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DEBUGGING SYCL PROGRAMS ON HETEROGENEOUS INTEL® ARCHITECTURES

Natalia Saiapova

Intel GmbH, Munich, Germany

Several people contributed to various parts of the debugger presented in this talk

Arik Adler

Sanimir Agovic

Tankut Baris Aktemur

Albertano Caruso

Ofir Cohen

Mircea Gherzan

Markus Metzger

Ofer Rubin

Natalia Saiapova

Fabian Schnell

Mihails Strasuns

Kai Trojahner

Talk plan

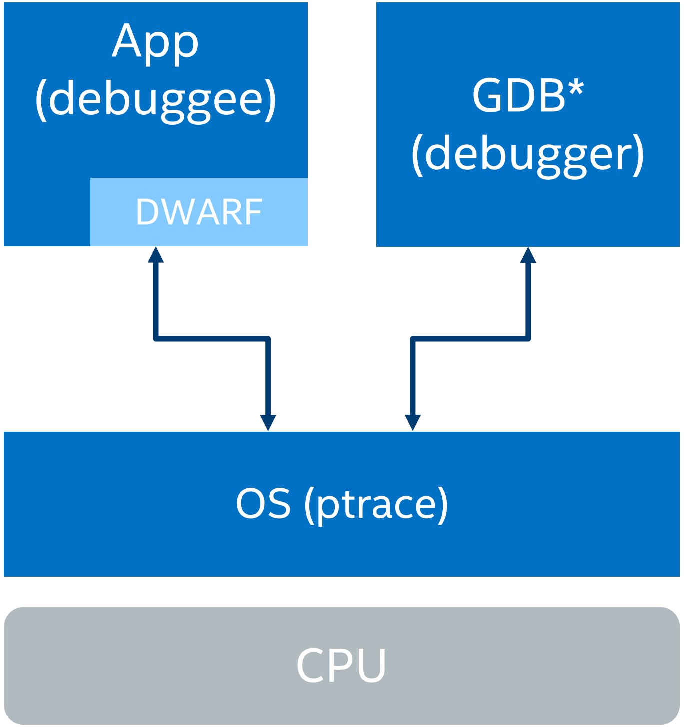
- oneAPI programming model
- How does a debugger work?
- Architecture
- Demo
- Challenges

oneAPI programming model

- **Problem:**
  - Modern problems imply workload diversity
  - Variety of hardware (CPU, **GPU**, accelerators) and programming languages, APIs, tools, libraries needed to achieve best performance
- **Aim:** a unified programming model to deliver uncompromised performance for diverse workloads across multiple architectures

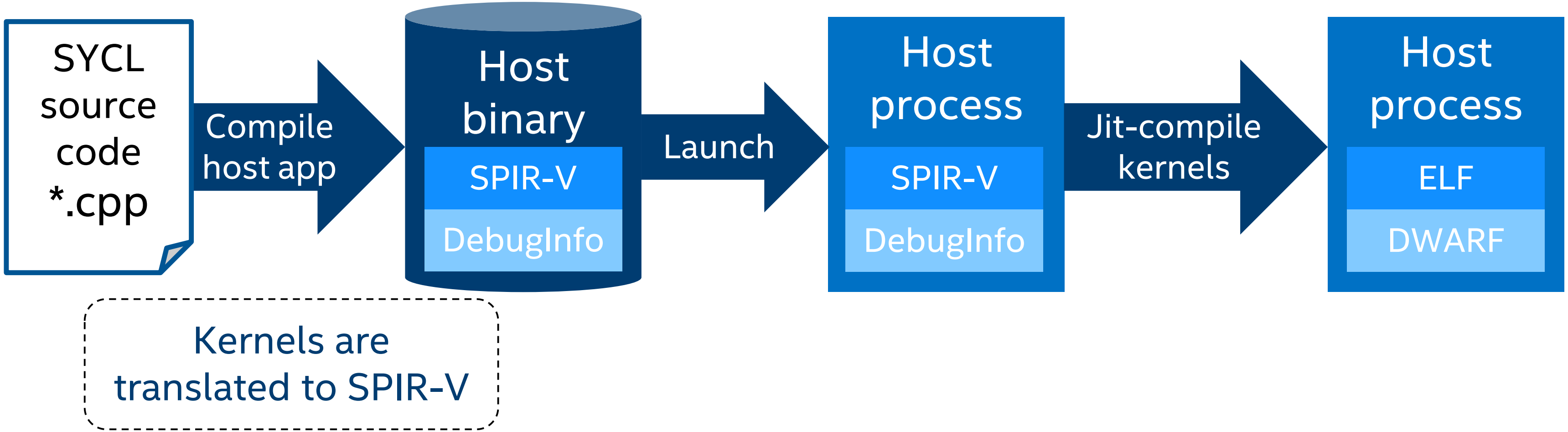
Beta release of Intel® oneAPI products made in November
https://software.intel.com/oneapi

How does a debugger work?



