STMicroelectronics
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University of Grenoble

Supporting Parallel Component Debugging in Embedded Systems Using GDB Python Interfaces.

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GNU Tools Cauldron 2012, July 9^{th}-11^{th}

Context

Embedded System Development

- High-resolution multimedia app. ⇒ high performance expectations.
  - H.265 HEVC
  - augmented reality,
  - ...
- Sharp time-to-market constraints

⇒ Important demand for
  - powerful parallel architectures
    - MultiProcessor on Chip (MPSoC)
  - convenient programming methodologies
    - Component-Based Software Engineering
  - efficient verification and validation tools
    - Our problematic

Context

MultiProcessor on Chip (MPSoC)

- Parallel architecture
  - more difficult to program
- Maybe heterogeneous
  - hardware accelerators,
  - GPU-like accelerators (OS-less)
- Embedded system
  - constrained environment,
  - on-board debugging complicated
    → performance debugging only
  - limited-scale functional debugging on simulators

Context

Component-Based Software Engineering

- Focus on design of independent building blocks
- Applications built with interconnected components
- Allows the adaptation of the application architecture according to runtime constraints
- Runnable components able to exploit MPSoC parallelism

Agenda

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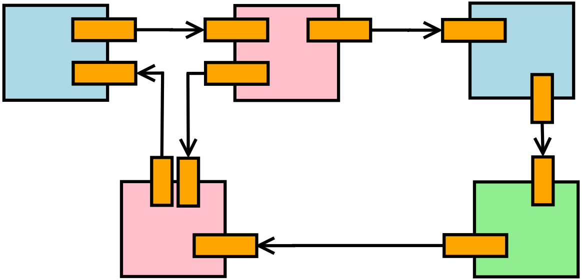
1. Component Debugging Challenges
2. Component-Aware Interactive Debugging
3. Feature Details
4. Python Implementation
5. Conclusion

Component Debugging Challenges

Component-based applications are dynamic

- various set of components deployed during the execution
- components are dynamically inter-connected



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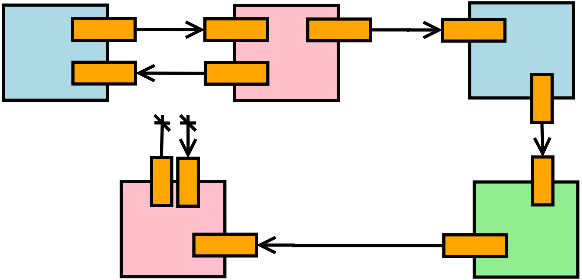

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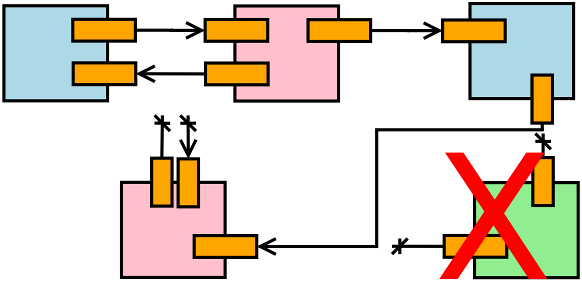

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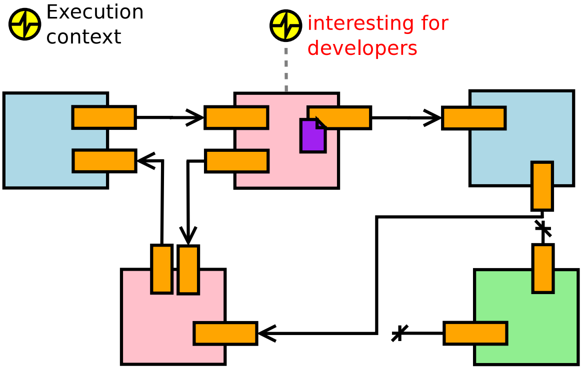

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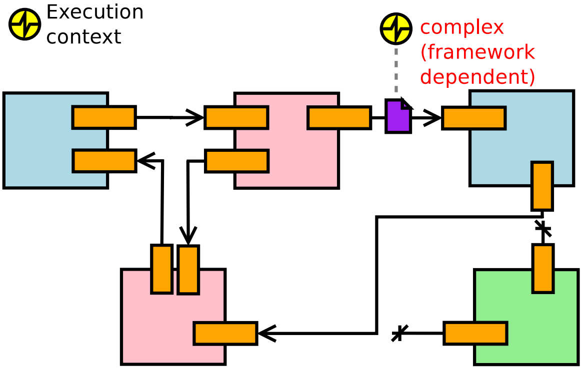

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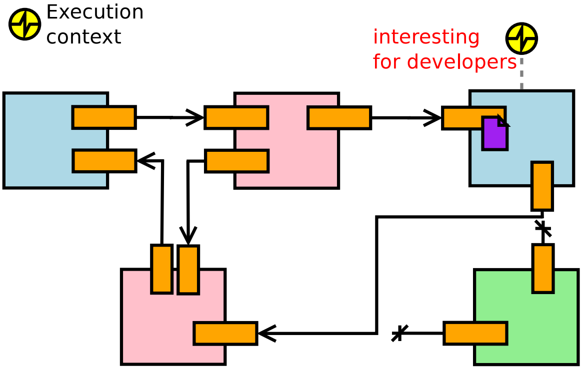

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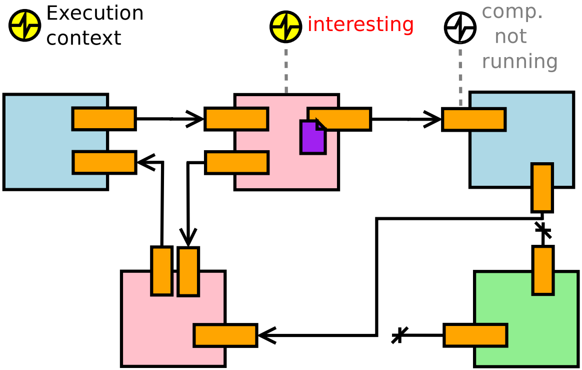

