Programming-Model Centric Debugging for OpenMP

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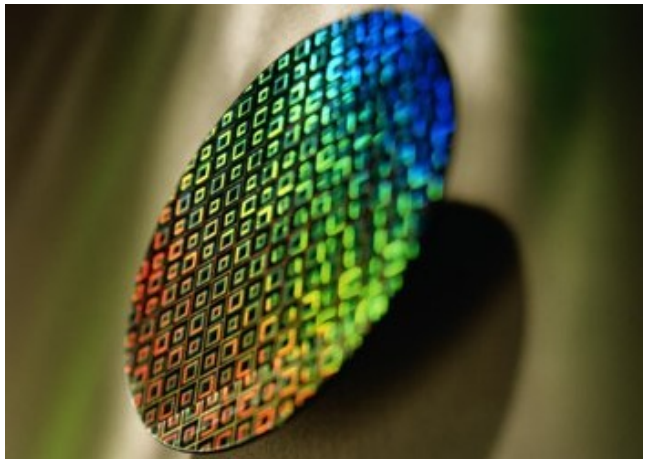
Introduction

Compiler Optimization and Runtime SystEms

Today's in parallel computing

- Multicore processors everywhere
- High-level programming environments
- Efficient verification & validation tools



informatics mathematics

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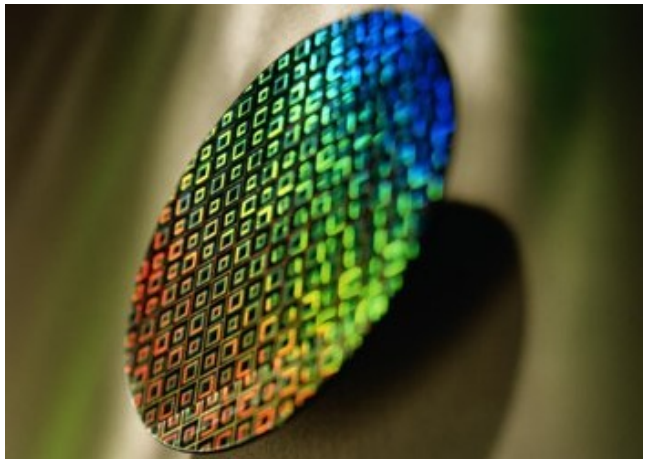

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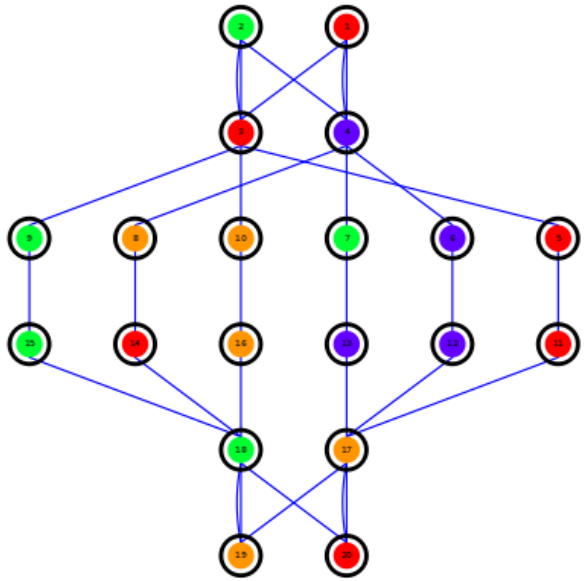
  - tasks with data-dependencies,
  - fork-join parallelism
  - $\Longrightarrow$ OpenMP
- Efficient verification & validation tools