- Debugger – separate process
- Translates between source-level and machine-level worlds
- OS provides debugger with:
  - Permission to control another process
  - Access to debuggee’s memory and its threads’ register state
  - Means to alter execution of debuggee
- Exceptions from the debuggee are delivered to the debugger

SYCL application compilation



Kernels are translated to SPIR-V

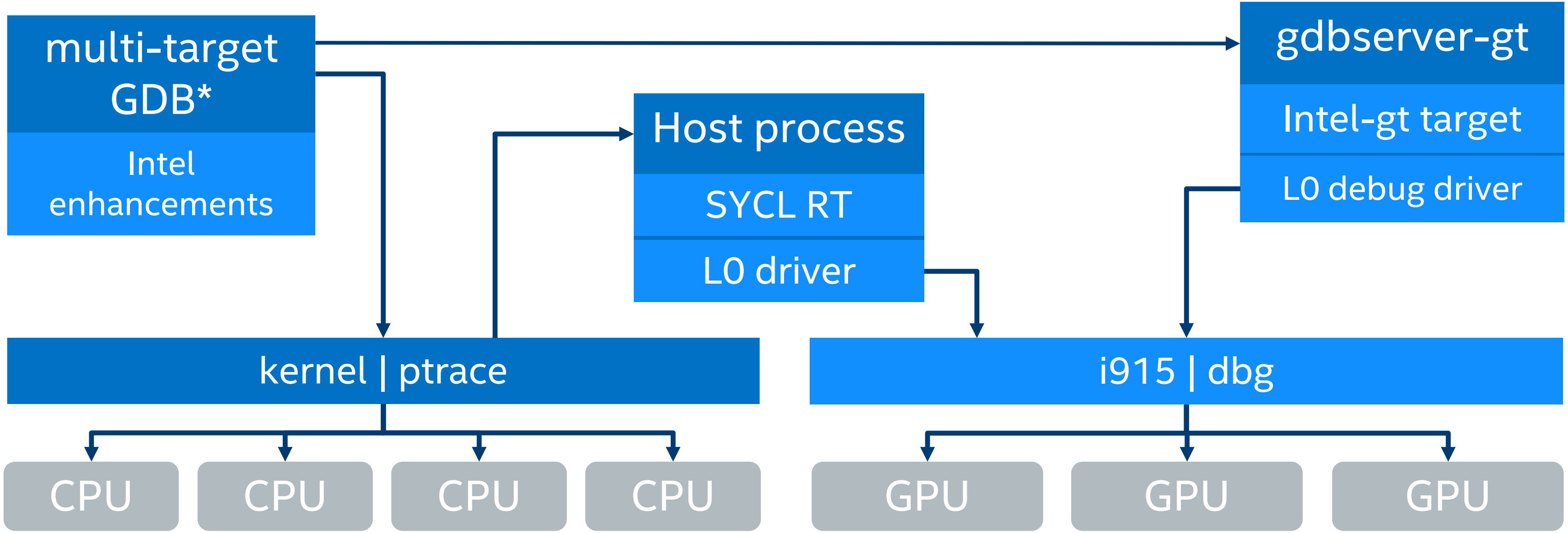
Standard GDB can debug the host part.

Kernels offloaded to GPU device are transparent to the debugger!

Legend: Debug | Device | Host

Refer to software.intel.com/articles/optimization-notice for more information regarding performance & optimization choices in Intel software products.