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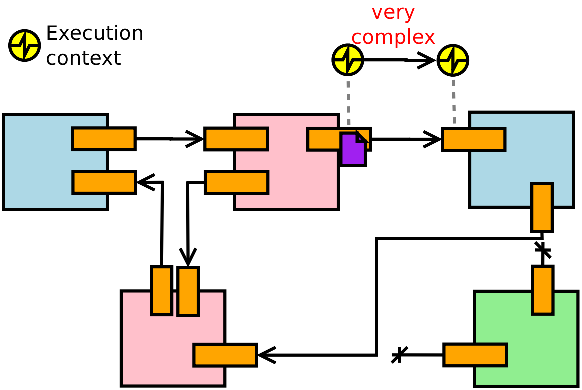

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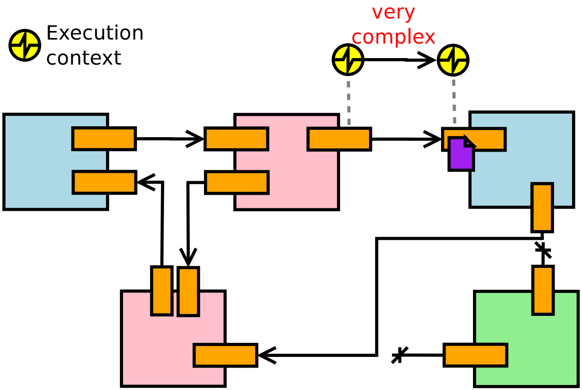

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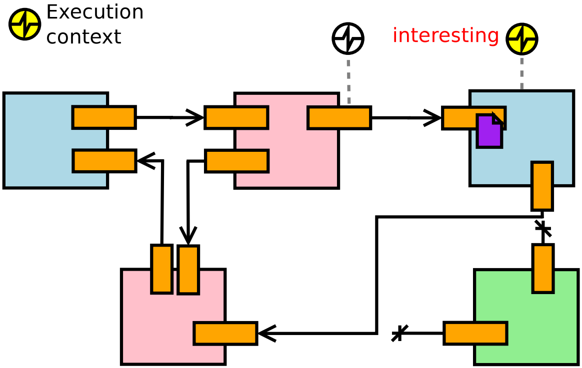
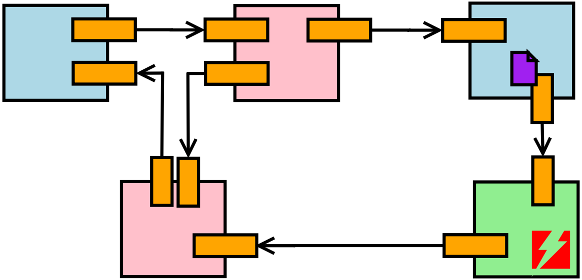


Component Debugging Challenges

Information flows over the components

- a corrupted data may be carried over various component before triggering a visible error



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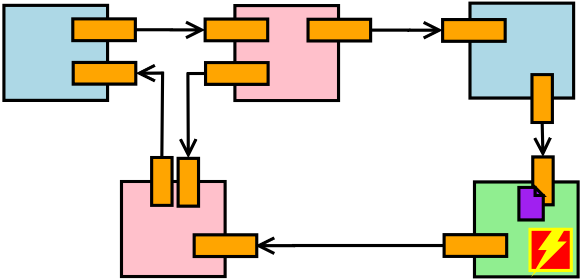

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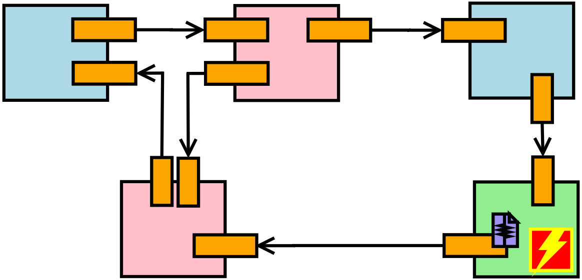

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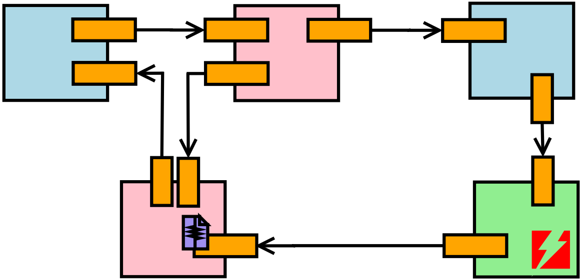

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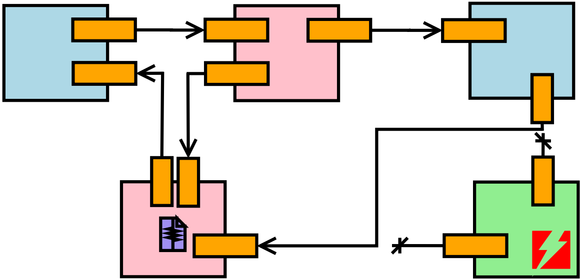

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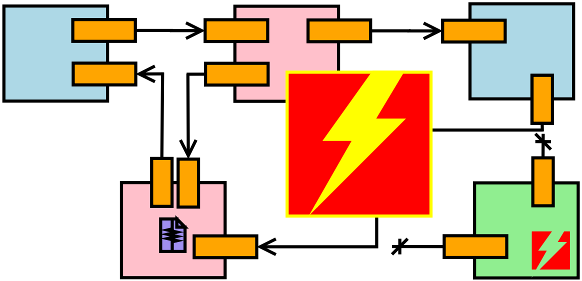

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  - component deployment
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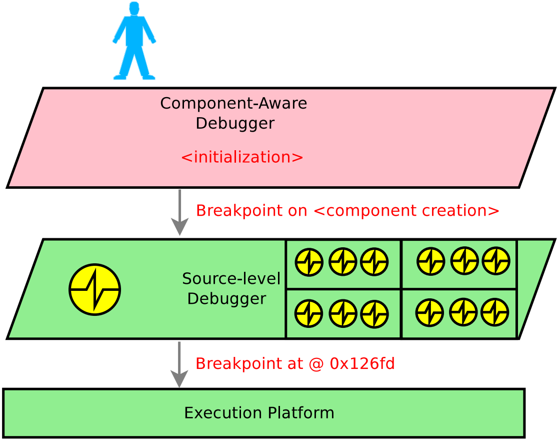
- Follow the execution flow(s) over the component graph
  - runnable component execution,
  - execution triggered by an interface call
  - ...
- Track inter-component data exchanges
  - message route history,
  - message- or interface-based breakpoints
  - ...