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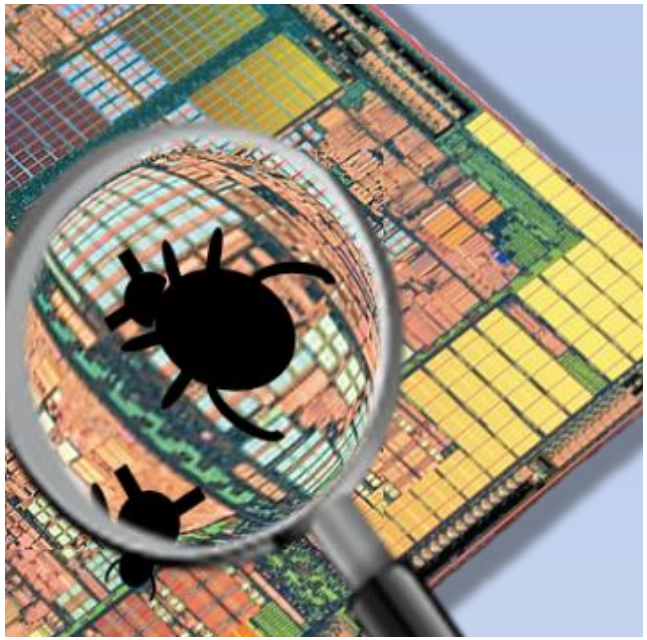
- Efficient verification & validation tools
  - our research effort!



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Agenda

Compiler Optimization and Runtime SystEms

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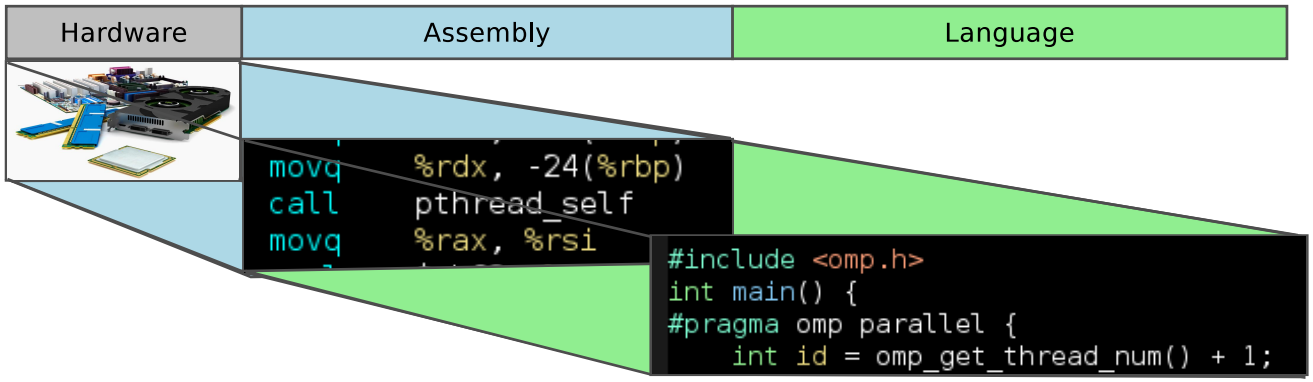
Verification and Validation: Debugging