Detailed view on architecture



Legend: Intel | 3rd party | Hardware

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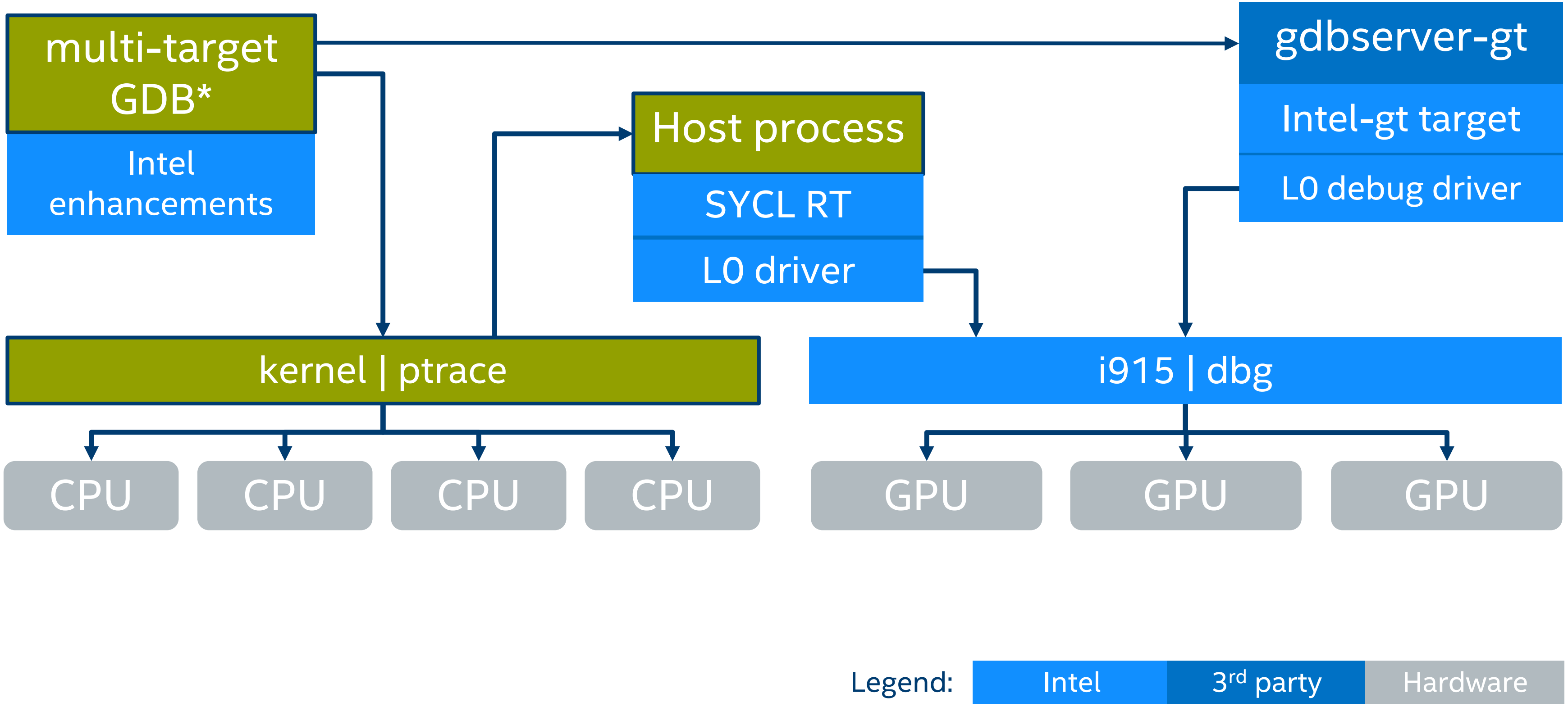

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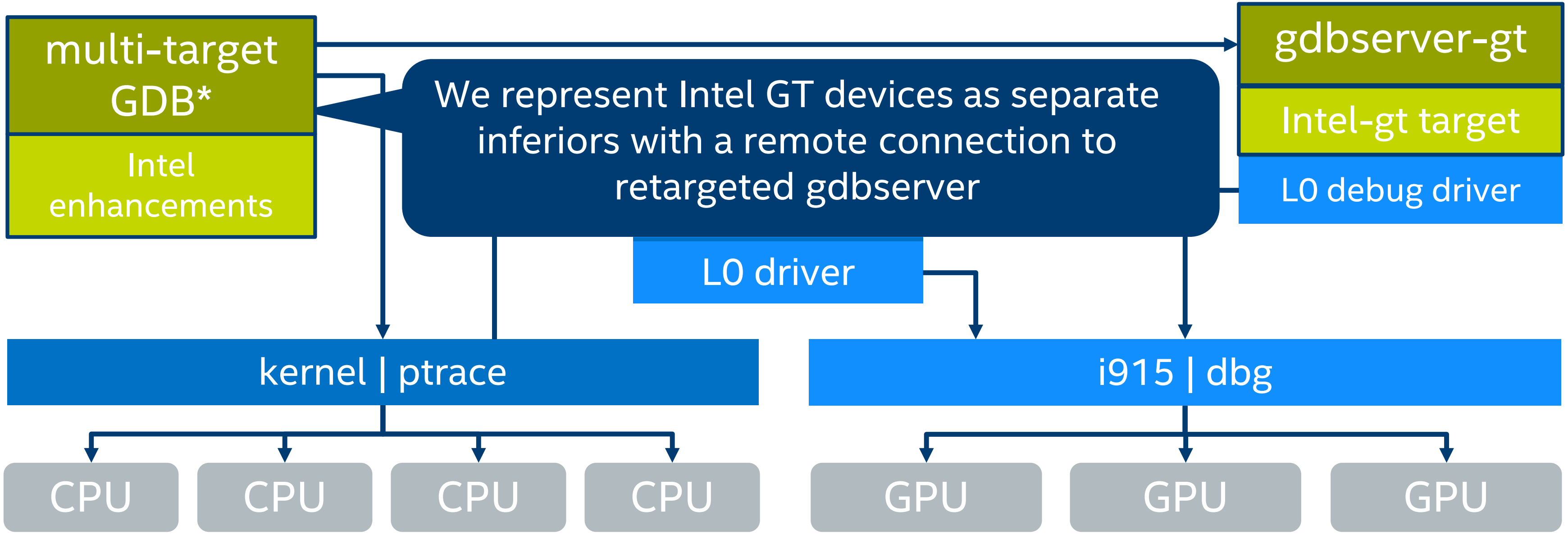