Component-Aware Interactive Debugging

Implementation

⇒ Detect and interpret key events in the component framework



→ Interface binding Execution context Interface Component

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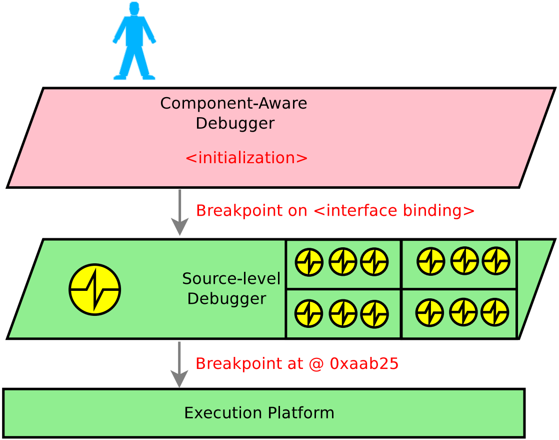

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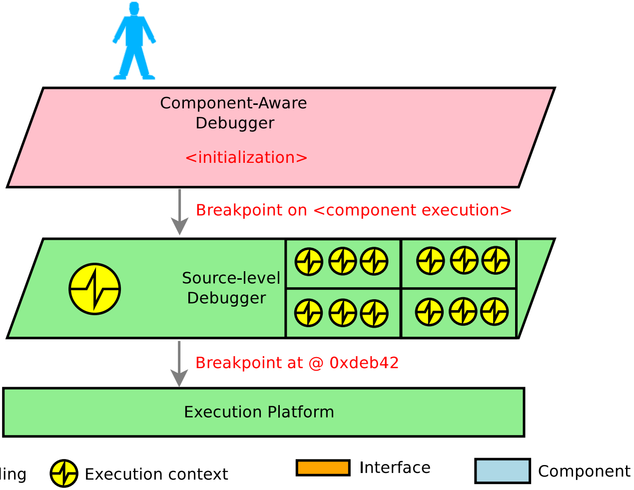

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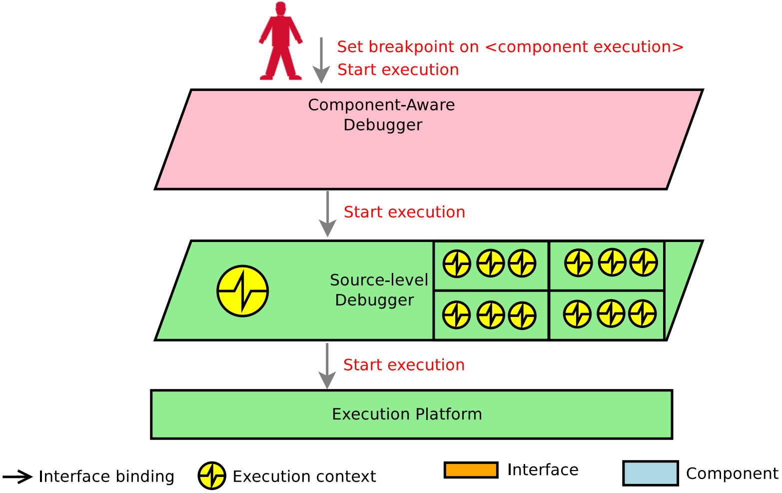

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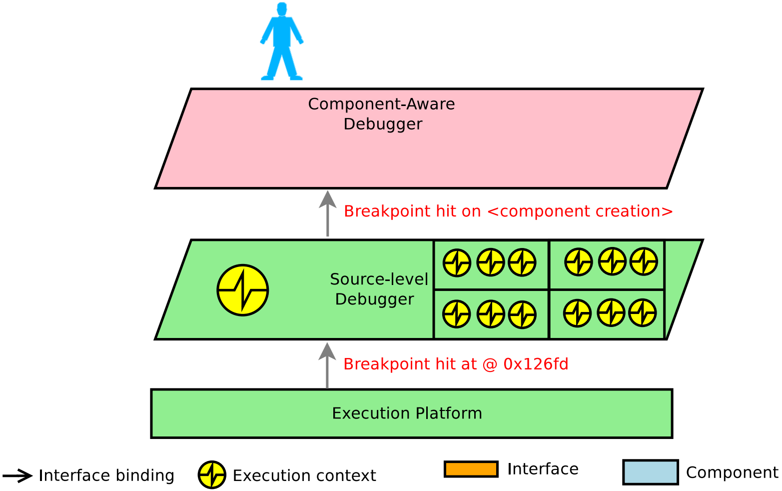

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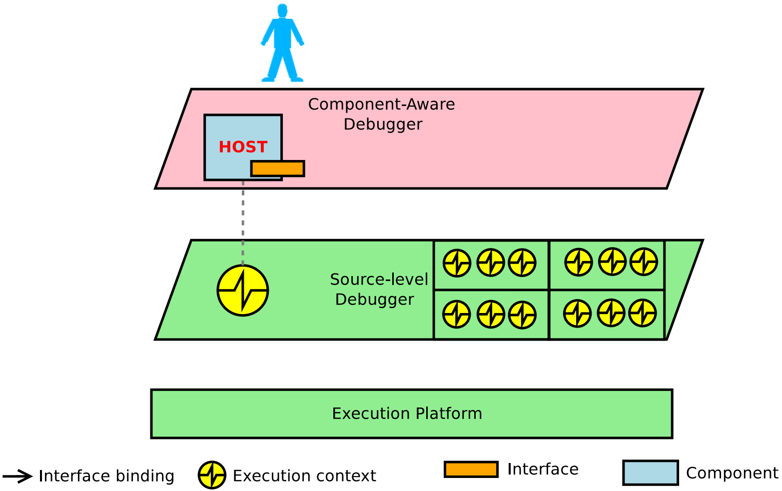