Compiler Optimization and Runtime SystEms

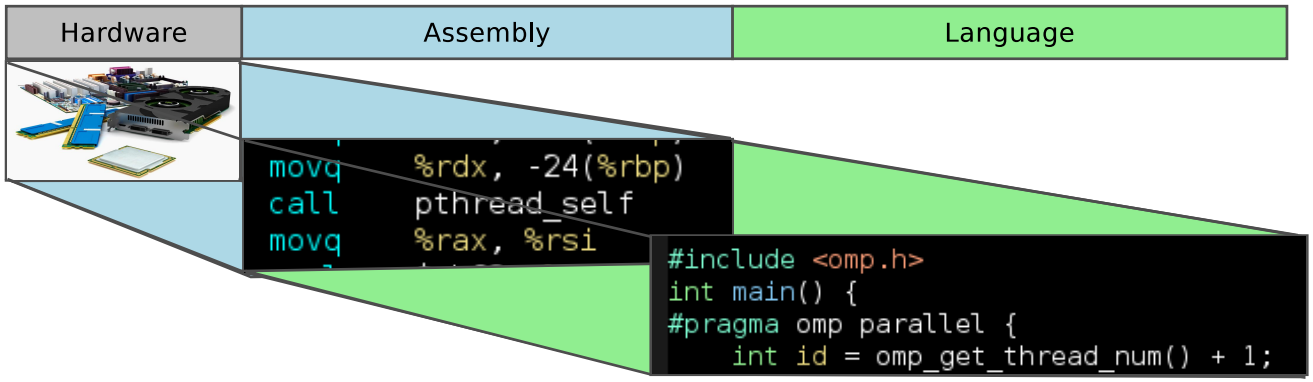


Source-Level Interactive Debugging (e.g. GDB)

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

Verification and Validation: Debugging

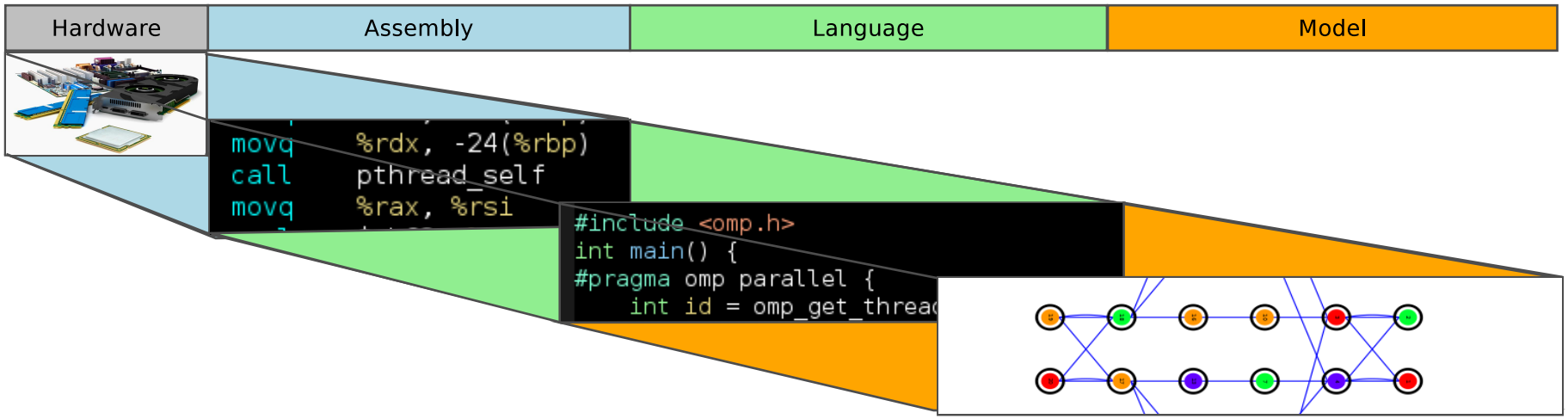
Compiler Optimization and Runtime SystEms



What about programming models?