We represent Intel GT devices as separate inferiors with a remote connection to retargeted gdbserver

Legend: Intel | 3rd party | Hardware

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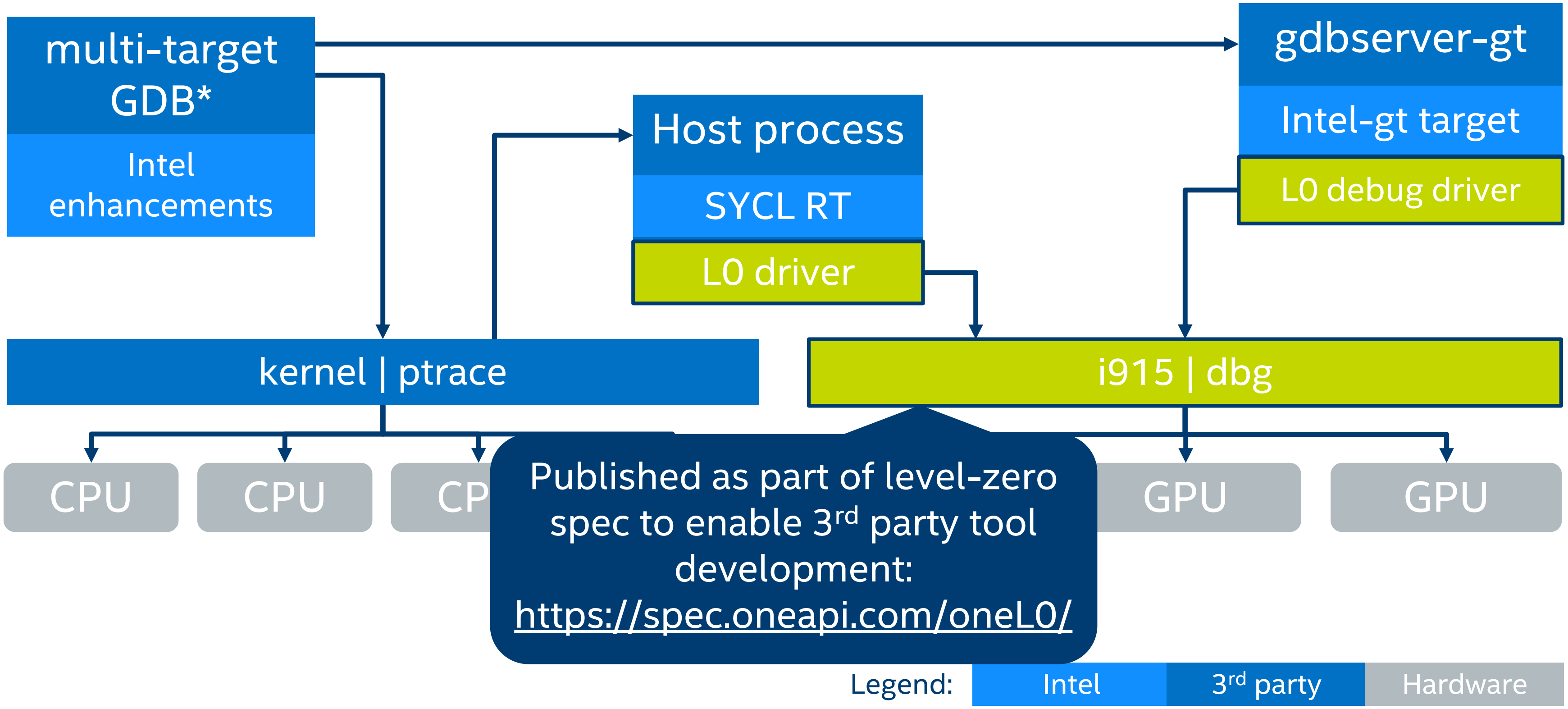