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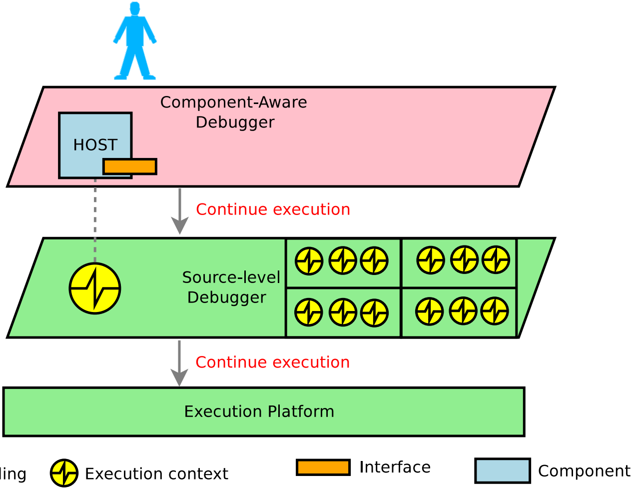

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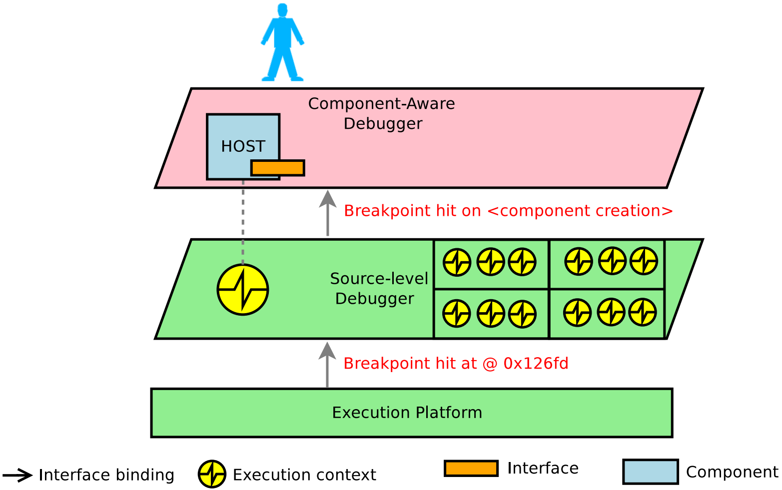

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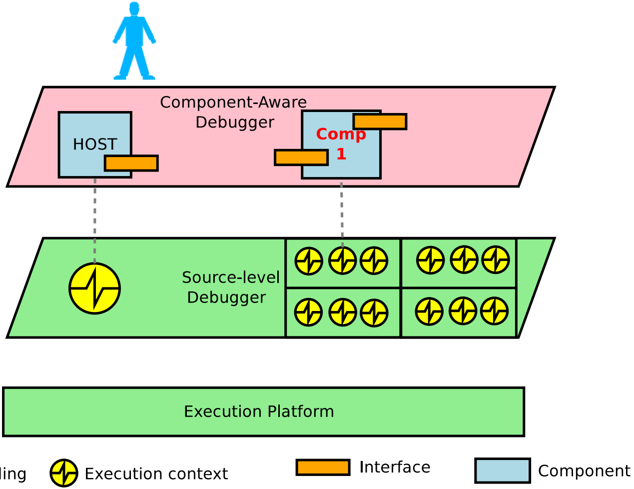

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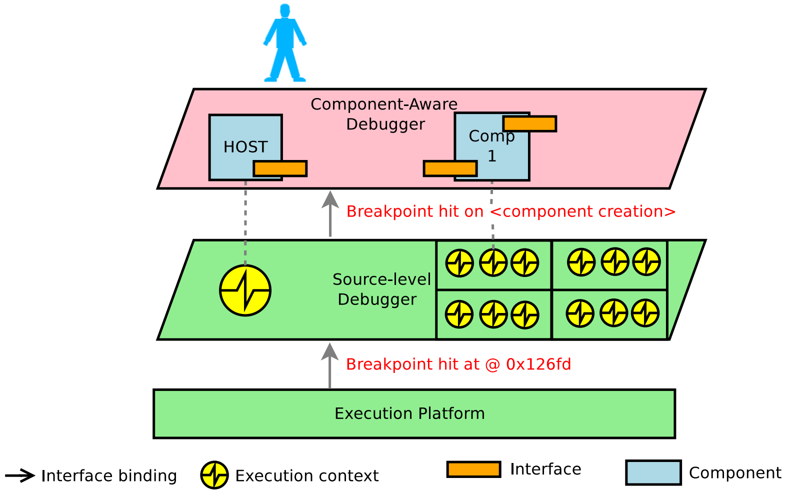

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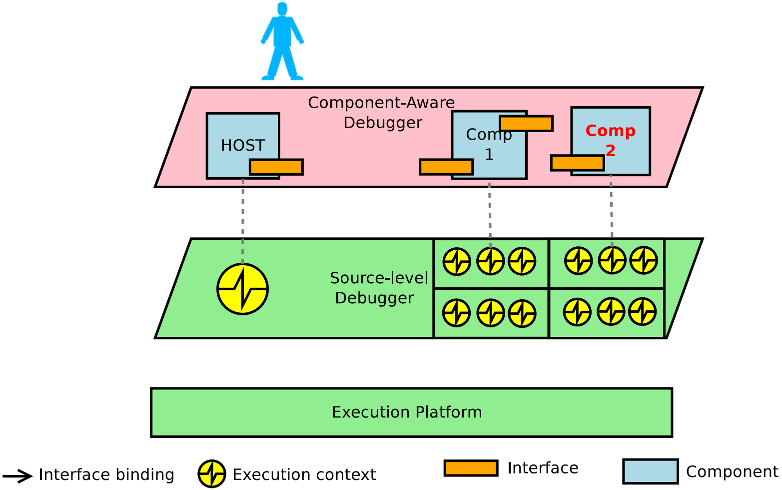

