STMicroelectronics
LIG
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Programming-Model Centric Debugging for Multicore Embedded Systems

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Introduction

Embedded Systems and MPSoC

Consumer Electronics Devices

- 4K digital televisions
- Smartphones
- Hand-held music players

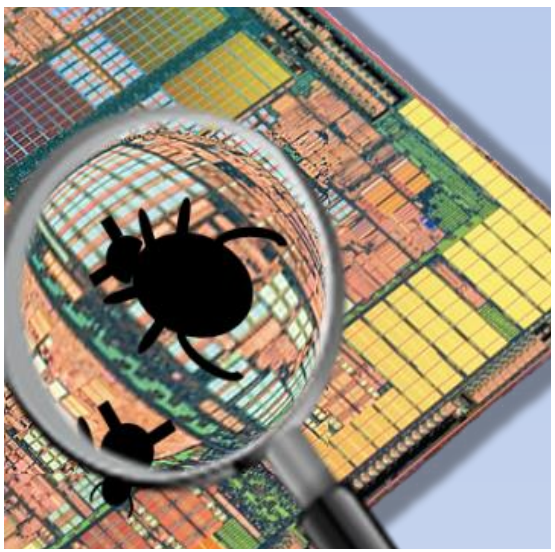
- High-resolution multimedia apps
  - H.265 HEVC
  - Augmented reality
  - 3D video games
  - ...

$\Rightarrow$ high performance expectations.

Introduction

Embedded Systems and MPSoC

Current applications have high performance expectations...



⇒ important demand for:

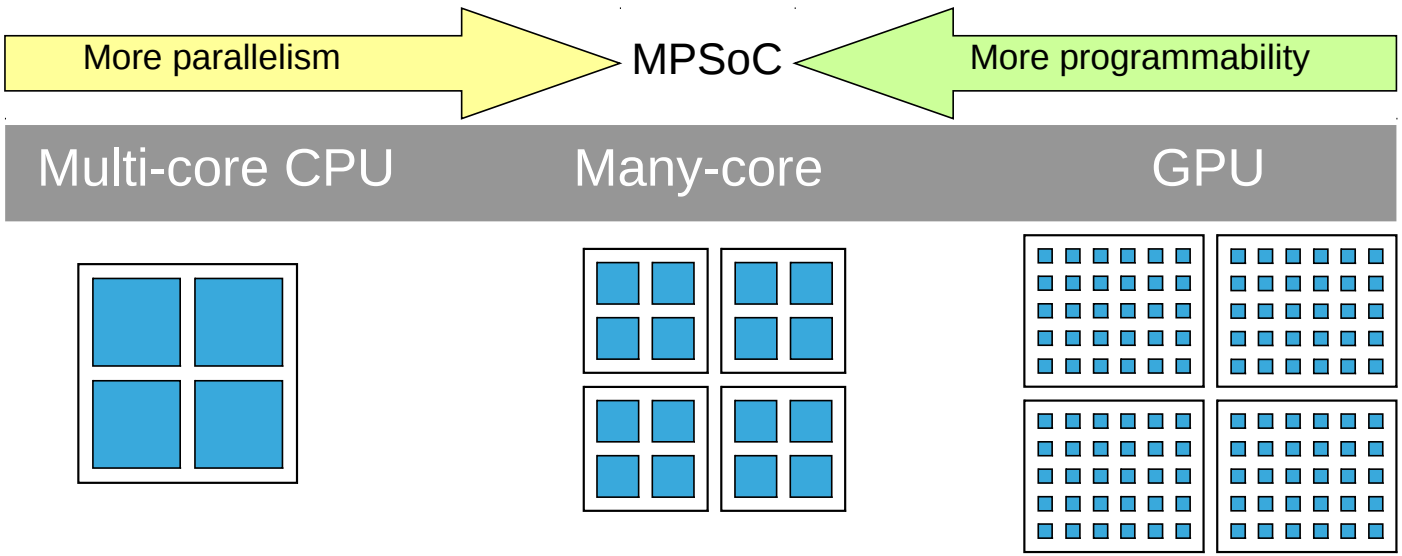
- Powerful parallel architectures
  - MultiProcessor Systems-on-a-Chip (MPSoCs)
- High-level development methodologies
  - Programming models & environments
- Efficient verification & validation tools
  - Workshop and our research effort

Agenda

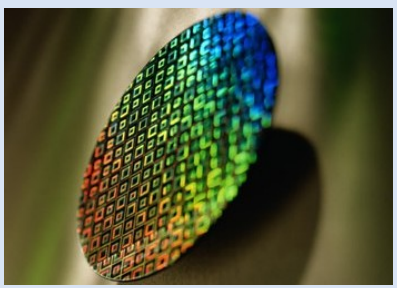
Background: MPSoC Programming and Debugging

MPSoC and GPU Systems

MultiProcessor System on-a-Chip



- *Many-core* processor for embedded systems
- *Heterogeneous* computing power
- Low energy-consumption



How to program such complex architectures?

Background: MPSoC Programming and Debugging

Programming Models and Supportive Environments

... with programming models!

- **Programmability** with high-level abstractions
- **Portability** thanks to an hardware-independent interface
- **Separation of concerns** between application / lower levels

Background: MPSoC Programming and Debugging

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$\rightarrow$ application written on top of an *abstract* machine

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... implemented by supportive environments:
programming frameworks, runtime libraries, APIs

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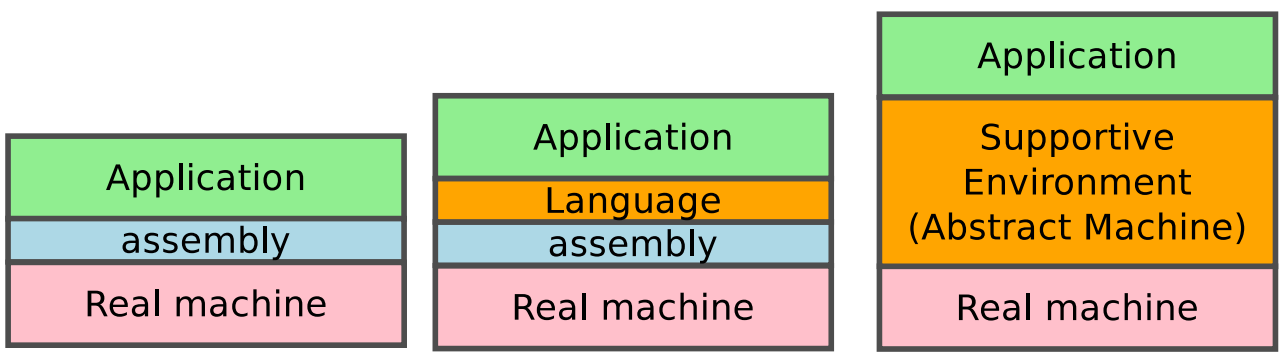


Background: MPSoC Programming and Debugging

Programming Models for ST MPSoCs

Components

Dataflow

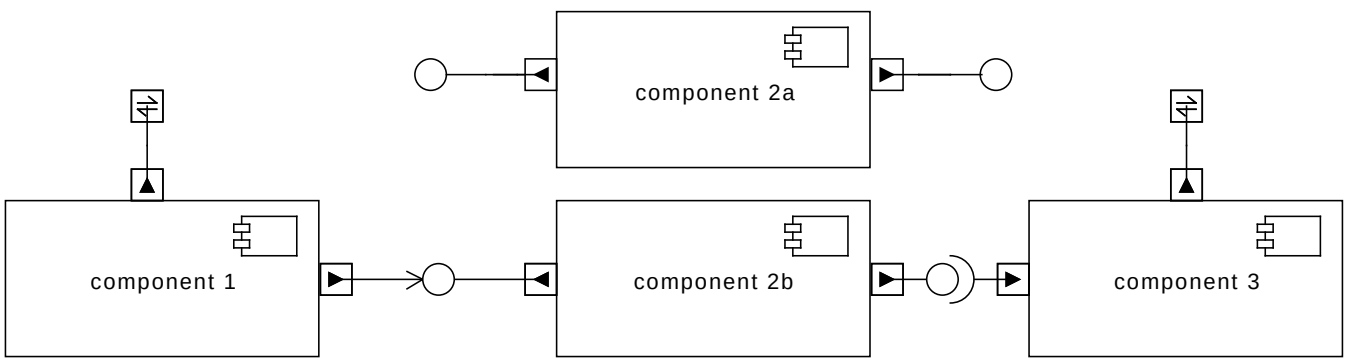
Background: MPSoC Programming and Debugging

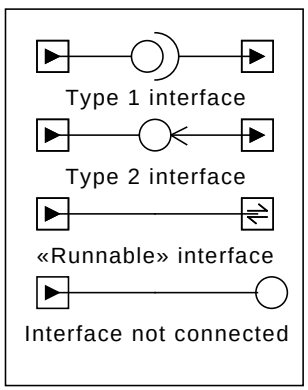
Programming Models for ST MPSoCs

Components

- code/data encapsulation
- lang.-free interfaces

Dataflow





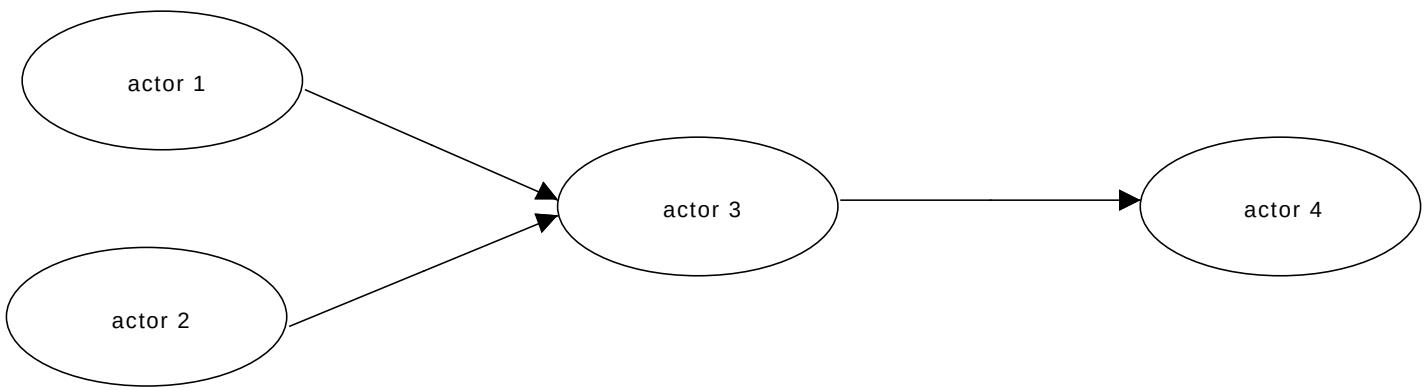
Background: MPSoC Programming and Debugging

Programming Models for ST MPSoCs

Components

Dataflow

- streams of data
- implicit parallelism



Background: MPSoC Programming and Debugging

Programming Models for ST MPSoCs

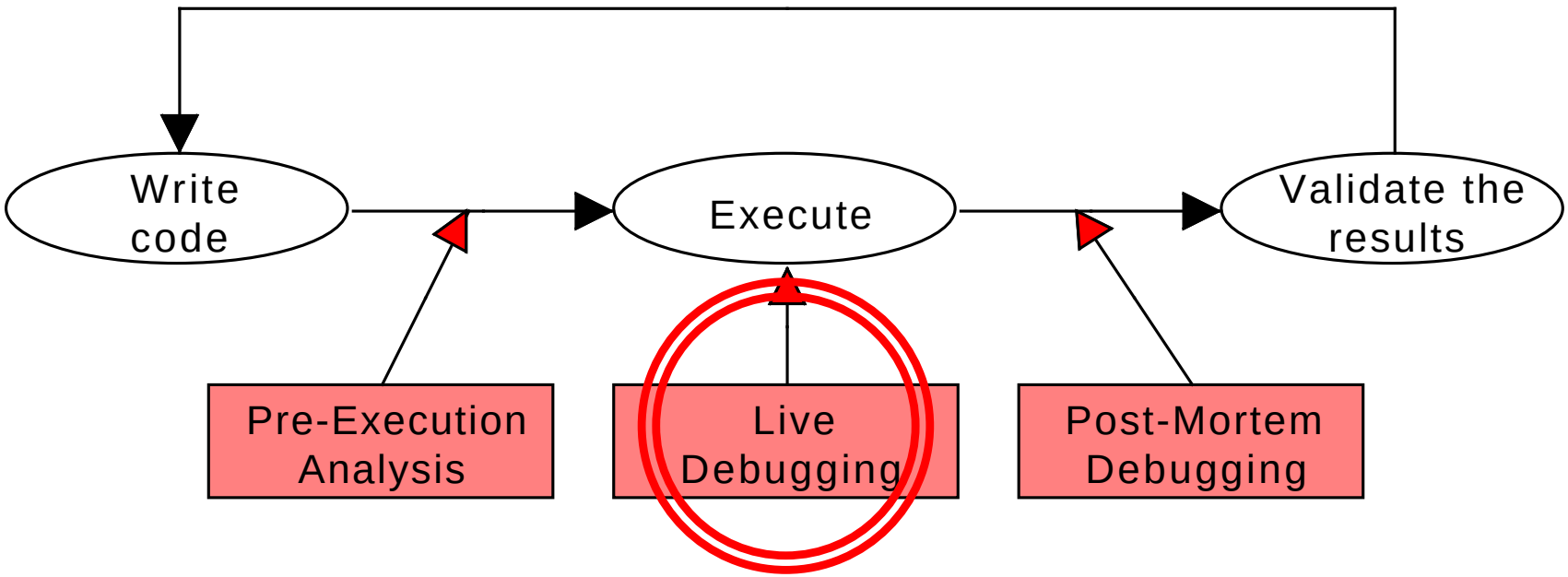
Components	Dataflow
• code/data encapsulation	• streams of data
• lang.-free interfaces	• implicit parallelism

large programming domain coverage...

... but what about Verification & Validation of MPSoC applications?