Published as part of level-zero spec to enable 3rd party tool development: https://spec.oneapi.com/oneL0/

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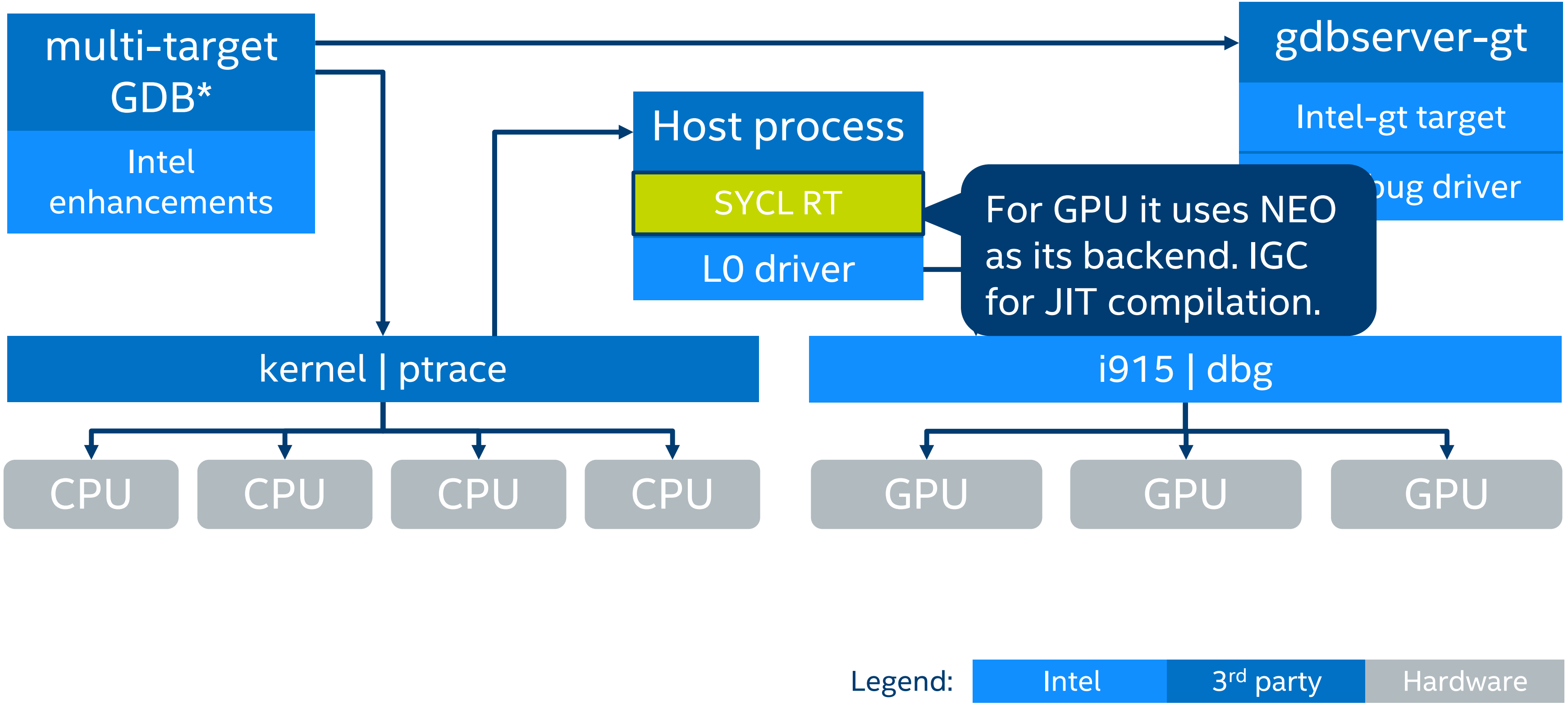