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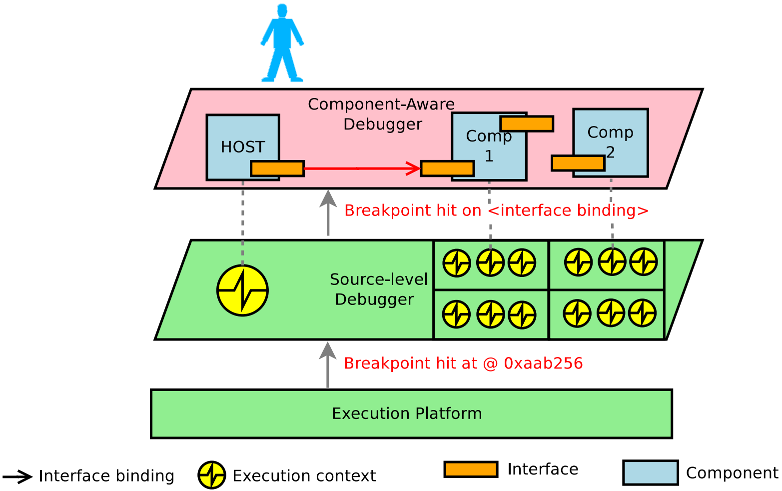

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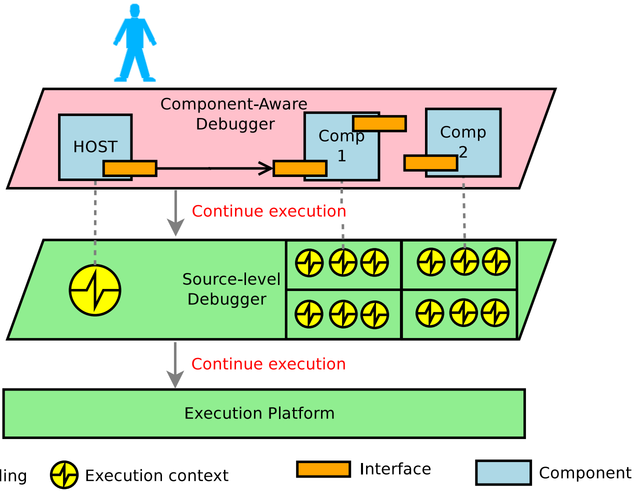

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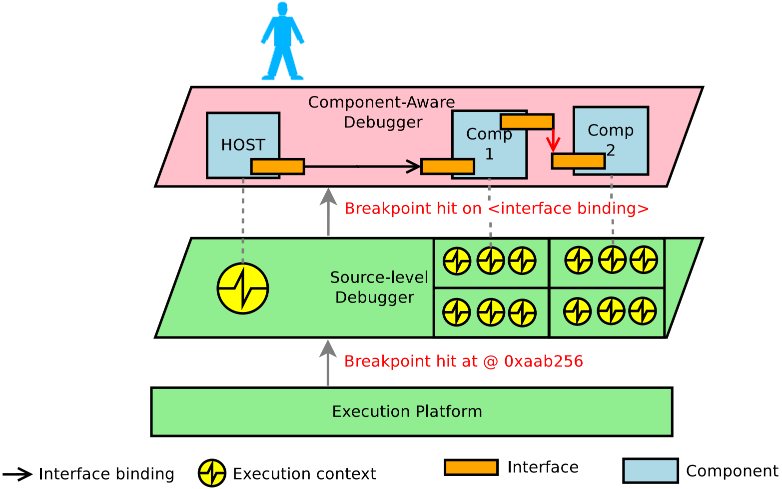

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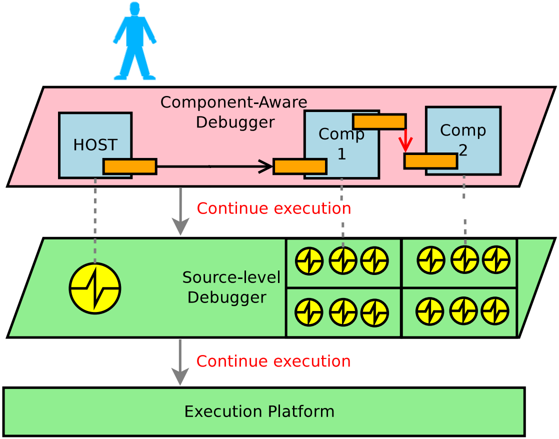

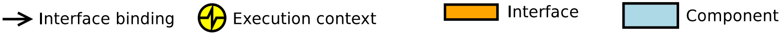

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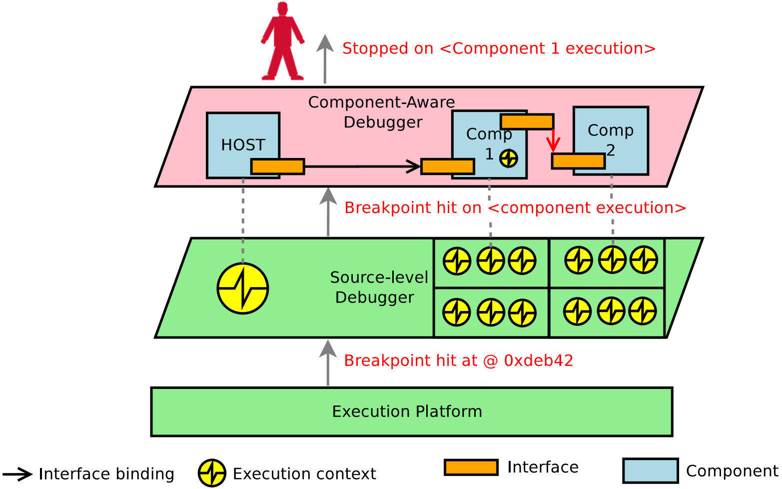