Background: MPSoC Programming and Debugging

Tools and Techniques, Advantages of Interactive Debugging



Interactive Debugging (eg.: GDB)

- Developers mental representation VS. actual execution
- Understand the different steps of the execution

Background: MPSoC Programming and Debugging

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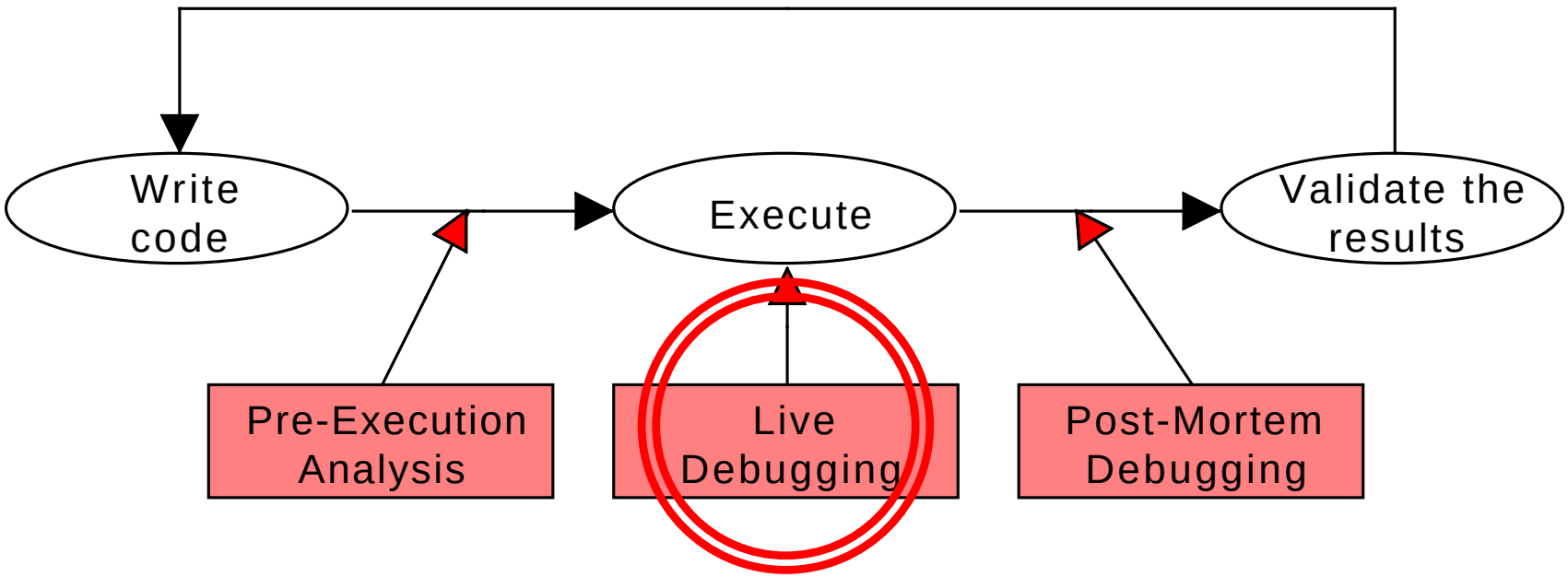


Interactive Debugging (eg.: GDB)

- Developers mental representation VS. actual execution
- Understand the different steps of the execution

... but nothing related to programming models ...

⇒ debuggers cannot access the *abstract* machine!

Background: MPSoC Programming and Debugging

Objective

Provide developers with means to
better understand the state of the high-level applications and control more easily their execution,
suitable for various models and environments.

Agenda

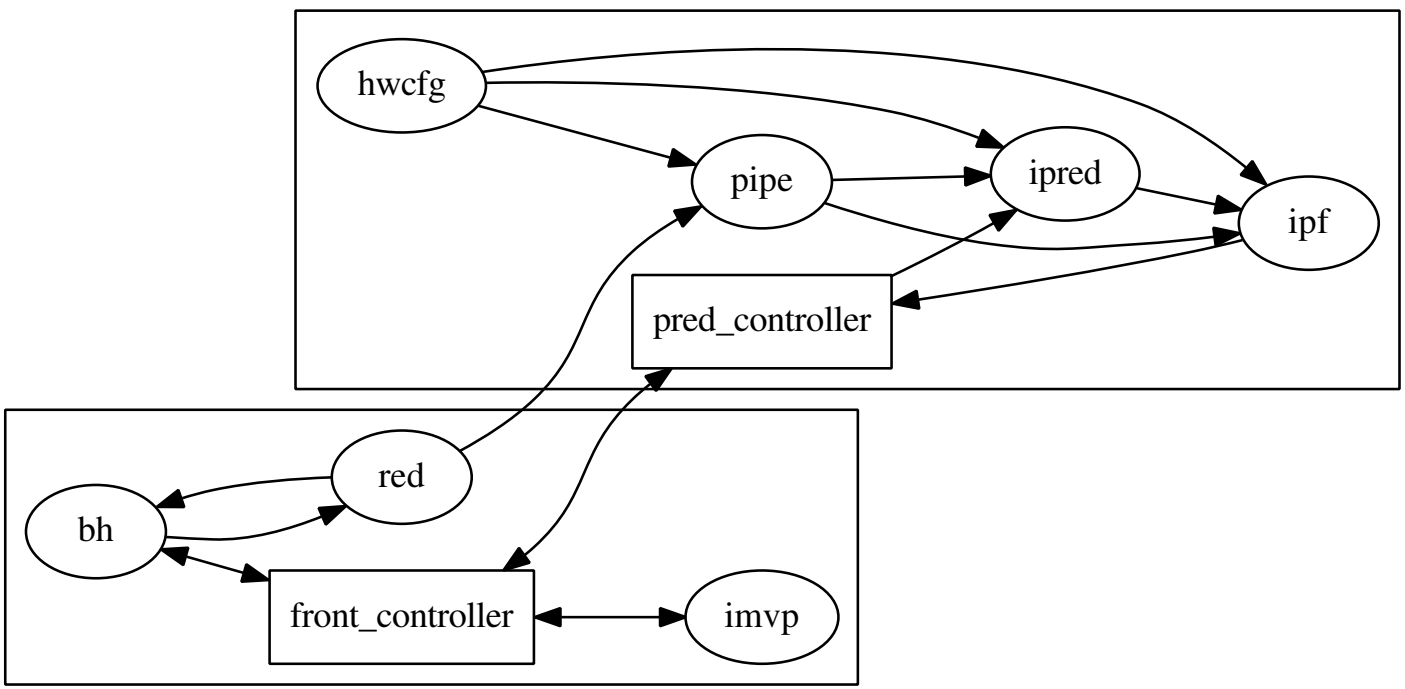
Programming Model Centric Interactive Debugging

Idea: **Integrate programming model concepts in interactive debugging**

Programming Model Centric Interactive Debugging

1 Provide a Structural Representation

- Draw application architecture diagrams
- Represent the relationship between the entities
- Offer catchpoints on architecture-related operations

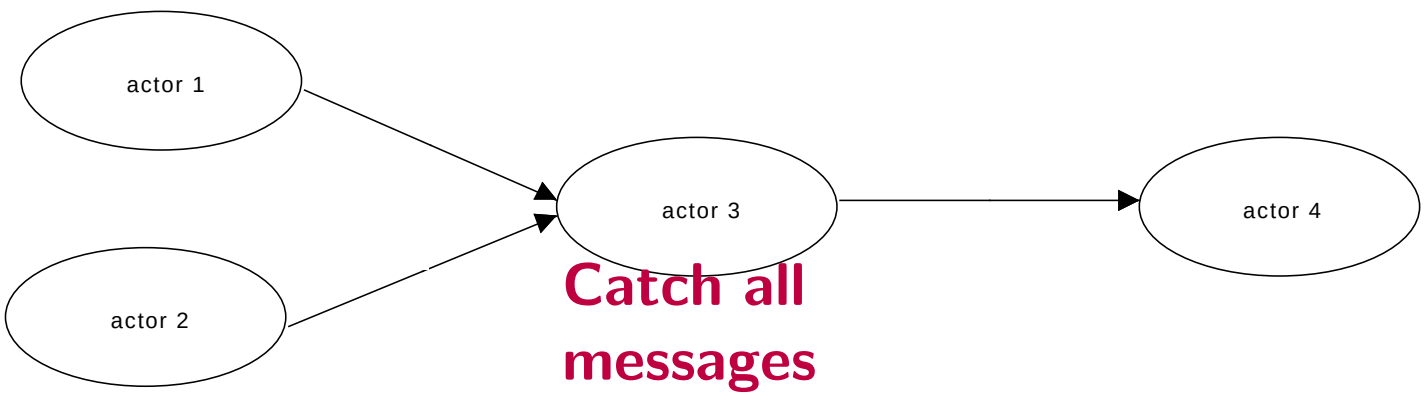


Dataflow graph from the case-study

Programming Model Centric Interactive Debugging

2 Monitor Dynamic Behaviors

- Monitor the collaboration between the tasks
- Detect communication, synchronization events
  - interpret their pattern and semantics (one-to-one, one-to-many, global or local barriers)
- Offer communication-aware catchpoint mechanisms



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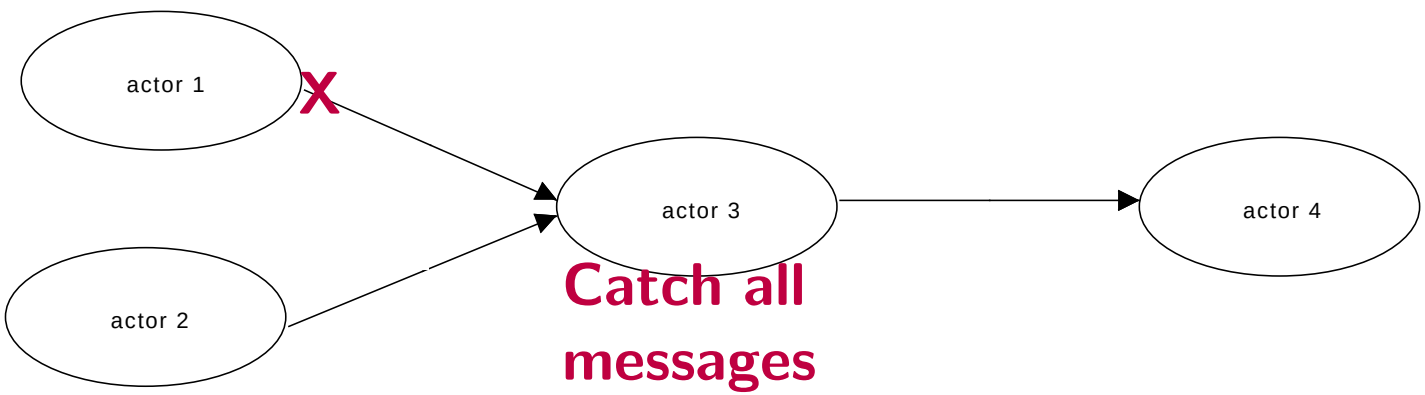

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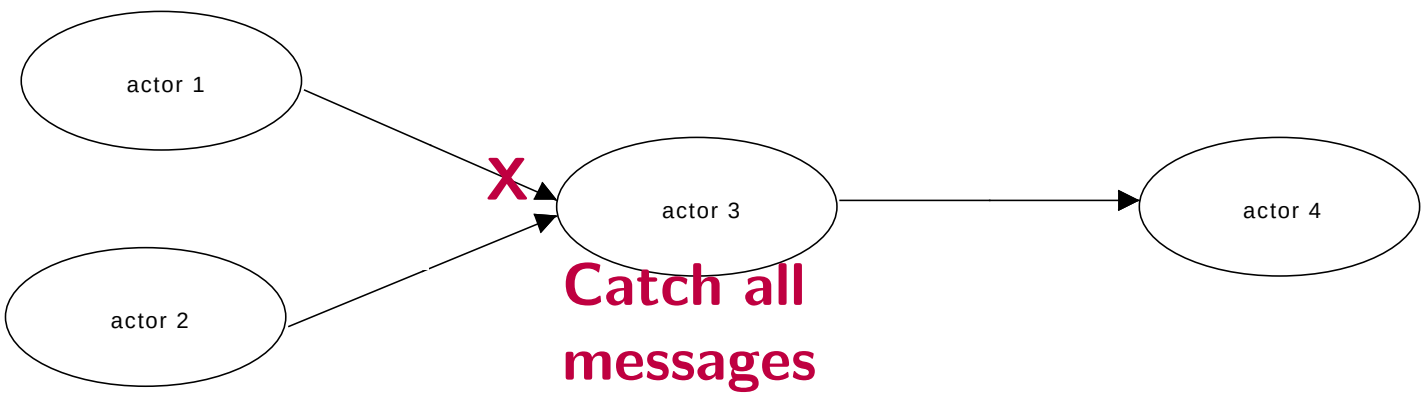

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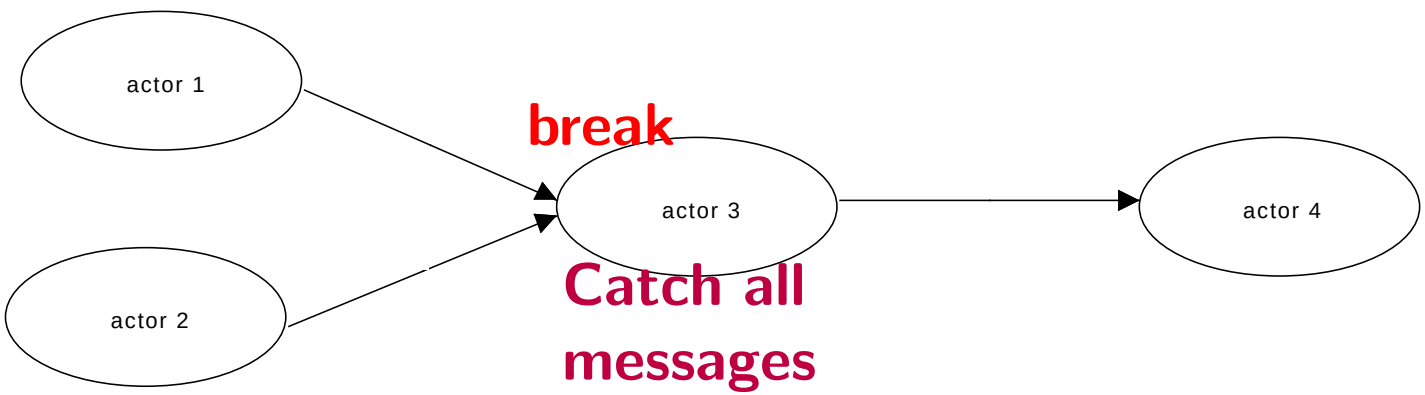