DEMO

Demo: sample kernel

```
#include <CL/sycl.hpp>
using namespace cl::sycl;

void compute(int input[], int output[]) {
  queue device_queue; // picks default device
  range<1> range{64};
  buffer<int, 1> buffer_in{input, range};
  buffer<int, 1> buffer_out{output, range};

  device_queue.submit([&](handler& cgh) {
    auto in = buffer_in.get_access<access::mode::read>(cgh);
    auto out = buffer_out.get_access<access::mode::write>(cgh);

    cgh.parallel_for<class kernel>(range, [=](id<1> index) {
      int element = in[index];
      if (index % 2 == 0)
        element = element + 1000; // then-branch (line #17)
      else
        element = -1;             // else-branch (line #19)
      out[index] = element;
    });
  });
}
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    });
  });
}
```

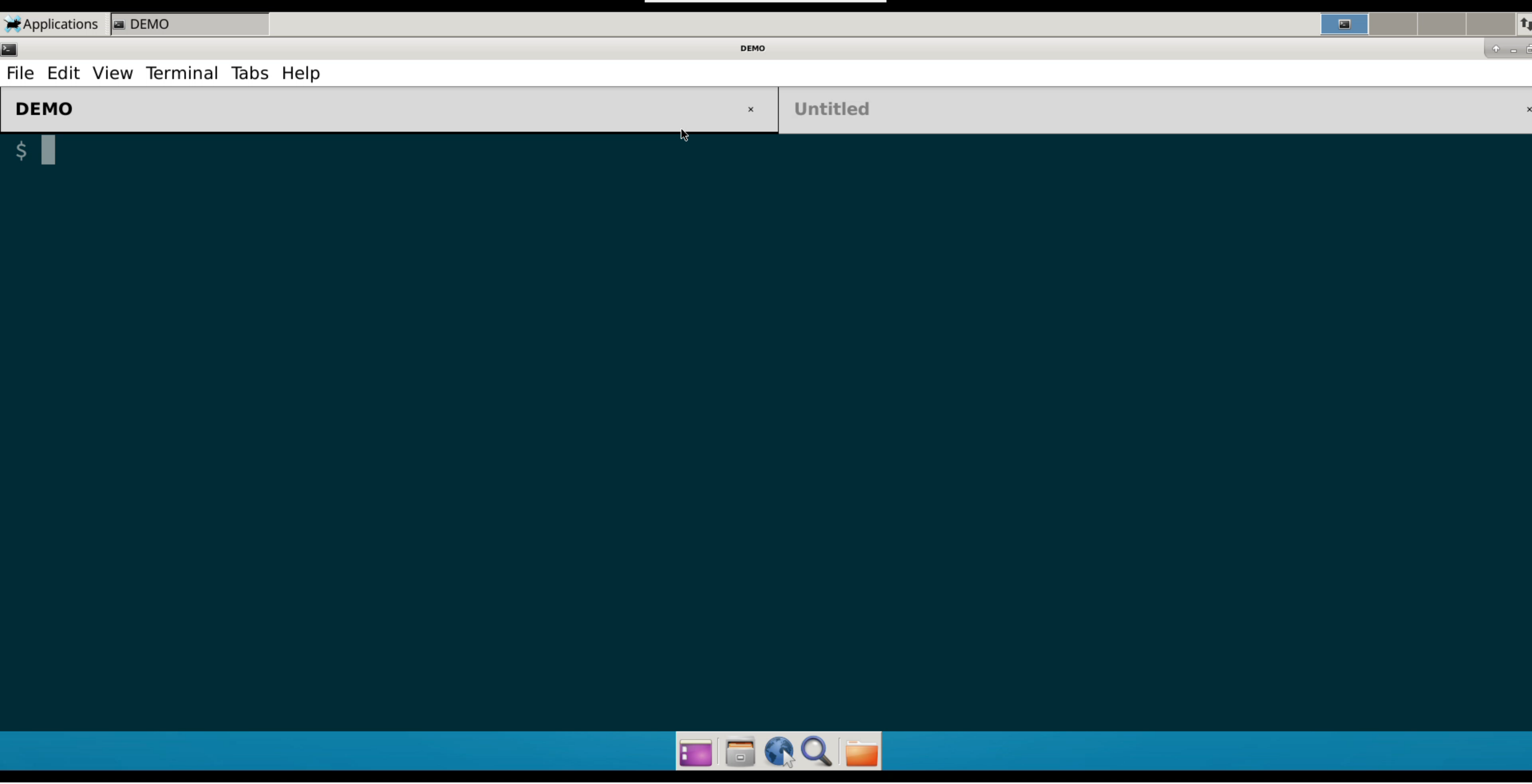
Demo: main function

```
int main() {
  int input[64];
  int output[64];

  // Initialize the input
  for (unsigned int i = 0; i < 64; i++)
    input[i] = i + 100;

  compute(input, output);

  return 0; // end of main (line #35)
}
```