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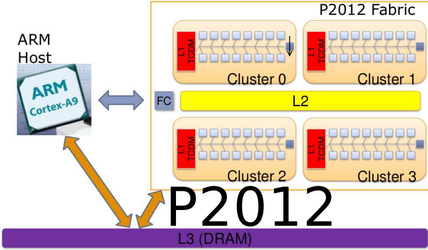
Feature Details

Proof-of-concept environment

Platform 2012

ST MPSoC research platform

- Heterogeneous
- 4x16 CPU OS-less comp. fabric



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- Provides communication components and interface

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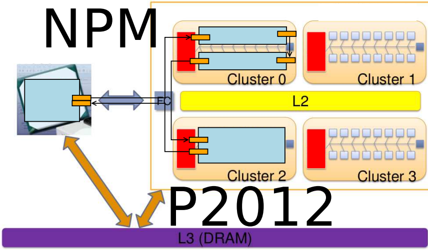

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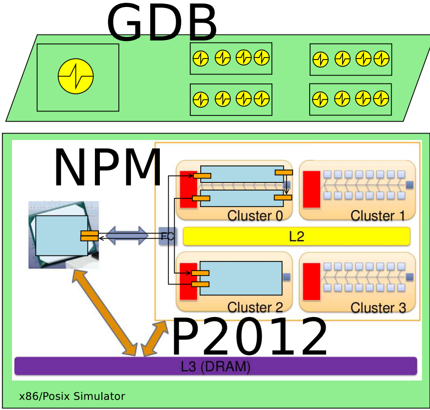

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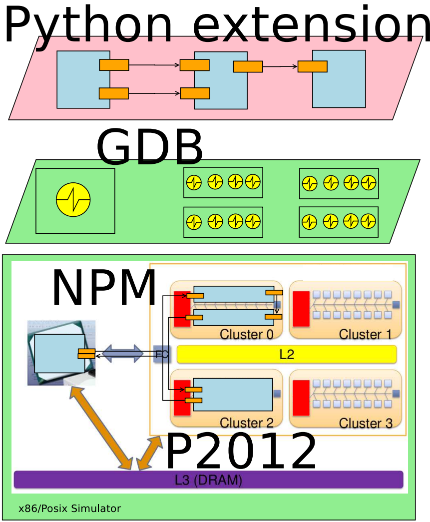
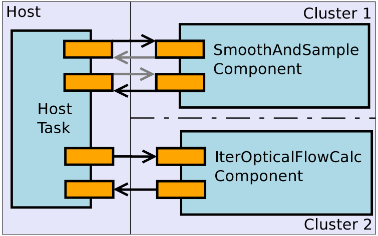


Feature Details

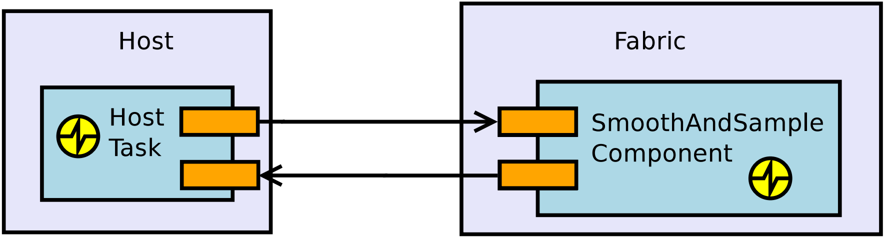
Case study: Debugging a Pyramidal Feature Tracker

- part of an augmented reality application
- analyzes video frames to track interesting features motion



Case study: Debugging a Pyramidal Feature Tracker

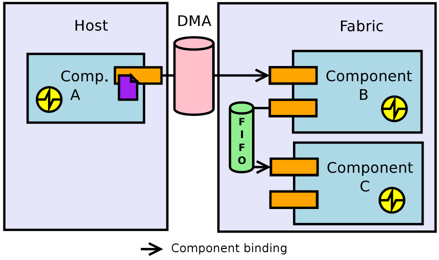
List components and their interfaces




```
 (gdb) info component +connections
  #1 Host[31272]
       DMAPush/0x...  <DMA> srcPullBuffer Component...  #2
       DMAPull/0x...  <DMA> dstPushBuffer Component...  #2
* #2 Component[SmoothAndSampleProcessor.so]
       srcPullBuffer <DMA> DMAPush/0x...  Host[31272]
       dstPullBuffer <DMA> DMAPull/0x...  Host[31272]
```

Case study: Debugging a Pyramidal Feature Tracker

Information about messages

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Message 1:
Component A # Message created
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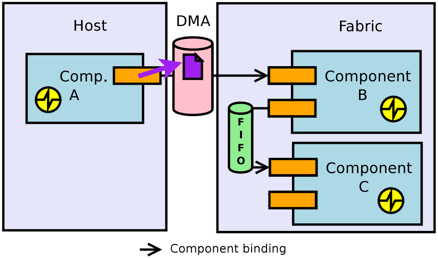

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Component A # Message created
Component A::Interface A.1 # Message sent

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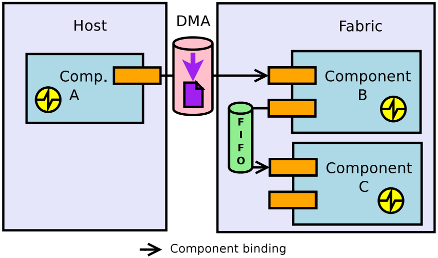


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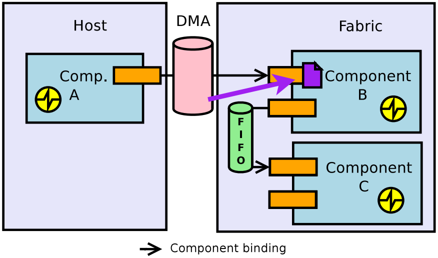


