernel functions
  - CPU: Supported
  - GPU: Not supported

Inferiors

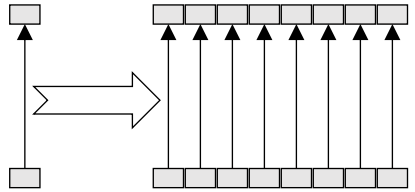
GDB uses *inferior* objects to represent states of program execution (usually a process)

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


```
$ icpx -fsycl -g -O0 array-transform.cpp -o array-transform
$ gdb-oneapi -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

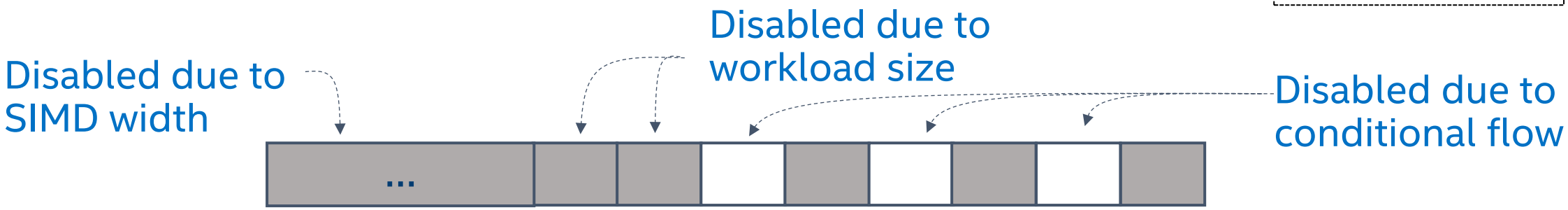
- Kernel code written for single work-item
- Code implicitly threaded and widened to vectors of work-items
- Variable locations expressed as functions of the SIMD lane
  - Lane field added to thread representation <inferior>.<thread>:<lane>
  - Applies to `info threads`, `thread`, `thread apply` …



```
(gdb) info thread 2.*
  Id           Target Id           Frame
* 2.1:0        Thread 1.1073741824 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lambc
    index=cl::sycl::id<1> = {...}) at array-transform.cpp:59
  2.1:[2 4 6]  Thread 1.1073741824 main::$_1::operator()<cl::sycl::handler>(cl::sycl::handler&) const::{lambc
    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
  - `info threads` to see active threads and lanes
- SIMD width is not fixed
- A user can switch only between enabled SIMD lanes
  - `thread <inferior>:<thread>.<lane>`
- After a stop, GDB switches to an enabled SIMD lane
- `print/t $emask` to see the execution mask

A thread might switch between different kernels with different SIMD widths

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)

GDB Commands Relevant for GPU Debugging

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

Commands with Different Behavior – CPU vs. GPU

Command	Description	GPU Behavior
`disassemble`	Disassemble code	GEN instructions and registers shown
`step, stepi, next`	Single-step source line into function calls, single-step machine instruction, single-step source line over function calls	SIMD lanes are supported, SIMD lane switches can occur

`break`	Create breakpoint	May create break point at a specific SIMD lane.
		`break 56 thread 2:3`
		May specify breakpoint for a particular inferior
		`break 56 inferior 2`

`commands`	Specify a list of commands for given breakpoints	With the `/a` modifier, breakpoint actions apply to all SIMD lanes

Enabling GPU Debug

- GPU Debugging is disabled by default for performance reasons
- Enable debugging in the Kernel Mode Driver (KMD):

```
echo 1 > /sys/class/drm/card0/prelim_enable_eu_debug
…
echo 1 > /sys/class/drm/cardN/prelim_enable_eu_debug
```

- Set ZET_ENABLE_PROGRAM_DEBUGGING=1 to enable debugging in the GPU Runtime (UMD)

```
export ZET_ENABLE_PROGRAM_DEBUGGING=1
```

- After finishing the debug session, disable debugging in the KMD:

```
echo 0 > /sys/class/drm/card0/prelim_enable_eu_debug
…
echo 0 > /sys/class/drm/cardN/prelim_enable_eu_debug
```