Applications
DEMO
DEMO
File
Edit
View
Terminal
Tabs
Help
DEMO
Untitled

```
$ 
```

Challenges

✓ Implicit Pass-By-Reference Arguments

✓ C++ Functions with Template Parameters

C++ language

✓ Thread View with SIMD Lanes

○ Modeling Device Threads

○ Conditional Breakpoints

GPU

C++ challenges: pass-by-value arguments

- GDB was not able to detect implicit pass-by-reference arguments

In `cl::sycl::accessor` class:

```
dataT &operator[](id<dimensions> index) const;
dataT operator[](id<dimensions> index) const;
```

```
(gdb) print in[index]
```

`id<dimensions>` is trivially copyable, true pass-by-value

✓We presented the solution and fixed the function call mechanism in GDB

✓We requested an addendum to the OpenCL Debug Information Spec:
`FlagTypePassByValue` and `FlagTypePassByReference`

C++ challenges: functions with template parameters

- SYCL specification relies on templated C++ classes and functions
- If not used in the source code, the compiler does not emit the symbol
- Debugger does not know how templates are instantiated

```
(gdb) print index + 5
Could not find operator+.
```

- Debugger cannot infer to which instance refers the expression `f(5)`:

  `f<int>(5)` or `f<char>(5)`

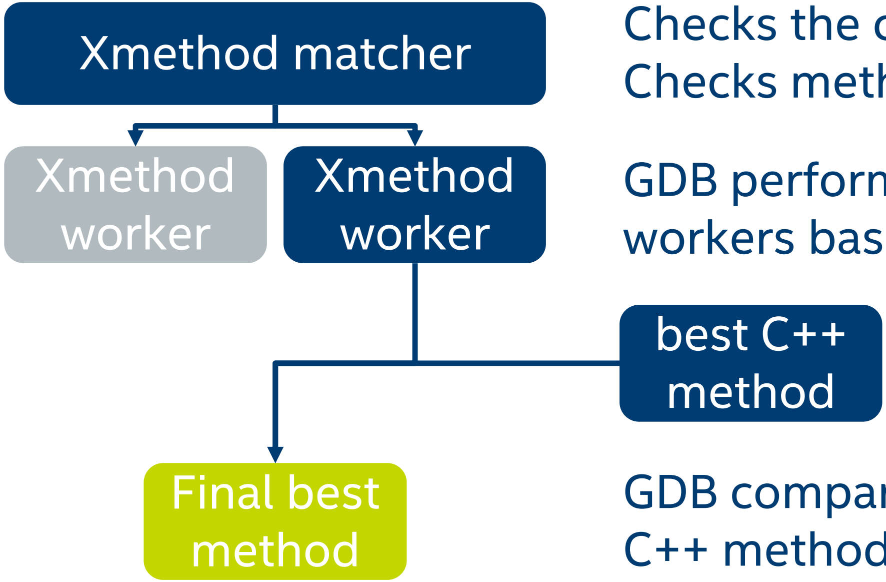
✓ Our mitigation: Xmethods for critical SYCL operators

✓ That allows us to simulate some inferior calls on GPU, where all functions are inlined, and inferior calls are not supported

GDB Python API: Xmethods feature

Additional methods or replacements for existing methods of a C++ class.
Useful when a method is unavailable to GDB (e.g. optimized or inlined).

[https://sourceware.org/gdb/onlinedocs/gdb/Xmethods-In-Python.html]



Checks the class: `cl::sycl::accessor<.+>`
Checks method name: `operator[]`

GDB performs overload resolution among workers based on their argument lists

GDB looks for the best match among available C++ methods

GDB compares the best Xmethod with the best C++ method. When a tie – Xmethod wins.

GPU challenges: threads view with SIMD lanes

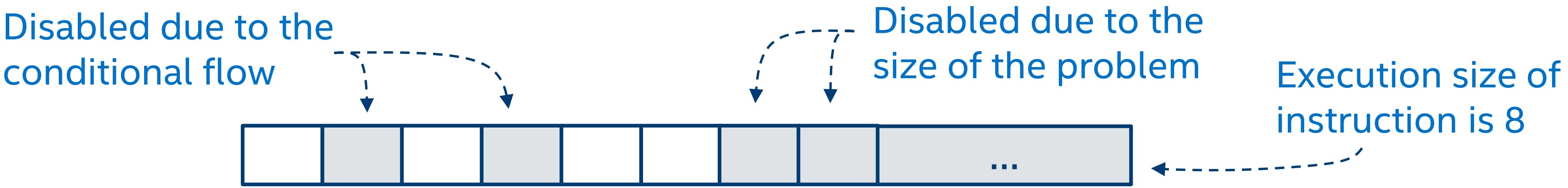
- SYCL programs are written with a focus to a single data element
- An Intel GT thread processes several work items at once (Single Instruction Multiple Data)