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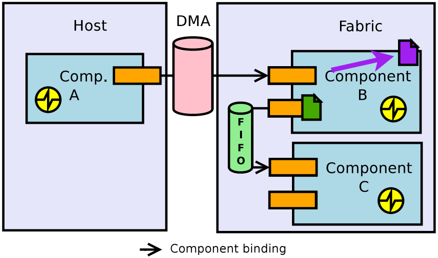


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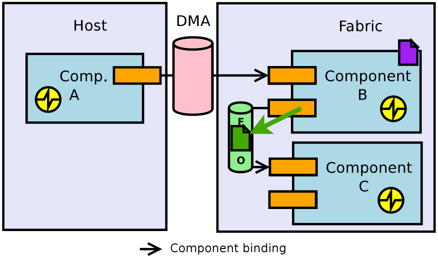


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Message 1:
Component A # Message created
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Message 2:
Component B # Message created
Component B::Interface B.2 # Message sent
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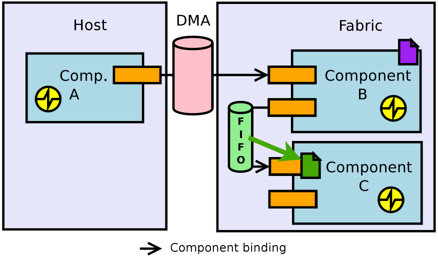

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Component B # Message created
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Component C::Interface C.1 # Message received

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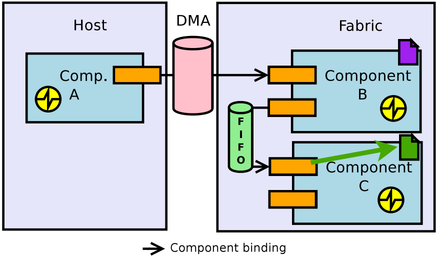


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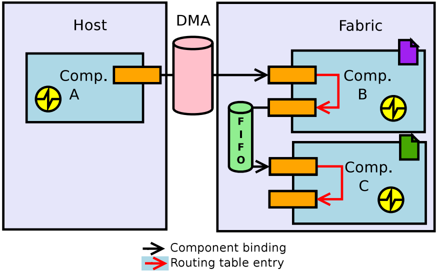

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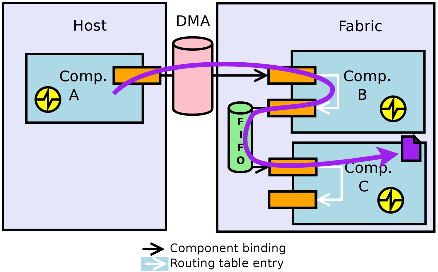

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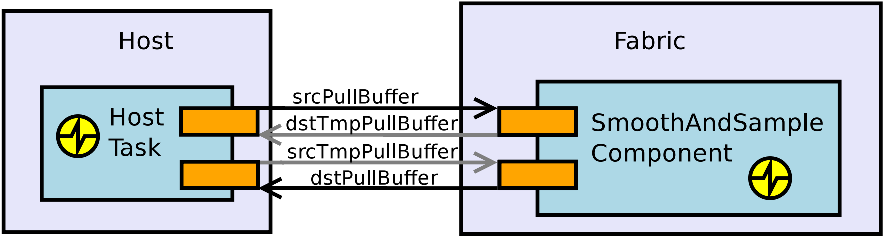
Case study: Debugging a Pyramidal Feature Tracker

Information about interface activity




```
(gdb) info components +counts
#2 CommComponent[SmoothAndSampleProcessor.so]
    srcPullBuffer #35 msgs
    dstTmpPushBuffer #36 msgs
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```

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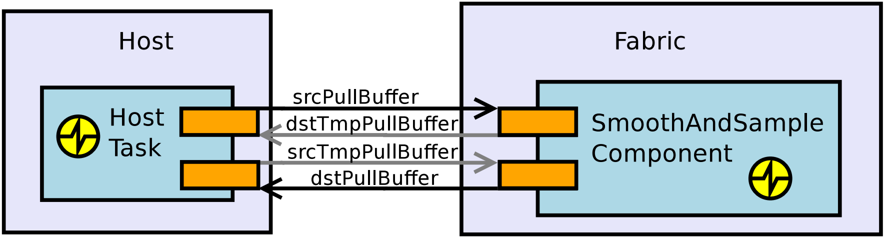


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```

- allowed us to find a bug in the application (msg sent to the wrong interface)

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Information about interface activity

Excerpt from a 300 lines-of-code file

```
/* Compute last lines if necessary */
if (tmp_size > 0) {
    ...
    /* Transmit the last lines computed */
    CALL(srcTmpPullBuffer, release)(...);
    CALL(dstTmpPushBuffer, push)(...);
}
```

Agenda

Python Implementation

Detect and **Interpret Key Events** in the Component Framework

Python Implementation

Detect and Interpret Key Events in the Component Framework

Detect

- Internal breakpoints
  - no apparent execution stop
  - no screen notification

→ Python notification for framework events

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Key Events

- New components, new binding
- Component execution trigger
- Message created, sent, received, . . .

Python Implementation

Detect and Interpret Key Events in the Component Framework

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Key Events

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Interpret

- Debug information (DWARF)
- API + Calling conventions

→ (almost[1]) everything we need

[1] some implementation-dependent bits still remain ...

Python Implementation

Debug Toolbox

Function breakpoints

Internal breakpoints triggered at the execution of a function

⇒ catch input, updated and output parameters

- `stop, do_after, data = prepare_before(self)`
- `stop = prepare_after(self, data)`

Python Implementation

Debug Toolbox

Function breakpoints

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- `stop, do_after, data = prepare_before(self)`
- `stop = prepare_after(self, data)`
  - ~~`gdb.execute(“finish”)`~~
    “*Thou shalt not alter the execution state of the inferior*”
    (gdbdoc 23,2,2,20)

  → `gdb.FinishBreakpoint` instead

Python Implementation

Debug Toolbox

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```
NPM_instantiateComponent(&cmp1_handle, type1, nb_procs);
NPM_instantiateComponent(&cmp2_handle, type2, nb_procs);

NPM_instantiateFIFOBuffer(&fifo_handle,
                          cmp1_handle, "src_itf",
                          cmp2_handle, "dst_itf");
```