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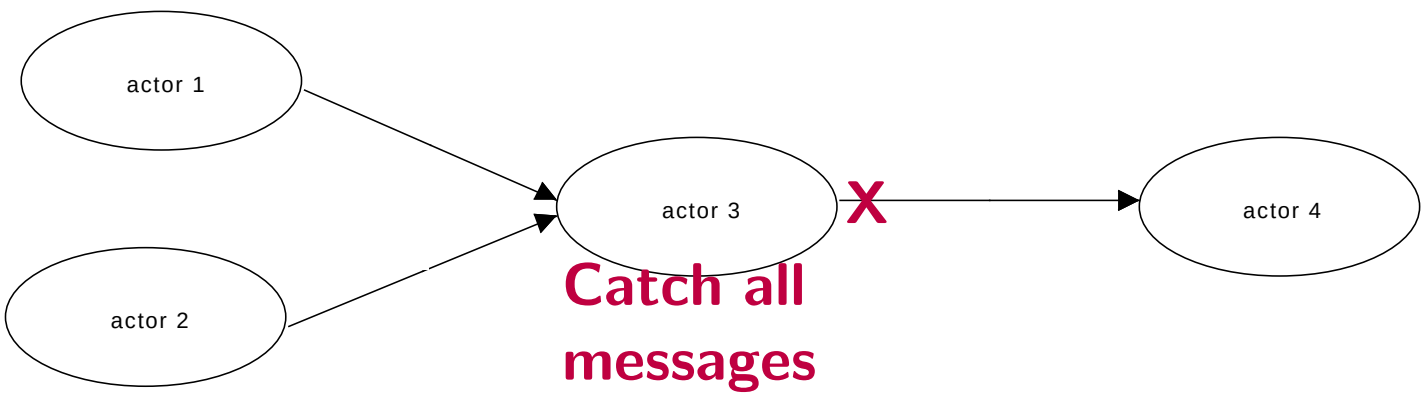

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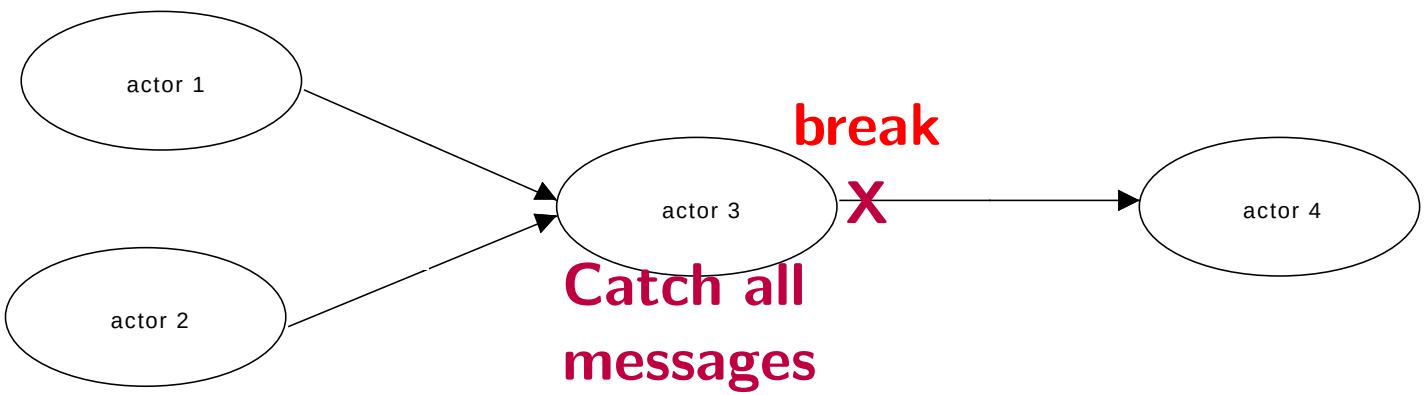
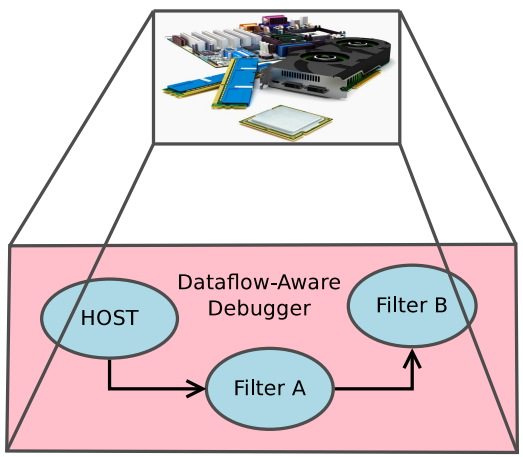


Programming Model Centric Interactive Debugging

3 Interact with the Abstract Machine

- Recognize the different entities of the model
- Provide details about their state, schedulability, callstack, ...
- Provide support to understand how they reached their current state



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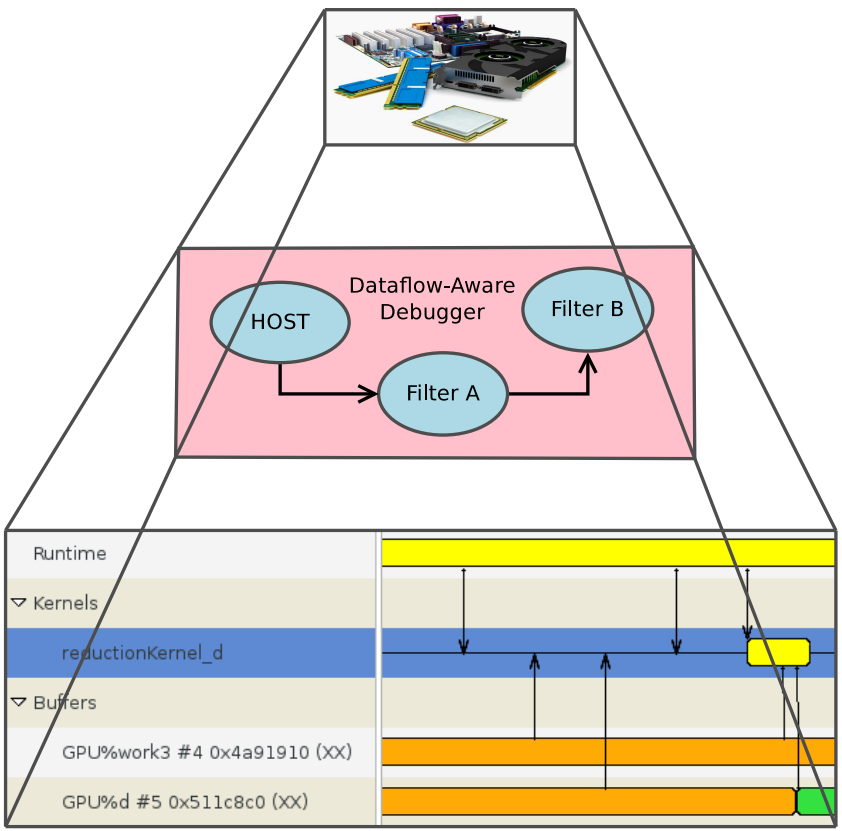
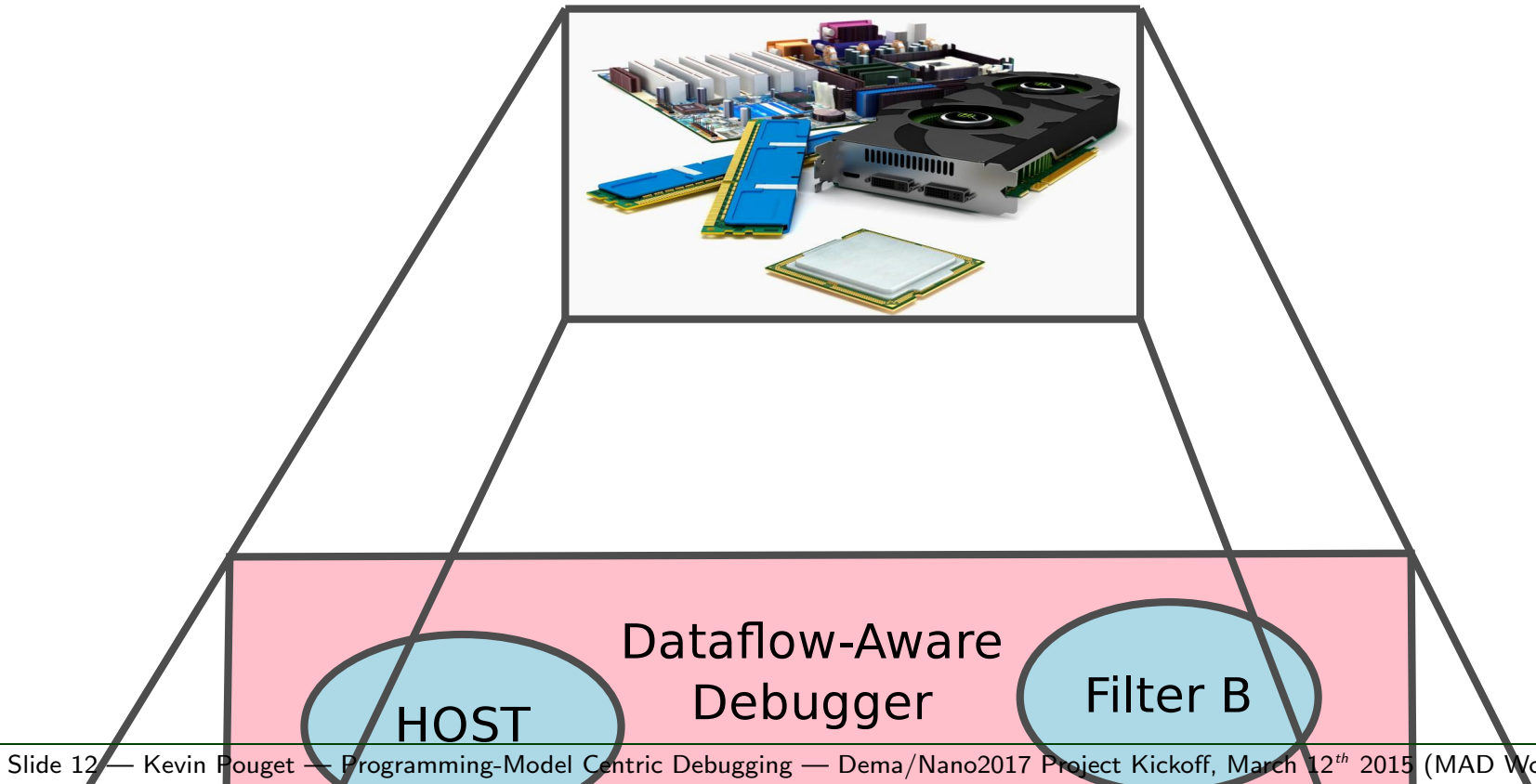


Programming Model Centric Interactive Debugging

3 Interact with the ~~Abstract~~ Machine

- Support interactions with *real* machine
  - memory inspection
  - breakpoints
  - step-by-step



Agenda

Model-Centric Debugger Case-Study

Proof-of-concept Environment

The GNU Debugger

- Adapted to low level/C debugging
- Large user community
- Extendable with Python API

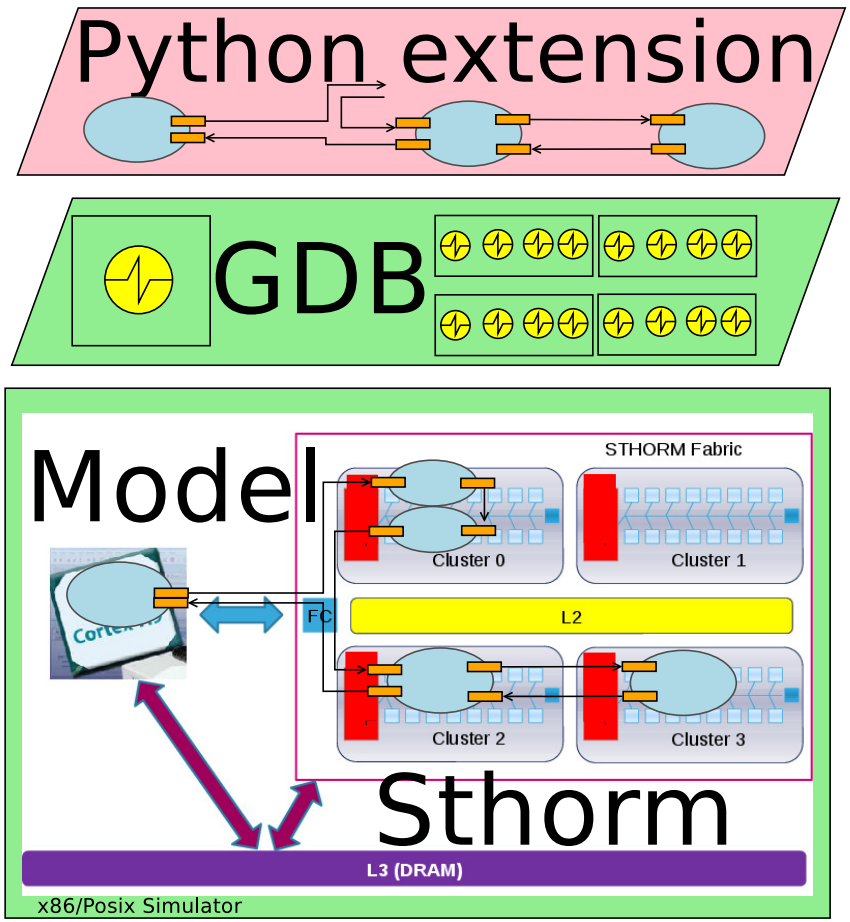
STHORM Progr. Environments

- Dataflow (PEDF)
- Components (NPM)
- Kernels (OpenCL)