Problem: provide a user with means to debug a single SIMD lane

✓ We extended GDB to support SIMD debugging:

- Added a current lane field to the thread representation
- `info threads, thread, thread apply, break, commands`
- Condition of a breakpoint is checked for all enabled SIMD lanes

Overview of SIMD lanes support


Disabled due to the conditional flow
Disabled due to the size of the problem
Execution size of instruction is 8
...

- We display only enabled SIMD lanes
- 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
- IGC support required

A thread might switch between different kernels with different SIMD widths

GPU unresolved challenges: modelling threads

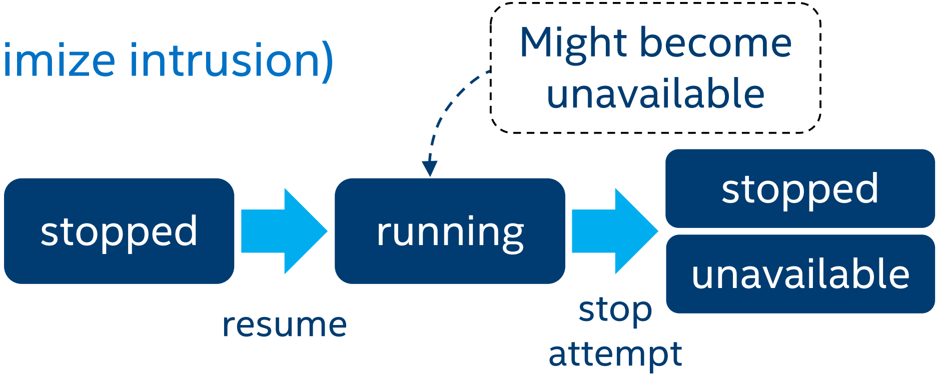
- HW dispatches available threads to active kernels:
  - HW thread can switch between different kernels or become idle

Current state

- The debugger knows only about threads that report an event
- We stop a kernel at initial breakpoint (BP) to place user-defined BPs

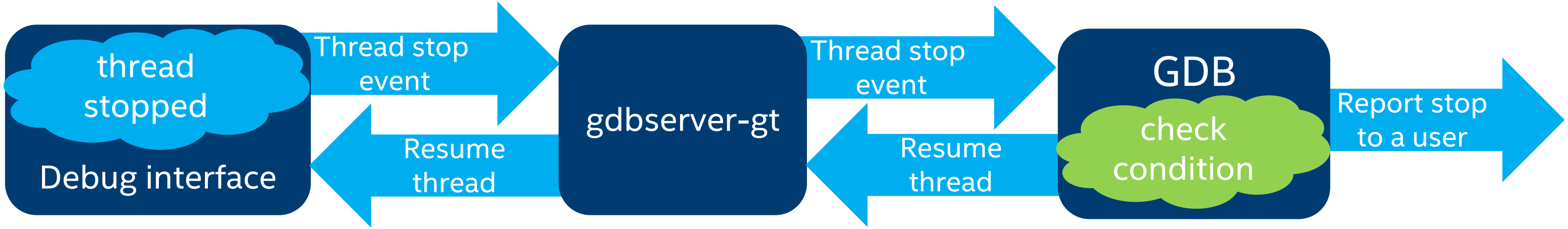
Different model under evaluation (minimize intrusion)

- New thread state: unavailable
- Place BPs when kernel gets loaded
- No thread entry/exit events



GPU unresolved challenges: conditional BPs

```
(gdb) break source.cpp:35 if id == 5
```



Scalability concerns: handshaking between GDB, gdbserver, and debug interface

Goal: move condition evaluation closer to device

- Evaluate the condition in gdbserver-gt
- Generate device code for the condition evaluation and inject to the kernel code
- For a specific class of conditions, we can evaluate the condition in the system routine

E.g. breakpoint on a specific work item

Summary

- Debug offloaded kernels on Linux* and Windows*, for GPU, CPU, FPGA (emu)
- Thread SIMD view
- GDB*
  - Fixed C++ function calls with call-by-value parameters
  - Used XMethods to replace calls to known SYCL template functions
- Scalability is expected to be a major challenge

Thank you!

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