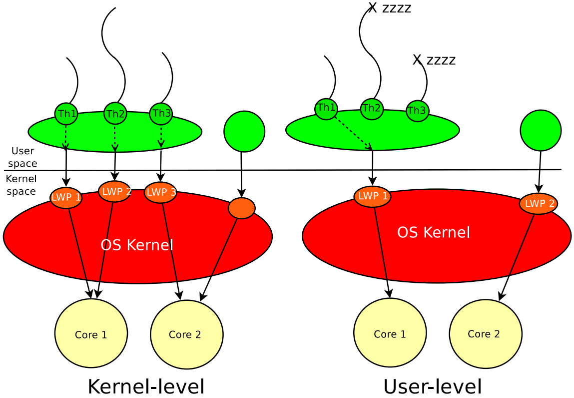
Python Implementation

Debug Toolbox

User-level Multithreading

- threading implemented with `longjmp/setjmp`

→ invisible to GDB



```python
REGISTERS = ("$esp", "$ebp", "$eip")
def save_current_thread():
    return [gdb.parse_and_eval(reg) for reg in REGISTERS]
```

```python
REGISTERS = ("$esp", "$ebp", "$eip")
def save_current_thread():
    return [gdb.parse_and_eval(reg) for reg in REGISTERS]

def switch_inactive_thread(next_):
    jmbuf = next_["context"][0]["__jmpbuf"]
    gdb.execute("set $esp=%s" % jmbuf[JB_SP])
    gdb.execute("set $ebp=%s" % jmbuf[JB_BP])
    gdb.execute("set $eip=__longjmp")
    gdb.execute("flushregs")
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def reload_current_thread(stop_regs):
    for reg_name, reg_val in map(REGISTERS, stop_regs):
        gdb.execute("set %s=%s" % (reg_name, str(reg_val))
```

Python Implementation

Debug Toolbox

User-level Multithreading

```
(gdb) info processors
  #1 Processor DMA 1          // user-level threads
  #2 Processor 1 Cluster 1    // <=> simulated processors
* #3 Processor 2 Cluster 1
  #4 Processor 1 Cluster 2
  ...
(gdb) info components
  #1 Host                     // component not scheduled
* #2 Component A1             // current component
  #3 Component A2
~ #4 Component B1             // component not schedulable
~ #5 Component B2             // <=> no execution context
```

Python Implementation

Debug Toolbox

User-level Multithreading

```
(gdb) component 3
[Switching to sleeping Component A2 #3]
(gdb) where
#0  0x47bb07a0 in __longjmp () from /usr/lib/libc.so.6
#1  0xf7fe3f20 in contextSwitch (old, new)
#2  0xf7fe406d in schedule_next_execution_context ()
#3  0xe7eb7838 in schedNext ()
...
#9  0xdd55e23d in outputBuffer_fetchNextBuffer (...)
#10 0xdd5d26c8 in rtmMaster (...)
#11 0xdd5d307d in thread_main (...)
...
```

Python Implementation

Debug Toolbox

User-level Multithreading

- far from being perfect
- no coordination with GDB `thread` capabilities

- user-level thread debugging is possible with Python

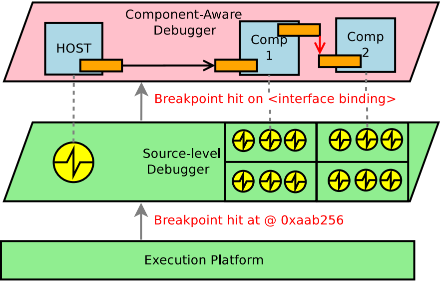
- a `Thread_db` library (e.g., *User-Level Thread_db*[2]) could make it more standard and reliable

[2] *ULDB: a debugging API for user-level thread libraries*, K. Pouget et al, MTAAP 10

Python Implementation

Entity Tracking

On framework function breakpoint:



1. identify operation and parameters
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   - `cmp_py = lookup_table[handle]`

Python Implementation

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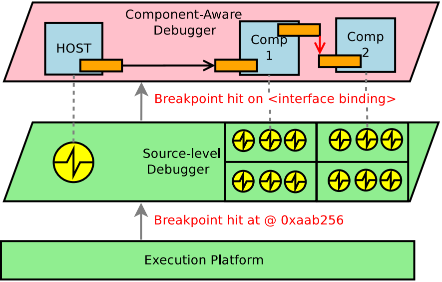

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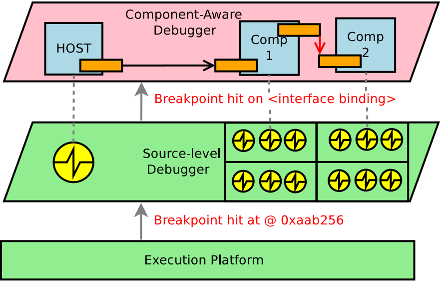

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Python Implementation

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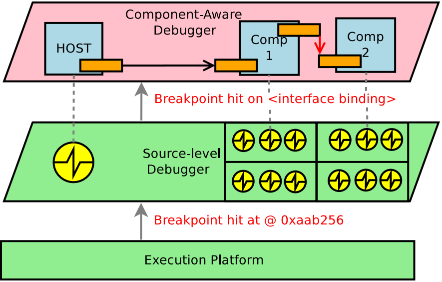

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4. check user breakpoints/catchpoint

Agenda

Conclusion

- Debugging dynamic component application is challenging
- Lack of high level information about components framework

- **Our work:** bring debuggers closer to the component model
  - better understanding application behavior
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- **Proof-of-concept**: GDB and its Python interface
  - interface good enough to build real improvements in Python
  - a few missing bits contributed to the project
    - `gdb.FinishBreakpoint`
    - multiple breakpoint hits
    - `gdb.selected_inferior()`

life.augmented

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- Going further programming-model aware debugging
  - OpenCL
  - Dataflow execution model
  - ...