STHORM / Platform 2012

ST/CEA MPSoC research platform

- x86 platform simulators



Model-Centric Debugger Case-Study

Interpreting Execution Events

$\Rightarrow$ Detect and interpret the exec. events of the runtime framework

Model-Centric Debugger Case-Study

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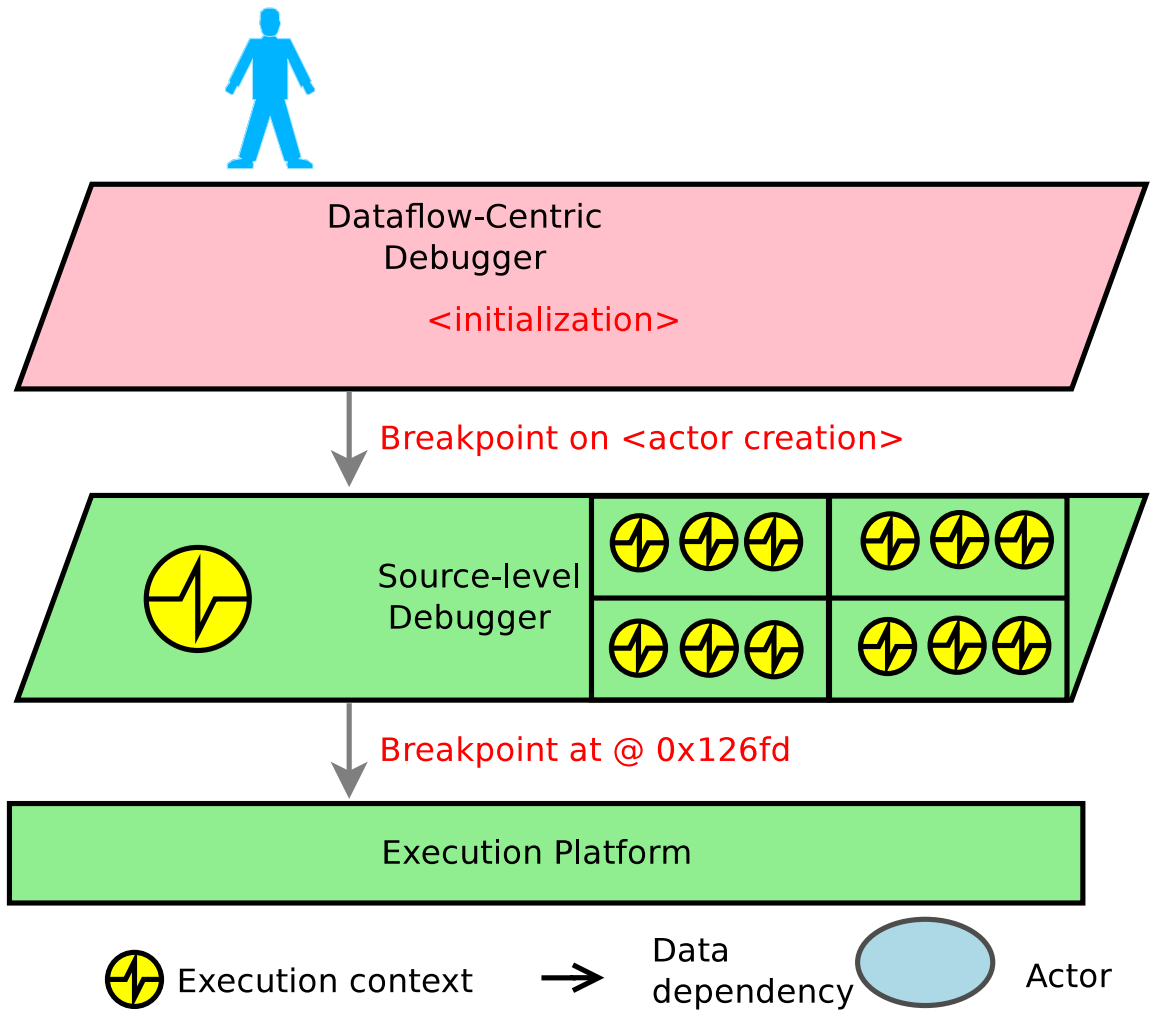

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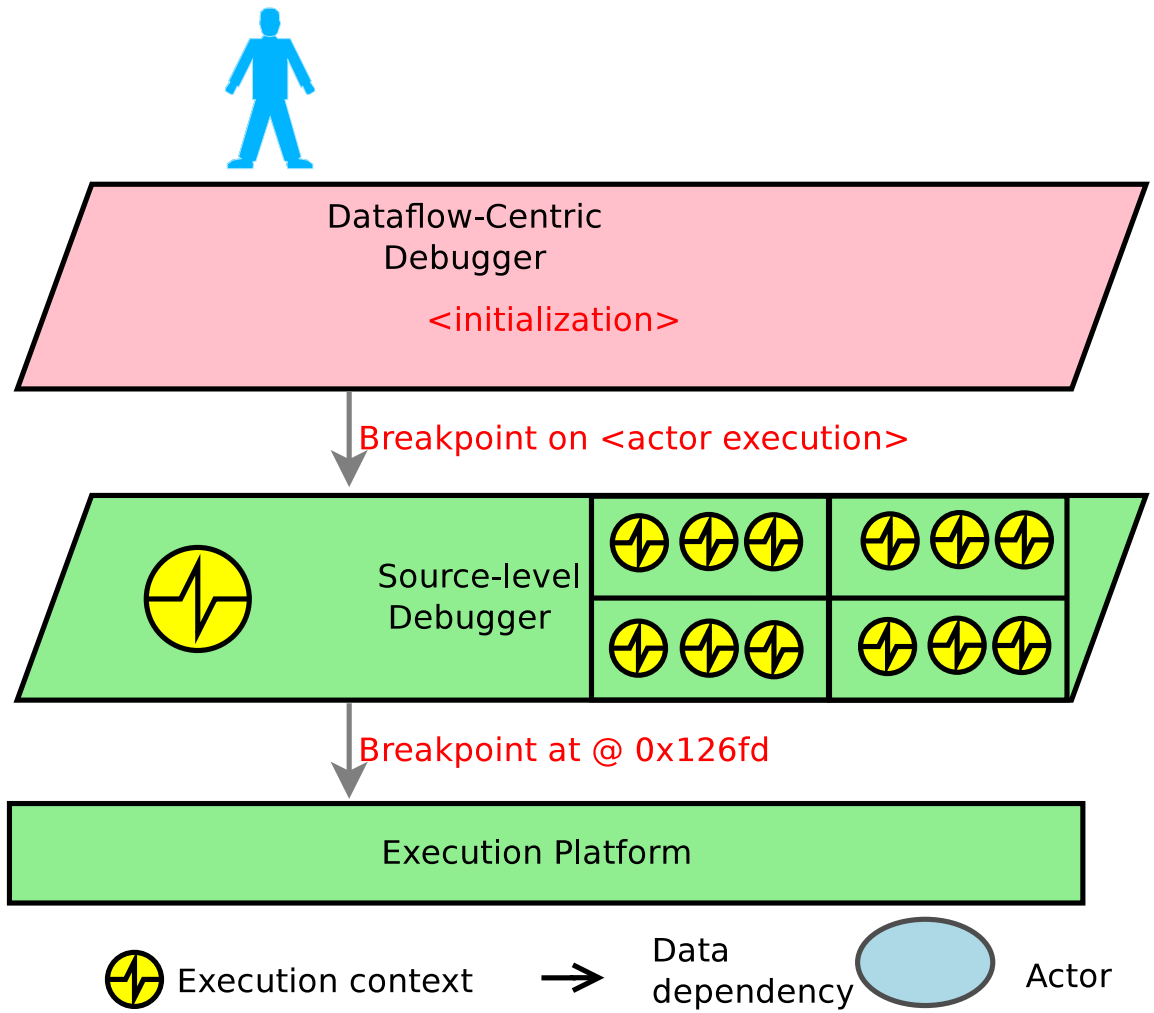

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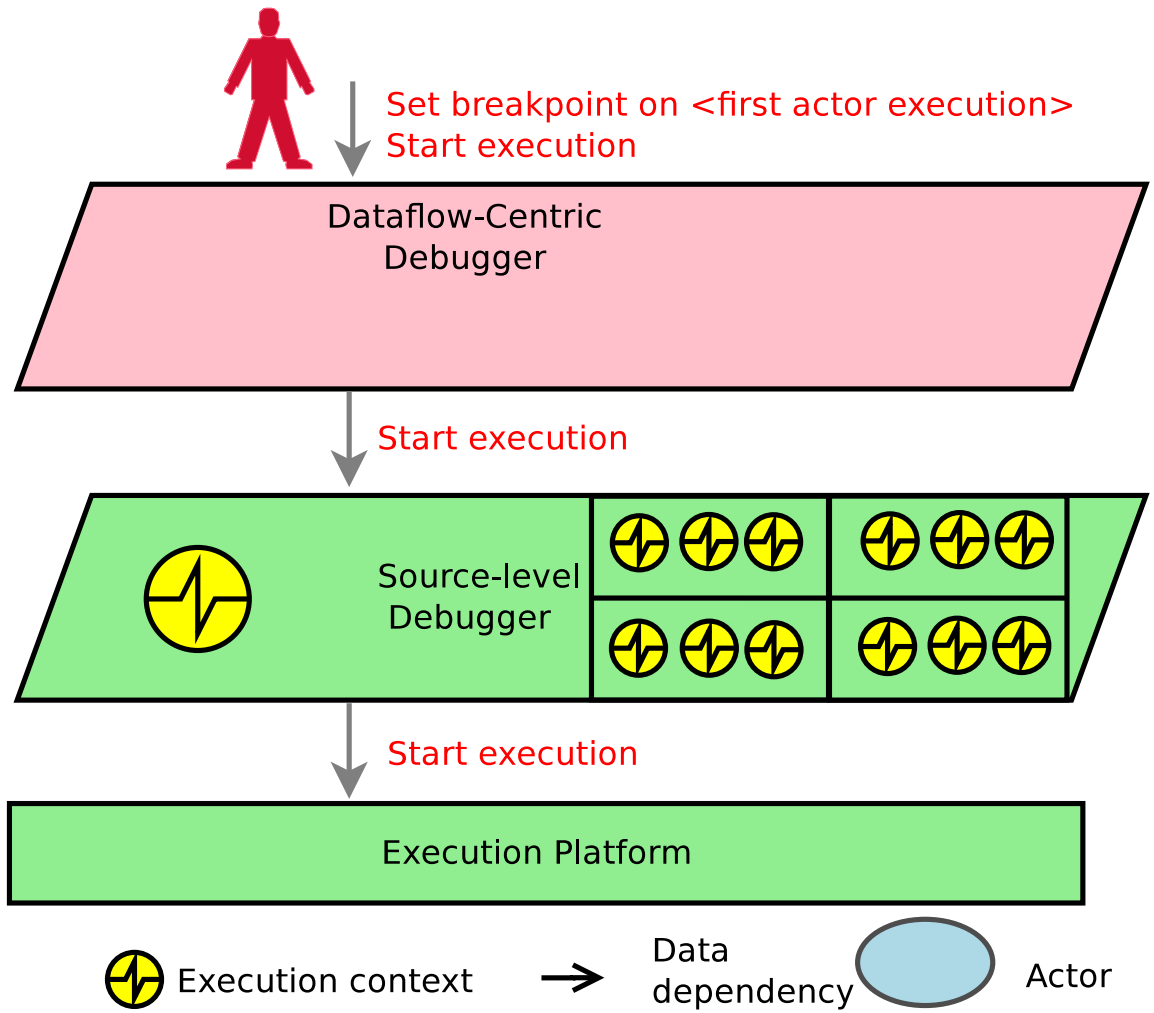

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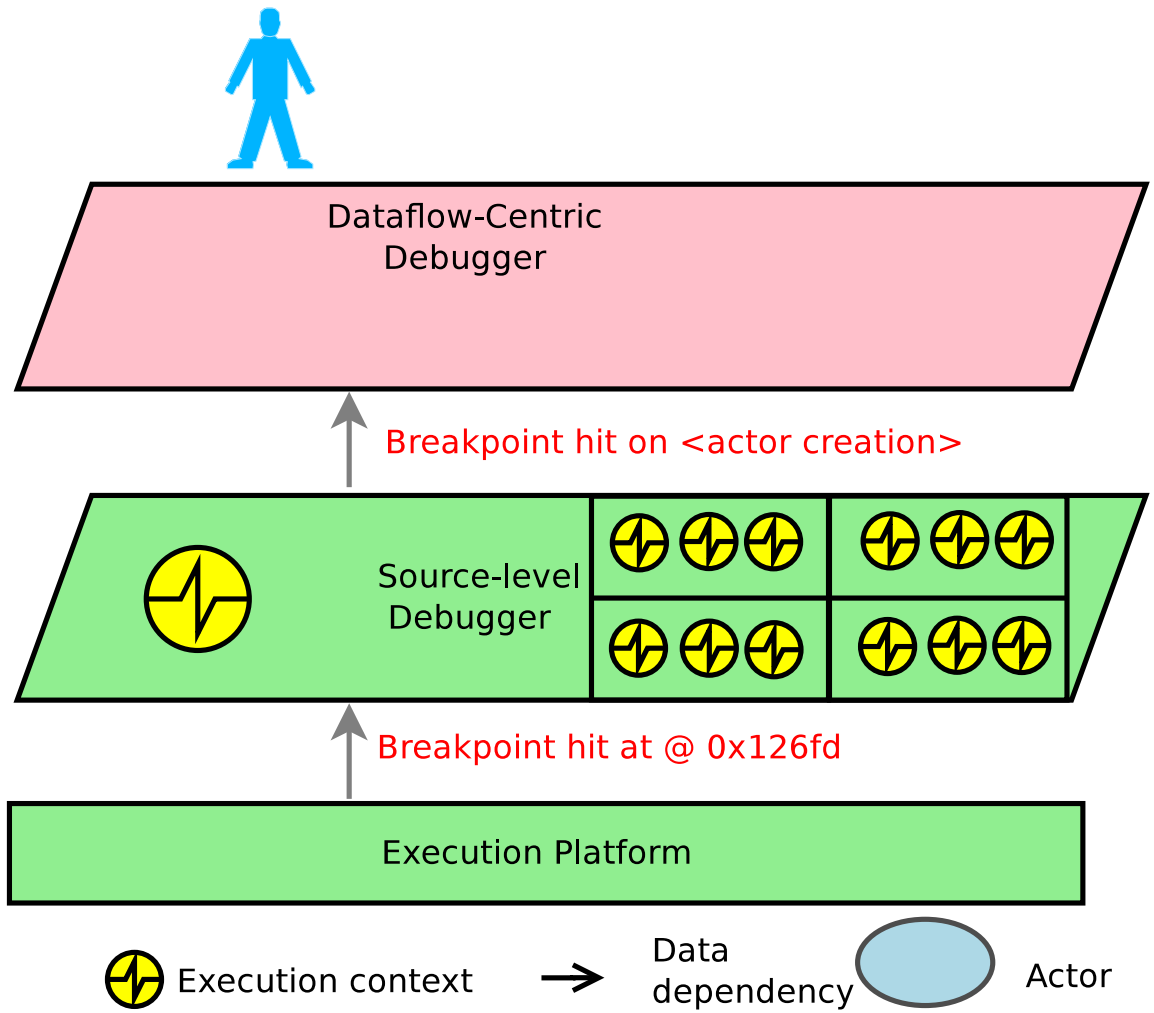