- Argonne Aurora specific:
  - ***helper_toggle_eu_debug.sh*** script to enable and disable KMD is provided here:
    - https://github.com/argonne-lcf/ALCFBeginnersGuide/blob/master/aurora/02_a_debugger.md

GPU Debug Demo

Sample GDB Session

```
$ gdb-oneapi -q ./array-transform
Reading symbols from ./array-transform...
(gdb) set print thread-events off
(gdb) break 61
Breakpoint 1 at 0x406362: file array-transform.cpp, line 61.
(gdb) run gpu
Starting program: /home/intel/oneAPI-samples/Tools/ApplicationDebugger/array-transform/src/array-transform gpu
[Thread debugging using libthread_db enabled]
Using host libthread_db library "/lib/x86_64-linux-gnu/libthread_db.so.1".
intelgt: gdbserver-gt started for process 124229.
Will listen for an attached process
[SYCL] Using device: [Intel(R) Iris(R) Plus Graphics 655 [0x3ea5]] from [Intel(R) Level-Zero]
intelgt: attached to device 1 of 1; id 0x3ea5 (Gen9)
[New inferior 2]
[Switching to Thread 1.32768 lane 1]

Thread 2.1 hit Breakpoint 1, with SIMD lanes [1 3 5 7],
main::{lambda(auto:1&)#1}::operator()<cl::sycl::handler>(cl::sycl::handler&)
const::{lambda(cl::sycl::id<1>)#1}::operator()(cl::sycl::id<1>) const (this=0x1c49310, index=cl::sycl::id<1> = {...}) at
array-transform.cpp:61
61                result = -1;  // else-branch
(gdb) list
56              int element = in[index];  // breakpoint-here
57              int result = element + 50;
58              if (id0 % 2 == 0) {
59                result = result + 50;  // then-branch
60              } else {
61                result = -1;  // else-branch
62              }
63              out[index] = result;
64            });
65            // kernel-end
(gdb) print index
$1 = cl::sycl::id<1> = {1}
(gdb)
```

GPU Debugging 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 in GPU 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
- Inspecting shared local memory (SLM) is not supported
- See Release Notes for complete list

Additional Debug Scenarios

- Core dump Analysis
  - Enable core dumps:
    ```
    ulimit -c unlimited
    mpiexec -ppn 1 --rlimits CORE pwd
    ```
  - Run the application and generate core dump file:
    ```
    mpiexec –n N debugged_application <options>
    ```
  - Load application in GDB and print the backtrace:
    ```
    gdb-oneapi debugged_application corefile
    thread apply all bt
    ```
- MPI Debugging
  - Debug a single rank by running that rank under the GDB, for example:
    ```
    mpirun --env ZET_ENABLE_PROGRAM_DEBUGGING=1 -n 1 gdb-oneapi <mpi_app>: -n 1 <mpi_app>
    ```
  - Debug several ranks, using several GDB instances, each one in its own xterm:
    ```
    mpirun --env ZET_ENABLE_PROGRAM_DEBUGGING=1 -n 2 xterm –e gdb-oneapi <mpi_app>
    ```
  - Non-interactive debug:
    ```
    gdb-oneapi -batch -ex <cmd1> -ex <cmd2> … -ex <cmdN> --args <mpi_app> <app_args>
    ```
    - Wrapper script: https://docs.alcf.anl.gov/aurora/debugging/gdb-oneapi/#noninteractive-debugging
- Python Debugging
  - Mainly intended for debugging C API extensions and CPython Internals
  - Use ***`python-gdb.py`*** extension
  - Documentation: https://docs.python.org/3/howto/gdb_helpers.html

    source `/usr/share/gdb/auto-load/usr/lib64/libpython3.6m.so.1.0-gdb.py` in GDB

Summary and References

- 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 mode
- References:
  - ALCF Beginners Guide - Debugging on Aurora
  - Debugging on Aurora with gdb-oneapi
  - 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

What questions do you have?