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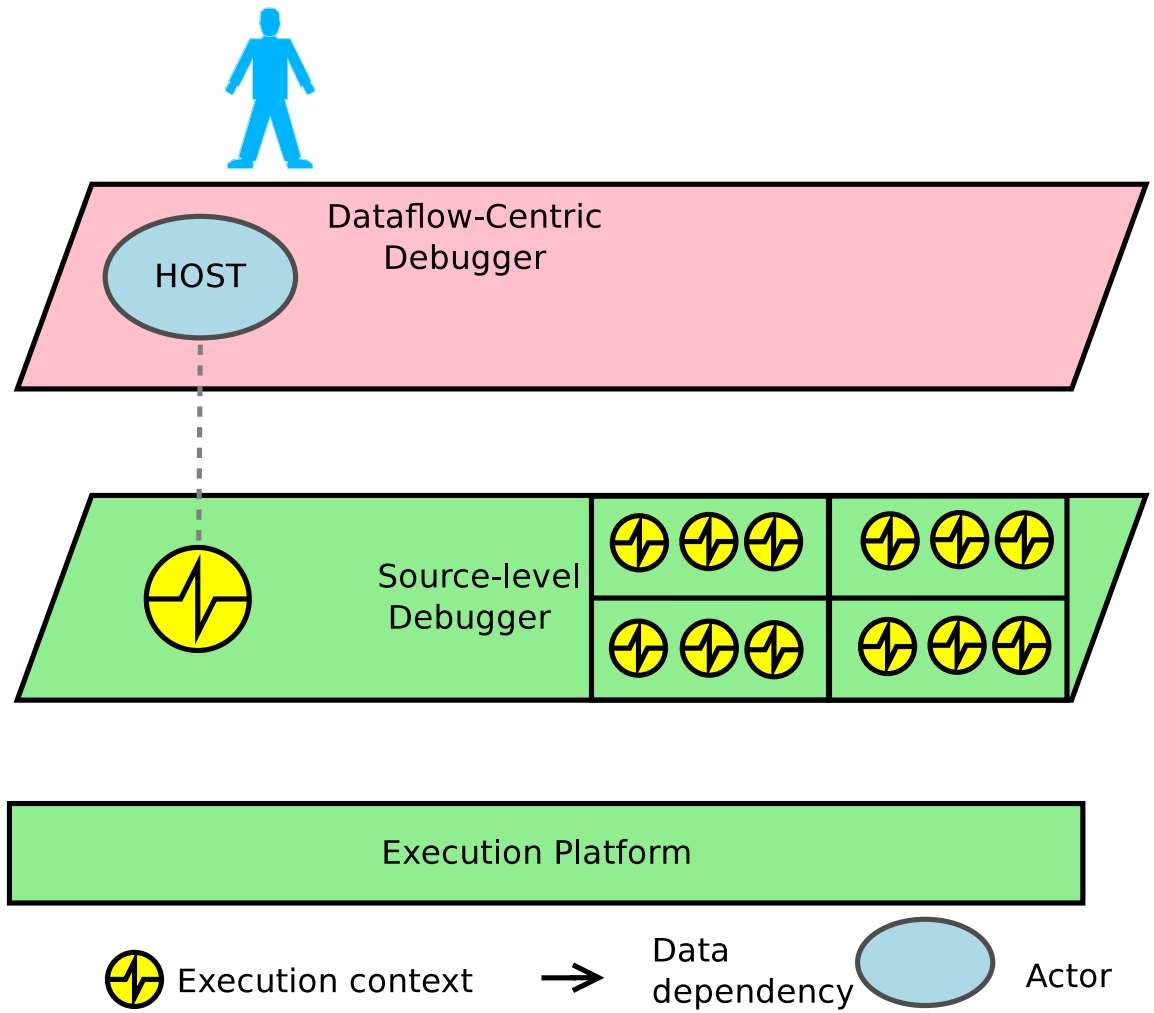

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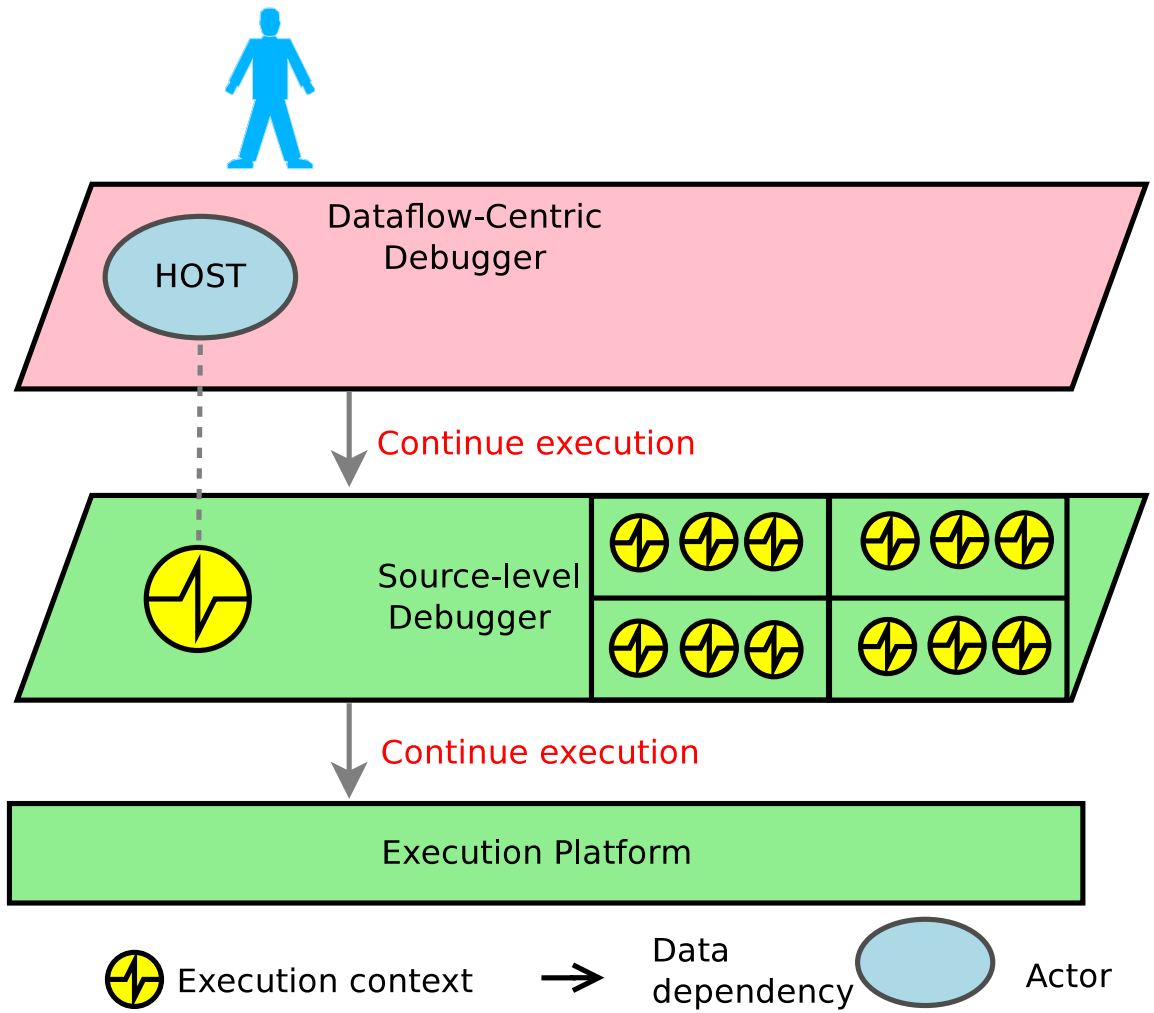

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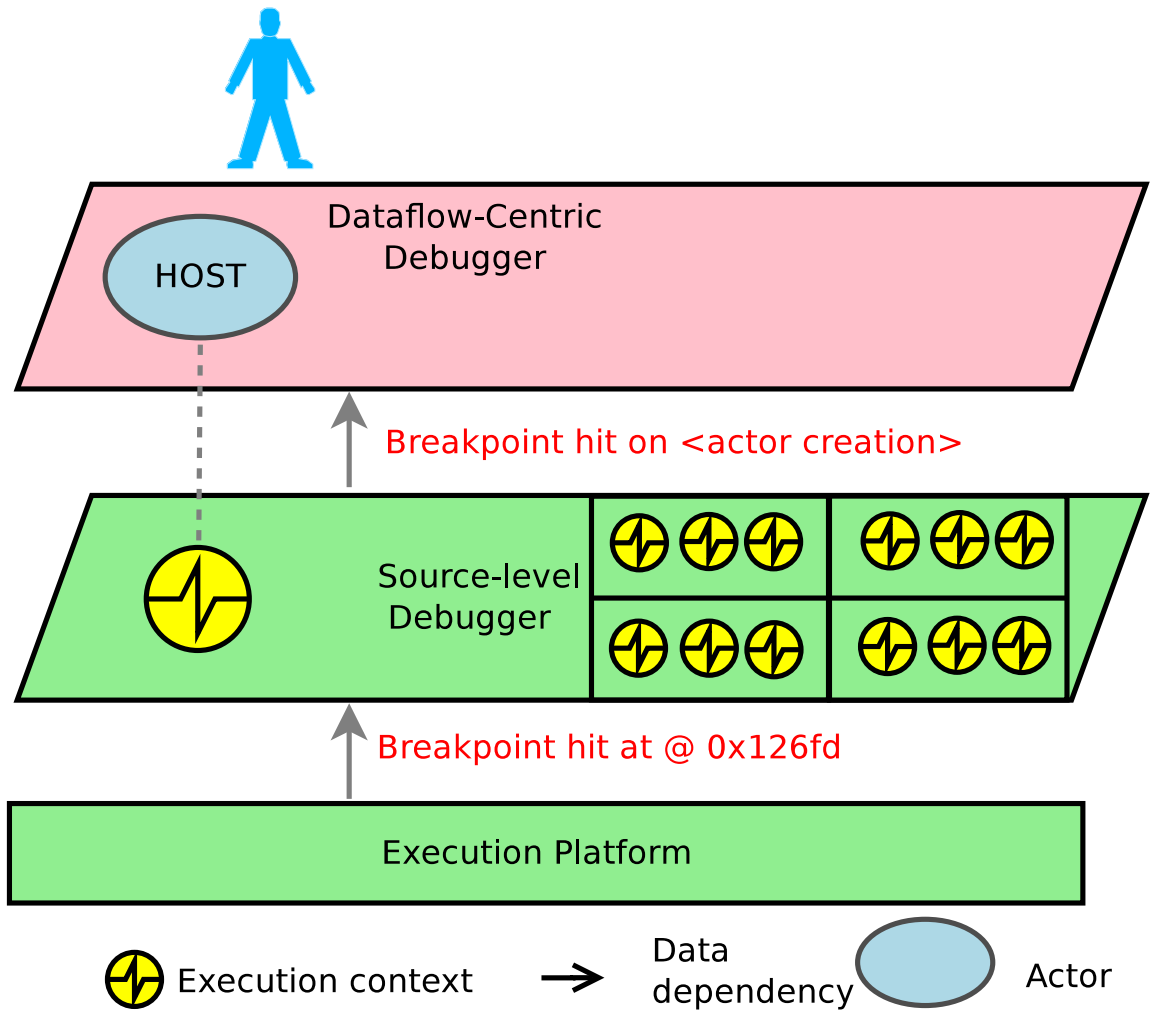

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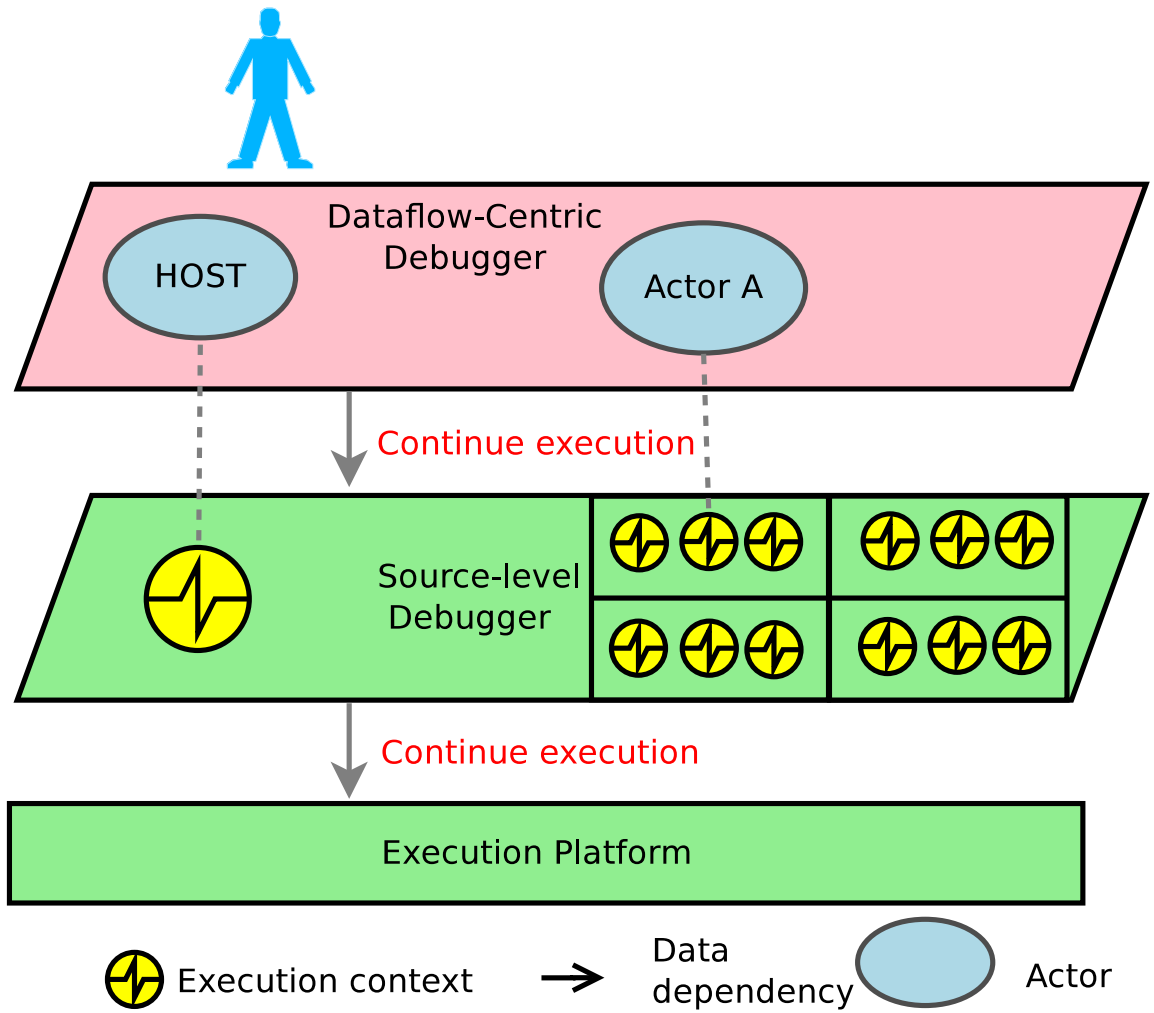

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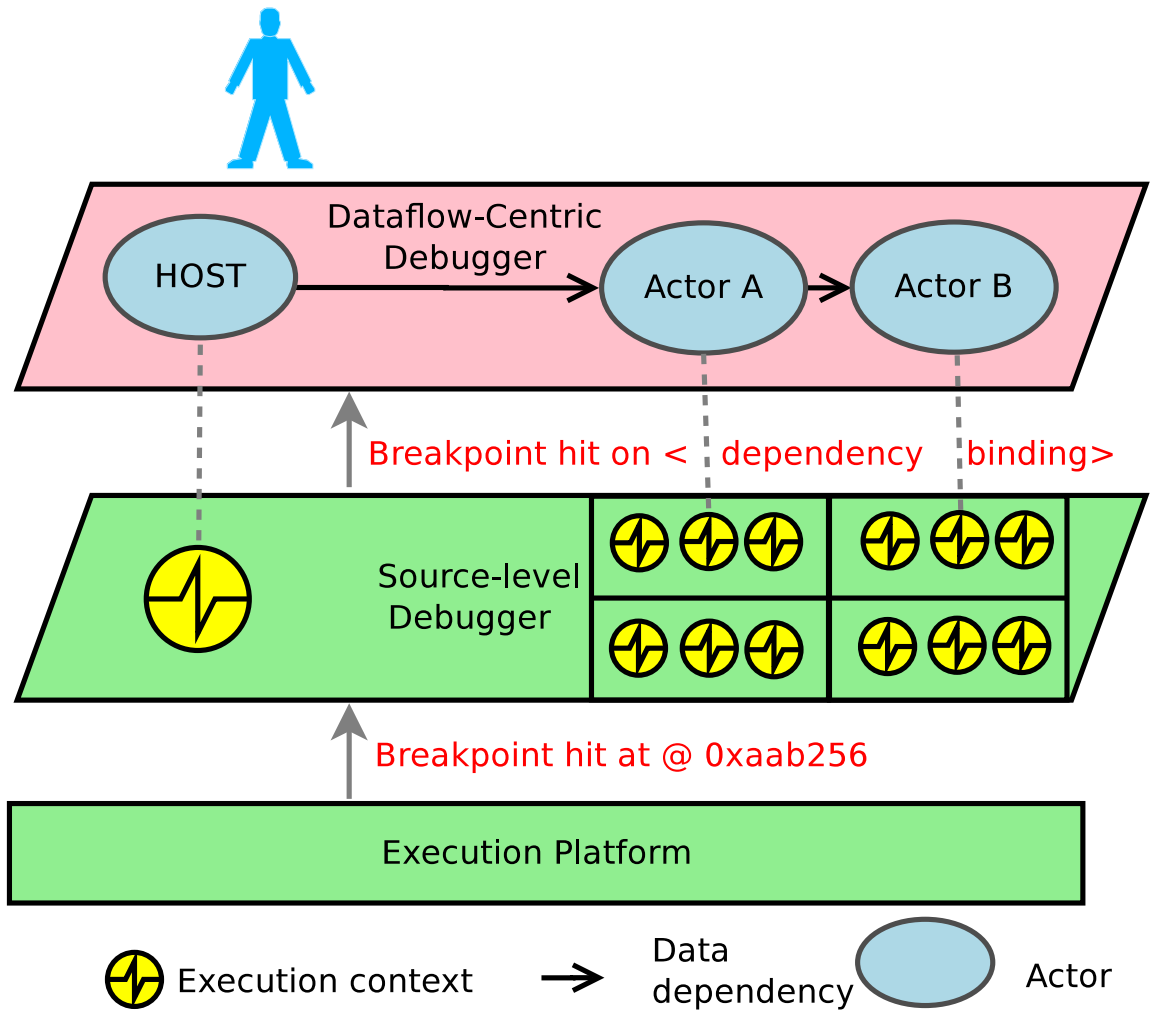

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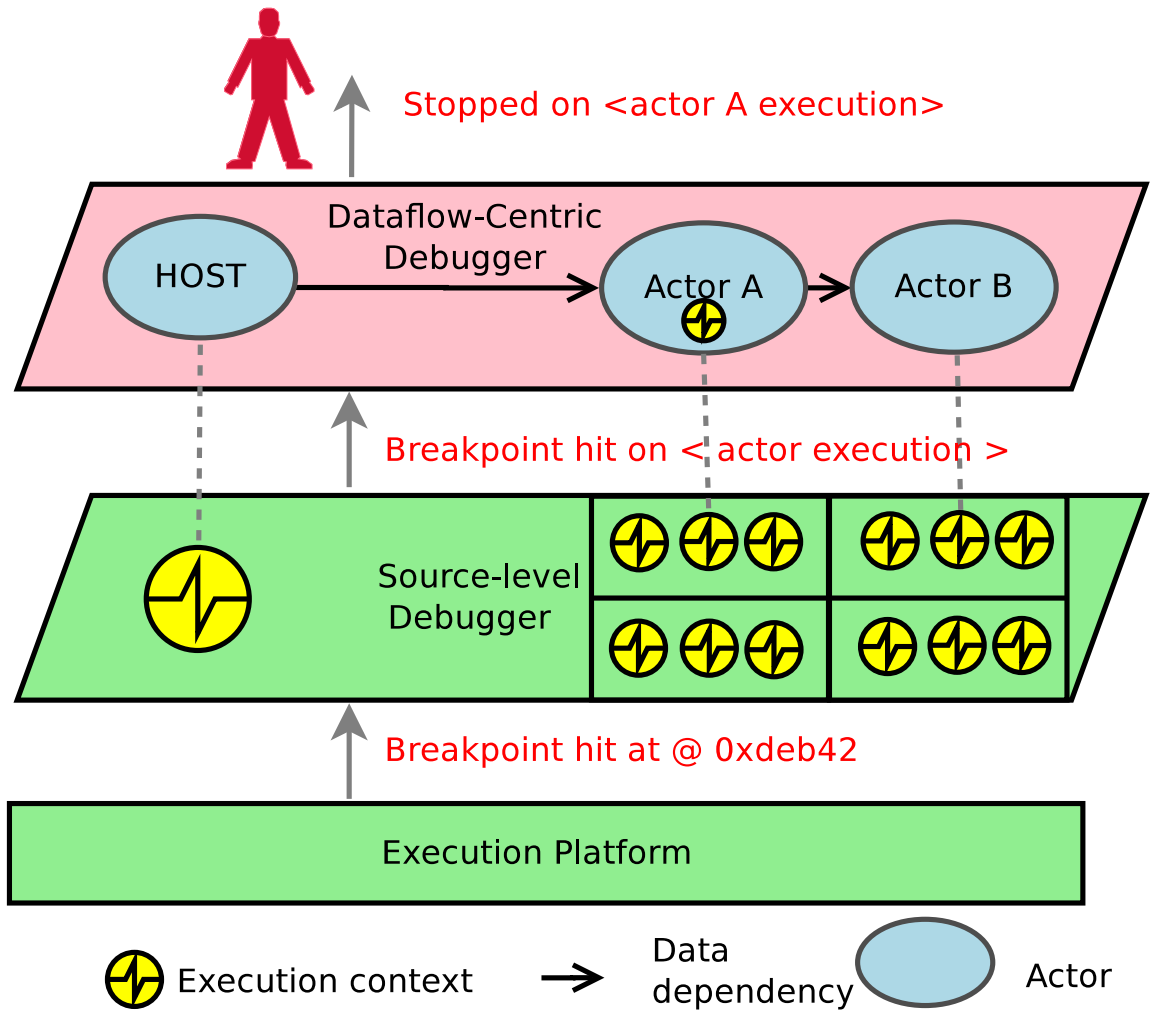
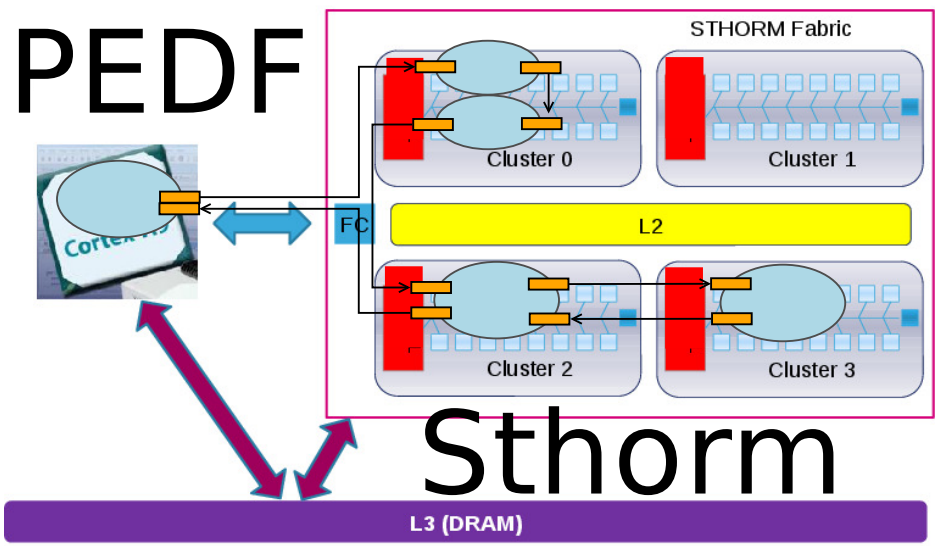


Model-Centric Debugger Case-Study

Dataflow Video Decoder

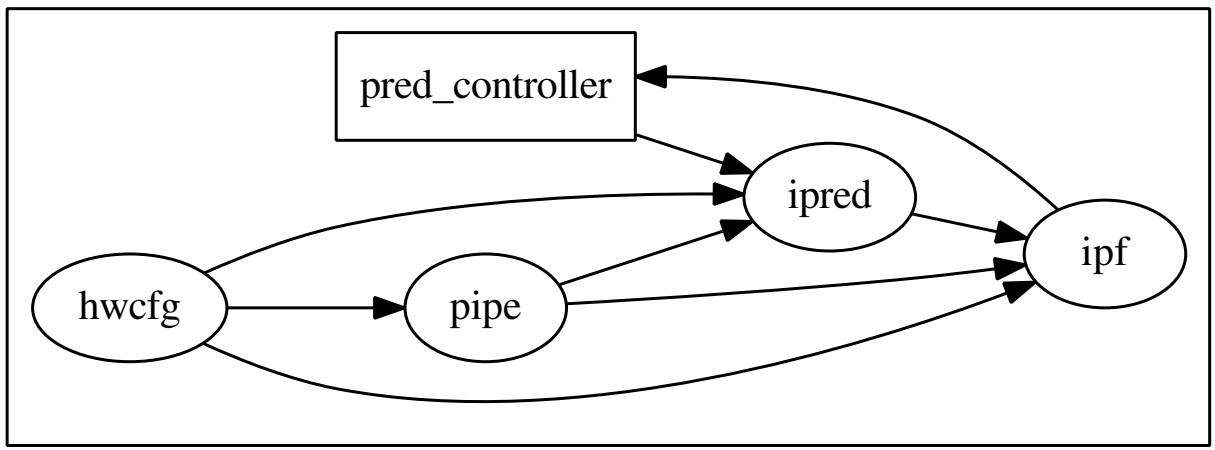


logo by bullboykennels

Model-Centric Debugger Case-Study: Dataflow Video Decoder

The application is frozen, how can GDB help us?

hint: not much!



(static graph provided by the compiler)

Model-Centric Debugger Case-Study: Dataflow Video Decoder

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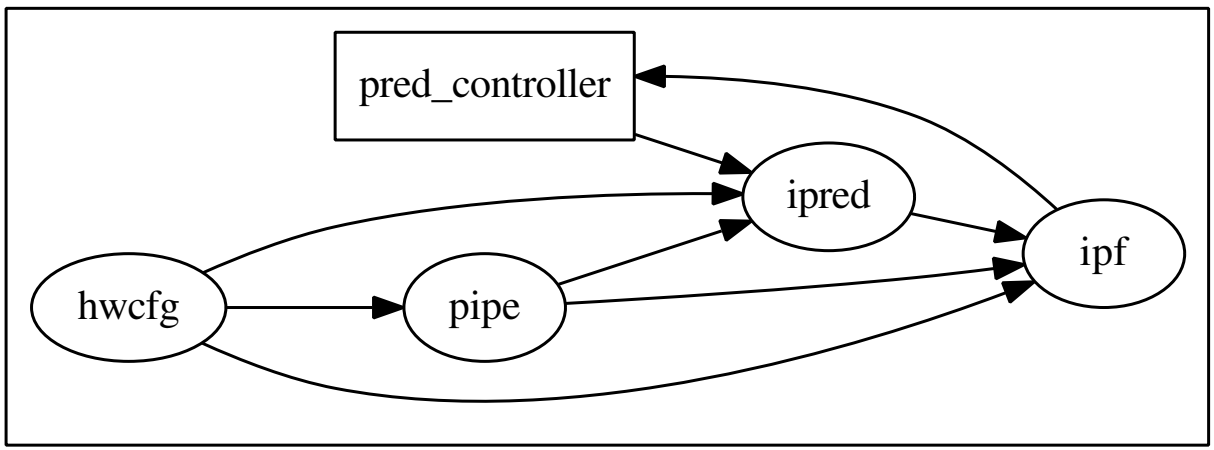

(gdb) info threads

```
 Id   Target Id         Frame
  1   Thread 0xf7e77b  0xf7ffd430 in __kernel_vsyscall ()
* 2   Thread 0xf7e797  operator= (val=..., this=0xa0a1330)
```

Model-Centric Debugger Case-Study: Dataflow Video Decoder

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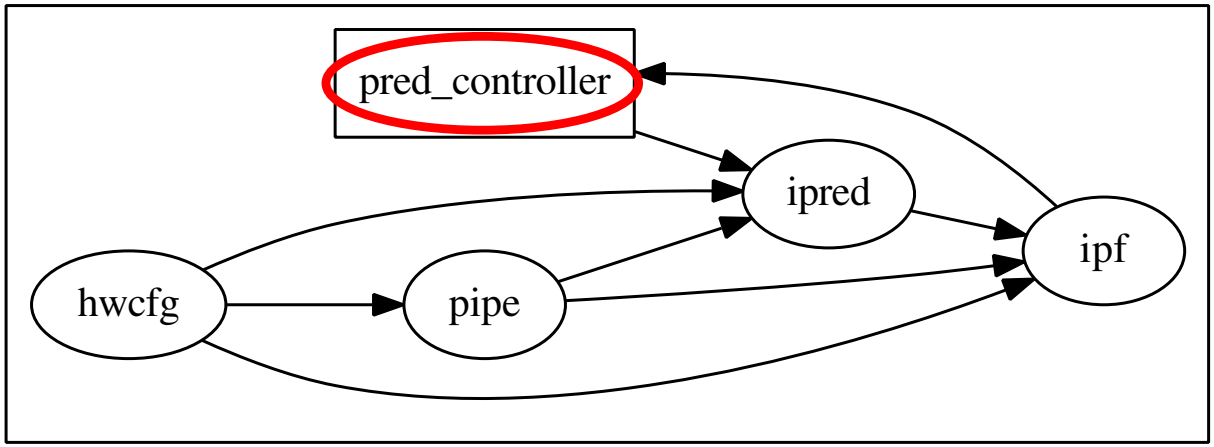

(gdb) thread apply all where

```
Thread 1 (Thread 0xf7e77b):
#0  0xf7ffd430 in __kernel_vsyscall ()
#1  0xf7fcd18c in pthread_cond_wait@ ()
#2  0x0809748f in wait_for_step_completion(struct... *)
#3  0x0809596e in pred_controller_work_function()
#4  0x08095cbc in entry(int, char**) ()
#5  0x0809740a in host_launcher_entry_point ()
```

Model-Centric Debugger Case-Study: Dataflow Video Decoder

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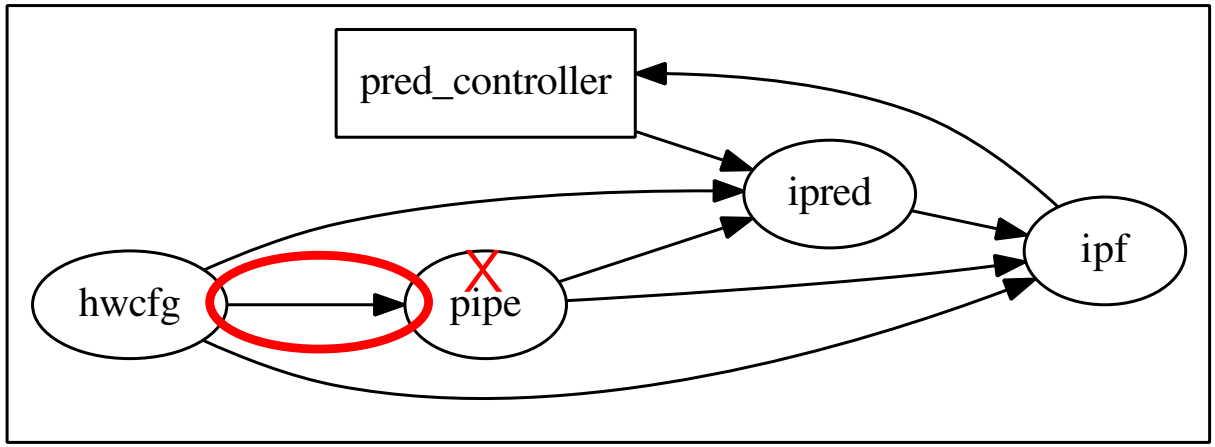


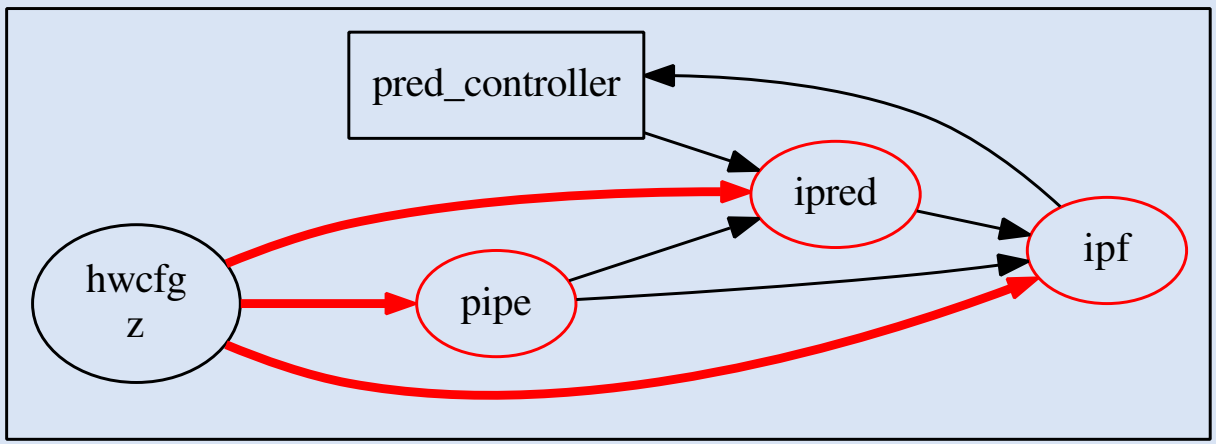
(gdb) thread apply all where

```
Thread 2 (Thread 0xf7e797):
#0 operator= (val=..., this=0xa0a1330)
#1 pipeRead (data=0) at pipeFilter.c:154
                  154   Smb = pedf.io.hwcfgSmb[count];
#2 0x0804da63 in PipeFilter_work_function () at pipe.c:361
#3 0x080a4132 in PedfBaseFilter::controller (this=0xa0d18)
#4 0x080c12f0 in sc_core::sc_thread_cor_fn (arg=0xa0a3598)
```

Model-Centric Debugger Case-Study: Dataflow Video Decoder

The application is frozen, how can mcGDB help us?

(mcgdb) info graph



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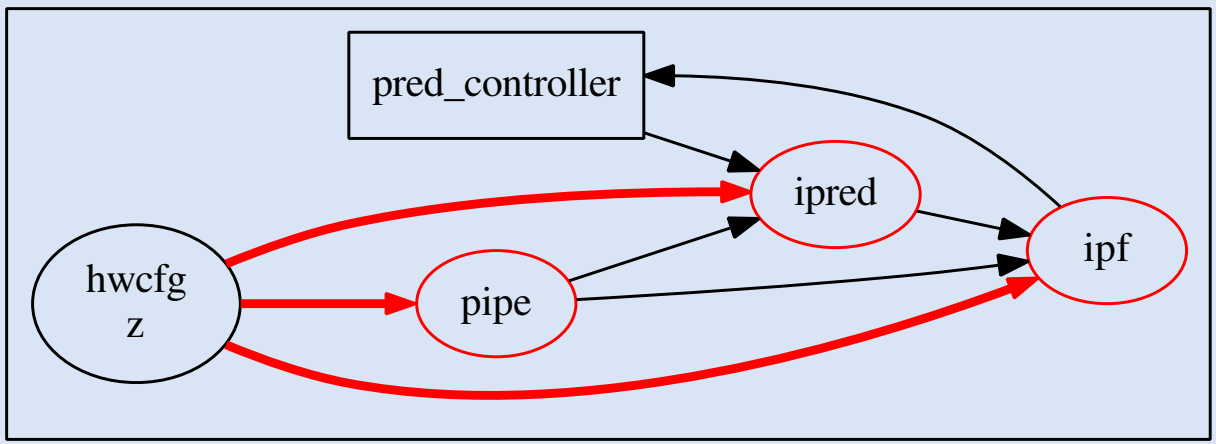

(mcgdb) info actors +state

```
#0 Controller 'pred_controller':
    Blocked, waiting for step completion
#1/2/3 Actor 'pipe/ipref/ipf':
    Blocked, reading from #4 'hwcfg'
#4 Actor 'hwcfg':
    Asleep, Step completed
```

Agenda

Part II, Current and Future Work on DEMA Project

Axis 2: Interactive Performance Debugging/Profiling — Ideas

- Setting conditions on when to start/stop the profiling,
- Section profiling, depending on application programming model,
- Interactive configuration of section parameters,
- ...

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

- Programming Interface for mcGDB Extention
- (Low-level Data Tracing)
- OpenMP Model-Centric Debugging

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Programming Interface for mcGDB Extention — Mostly done

- Code refactoring
- Code documentation
- Methodology for extending mcGDB

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Programming Interface for mcGDB Extention — Mostly done

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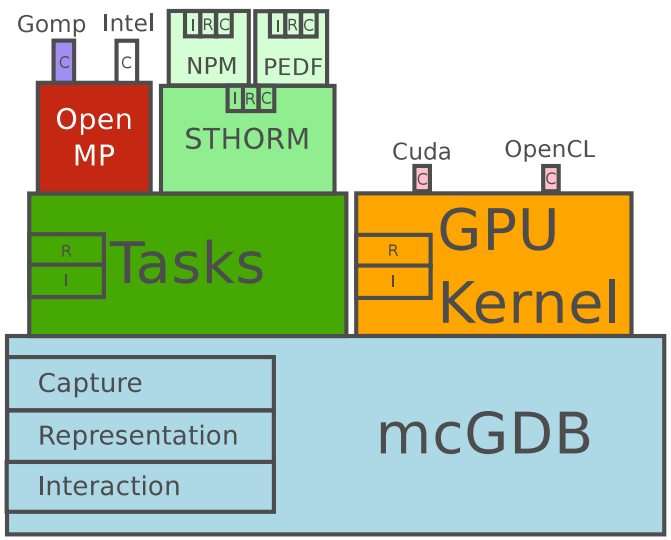
- Top modules relying on lower levels
- `Capture`, `Representation` and `Interaction` sub-modules
  - Guidelines/examples for future modules



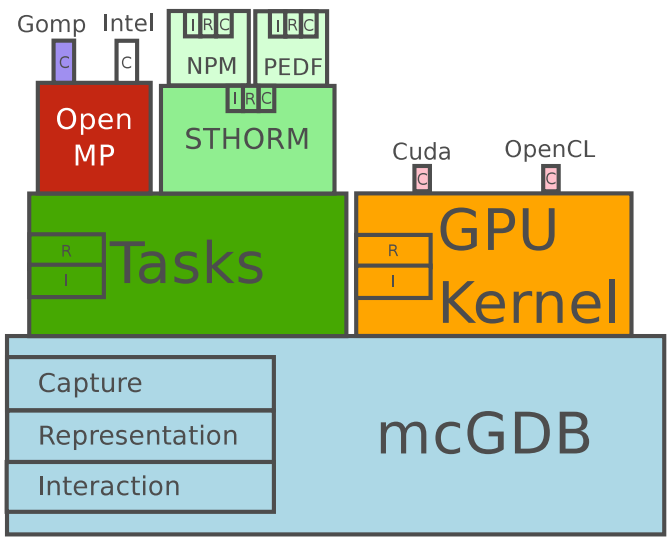
Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Programming Interface for mcGDB Extention — Mostly done

- Code refactoring
- Code documentation
- Methodology for extending mcGDB

- Rule of thumb for estimating the porting-effort difficulty:
  - Proportional to the difficulty of porting an application from model A to model B!
  - Cuda → OpenCL: limited, all but `Capture` in common
  - OCL → OpenMP, MPI: harder, fewer modules can be shared



Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Programming Interface for mcGDB Extention — Mostly done

- Code refactoring
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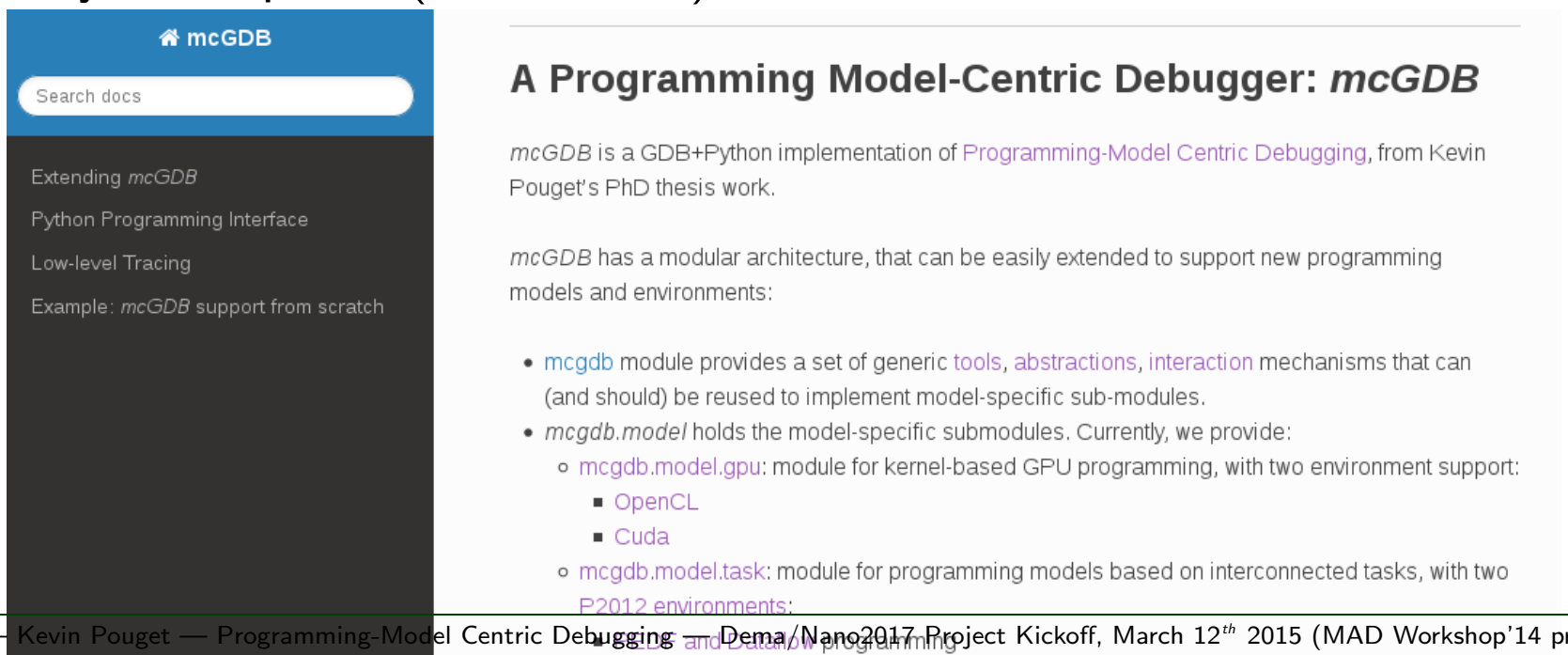
- Python Sphinx (Javadoc-like): commented source-code + website



Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Programming Interface for mcGDB Extention — Mostly done

- Code refactoring
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Step-by-step development example of a
simple model-centric debugging support
for a simple task-based programming model

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

Low-level data tracing — Done

- Paje trace format (easy to change)
- To be fed to independ. post-mortem visualization/processing tools
- Also for mcGDB internal debugging

```
0 Th_1 GOMP_parallel_start
  <in> num_threads=>0|job=>ParallelJob_@1|fn=>0x400a7d_<main._
4 Th_3 GOMP_parallel_function =>
  <in>|job=>ParallelJob_@1|fct_name=><main._omp_fn.0>
8 Th_3 GOMP_single_start =>
  <in>/<out>|single=>SingleJob_@1|ret=>1
11 Th_1 GOMP_single_start => <in>/<out>|single=>SingleJob_@1|r
13 Th_3 GOMP_barrier => <in>|barrier=>Barrier_@1
14 Th_1 GOMP_single_start => <out>|single=>SingleJob_@1|ret=>0
15 Th_4 GOMP_barrier => <in>|barrier=>Barrier_@1
```

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

OpenMP Model-Centric Debugging — Work in Progress

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

OpenMP Model-Centric Debugging — Work in Progress

- Taking OpenMP 3.0 constructs into account

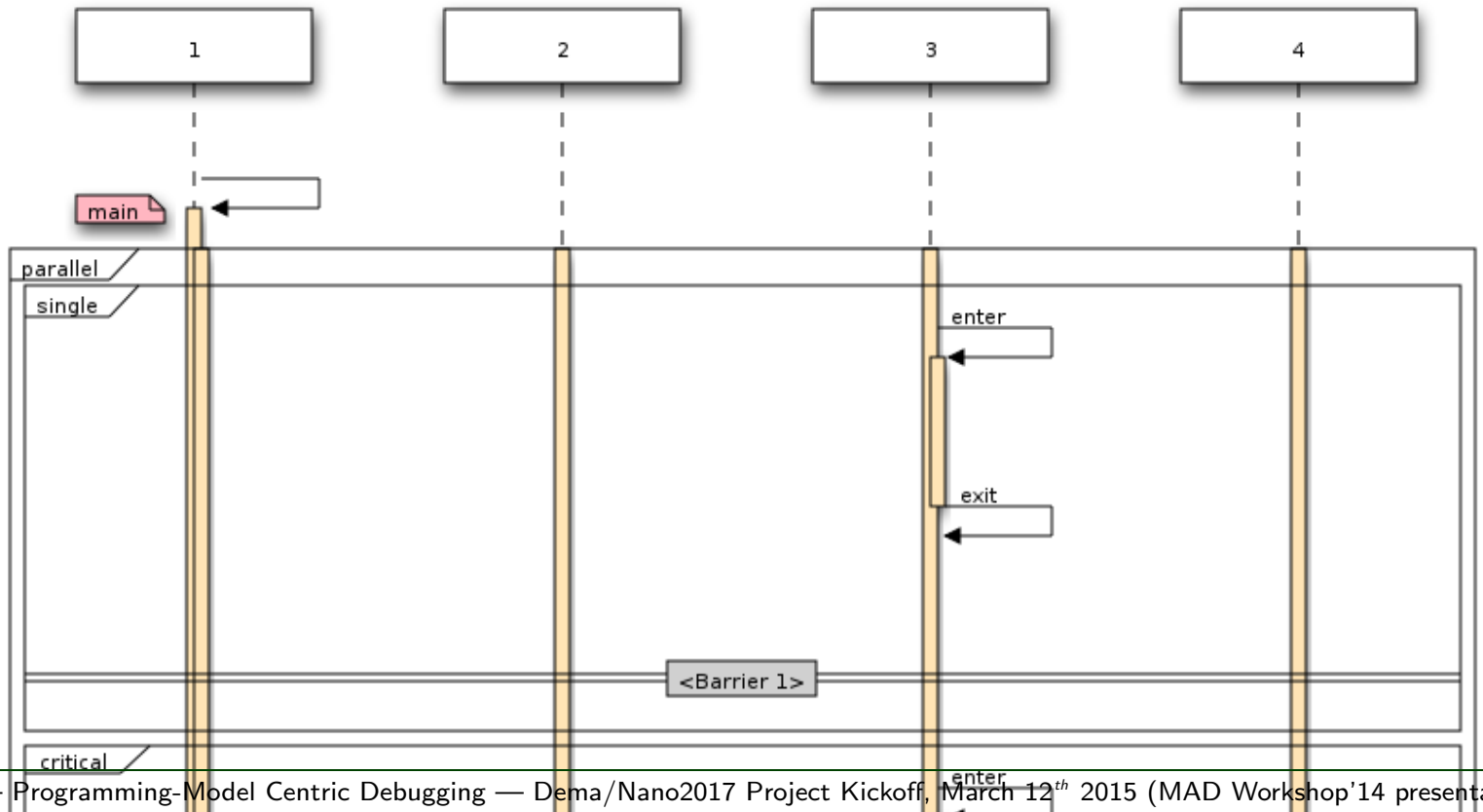
```
#pragma omp parallel
  {
    int id = omp_get_thread_num() + 1;

#pragma omp single
    { ... }

#pragma omp critical
    { ... }
  }
```

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

OpenMP Model-Centric Debugging — Work in Progress

- Taking OpenMP 3.0 constructs into account
  - distinction of OpenMP parallel zones, parallelism level, etc
    - sequence-diagram-like visualization of OpenMP execution



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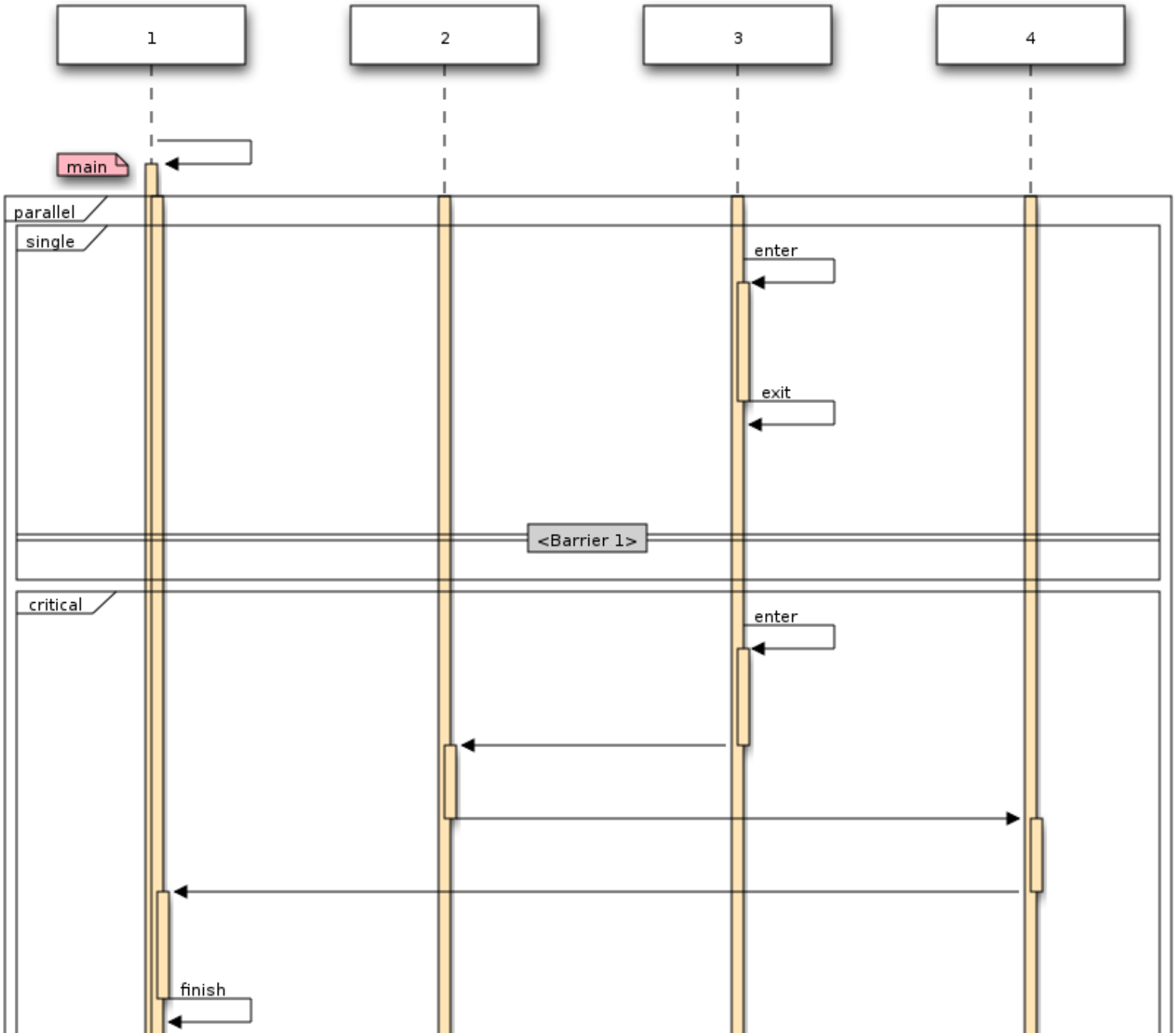

Part II, Current and Future Work on DEMA Project

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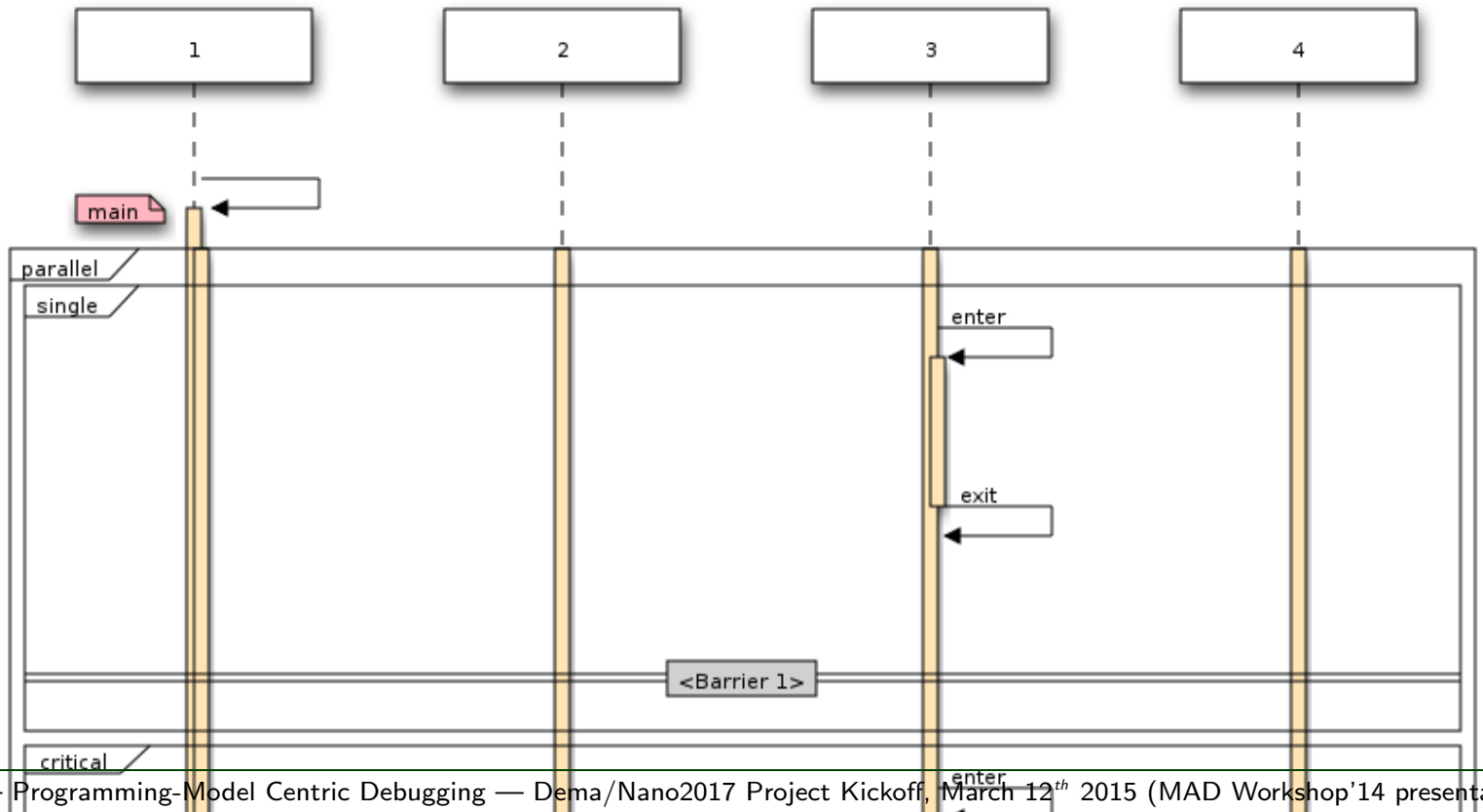

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

OpenMP Model-Centric Debugging — Work in Progress

- Taking OpenMP 3.0 constructs into account
  - distinction of OpenMP parallel zones, parallelism level, etc
    - sequence-diagram-like visualization of OpenMP execution
  - better execution control and data query commands
    - `opm next <zone>; opm step in/out; ...`
    - `opm print --all <var>`

Part II, Current and Future Work on DEMA Project

Axis 1: Model-Centric Interactive Debugging

OpenMP Model-Centric Debugging — Work in Progress

- Taking OpenMP 3.0 constructs into account
  - distinction of OpenMP parallel zones, parallelism level, etc
    - sequence-diagram-like visualization of OpenMP execution
  - better execution control and data query commands
    - `opm next <zone>; opm step in/out; ...`
    - `opm print --all <var>`
- Focus on OPM 4 task-based parallelism — Future work
  - dependencies, task graph, ...

```
#pragma opm task shared (x, ...) depend(out: x)
  preprocess_some_data(...);
#pragma opm task shared (x, ...) depend(in: x)
  do_something_with_data(...);
#pragma opm task shared (x, ...) depend(in: x)
  do_something_independent_with_data(...);
```

Publications

Kevin Pouget.
Programming-Model Centric Debugging for Multicore Embedded Systems. PhD thesis, Université de Grenoble, École Doctorale MSTII, feb 2014.

Kevin Pouget, Marc Pérache, Patrick Carribault, and Hervé Jourdren.
User level DB: a debugging API for user-level thread libraries. In *Parallel Distributed Processing, Workshops and Phd Forum (IPDPSW), 2010 IEEE International Symposium on*, pages 1–7, 2010.

Kevin Pouget, Miguel Santana, Vania Marangozova-Martin, and Jean-François Mehaut.
Debugging Component-Based Embedded Applications. In *Joint Workshop Map2MPSoC (Mapping of Applications to MPSoCs) and SCOPES (Software and Compilers for Embedded Systems)*, St Goar, Germany, may 2012. Published in the ACM library.

Kevin Pouget, Patricia López Cueva, Miguel Santana, and Jean-François Méhaut.
Interactive Debugging of Dynamic Dataflow Embedded Applications. In *Proceedings of the 18th International Workshop on High-Level Parallel Programming Models and Supportive Environments (HIPS)*, Boston, Massachusetts, USA, may 2013. Held in conjunction of IPDPS.

Kevin Pouget, Patricia López Cueva, Miguel Santana, and Jean-François Méhaut.
A novel approach for interactive debugging of dynamic dataflow embedded applications. In *Proceedings of the 28th Symposium On Applied Computing (SAC)*, pages 1547–1549, Coimbra, Portugal, apr 2013.

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Dema/Nano2017 Project Kickoff, March 12th 2015 (MAD Workshop'14 presentation)