Verification and Validation: Debugging

Compiler Optimization and Runtime SystEms



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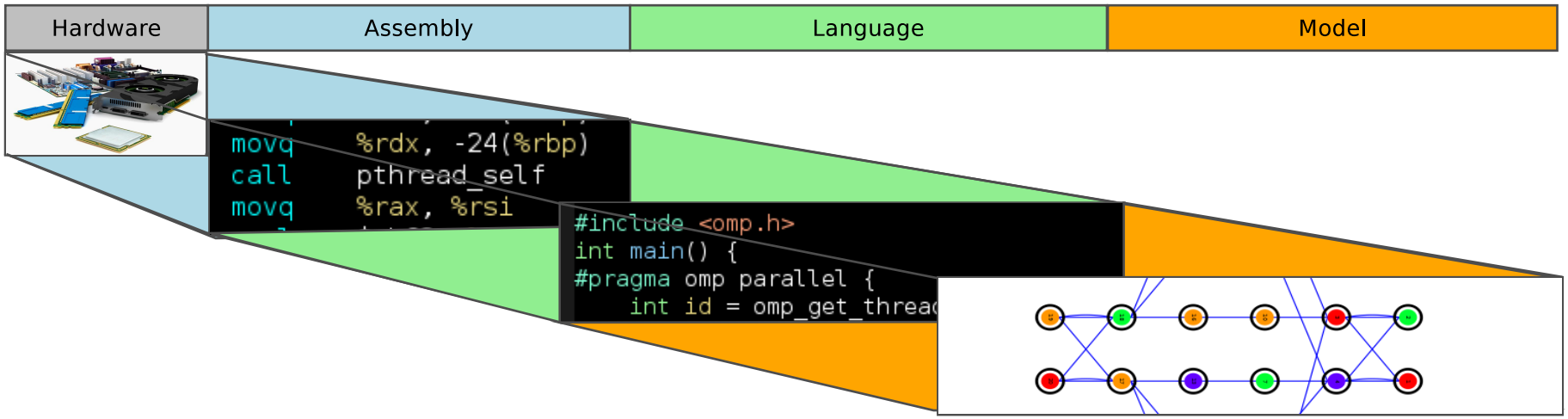

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Source-level interactive debuggers operate at language-level.

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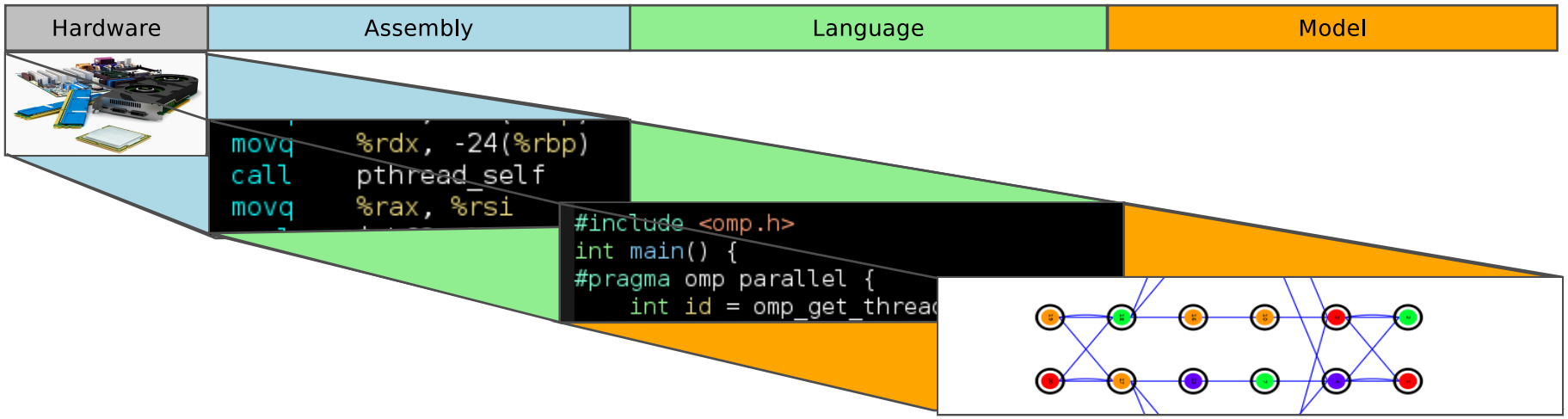

What about programming models?

Source-level interactive debuggers operate at language-level.

They have **no knowledge** about high-level **abstract machines**!

Agenda

Compiler Optimization and Runtime SystEms

Programming Model Centric Debugging

Compiler Optimization and Runtime SystEms

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.

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

1. Provide a Structural Representation
   - Draw application architecture diagrams
   - Represent the relationship between the entities
2. Monitor Dynamic Behaviors
   - Monitor the collaboration between the tasks
   - Detect communication, synchronization events
3. Interact with the Abstract Machine
   - Control the execution of the entities
   - Support interactions with *real* machine

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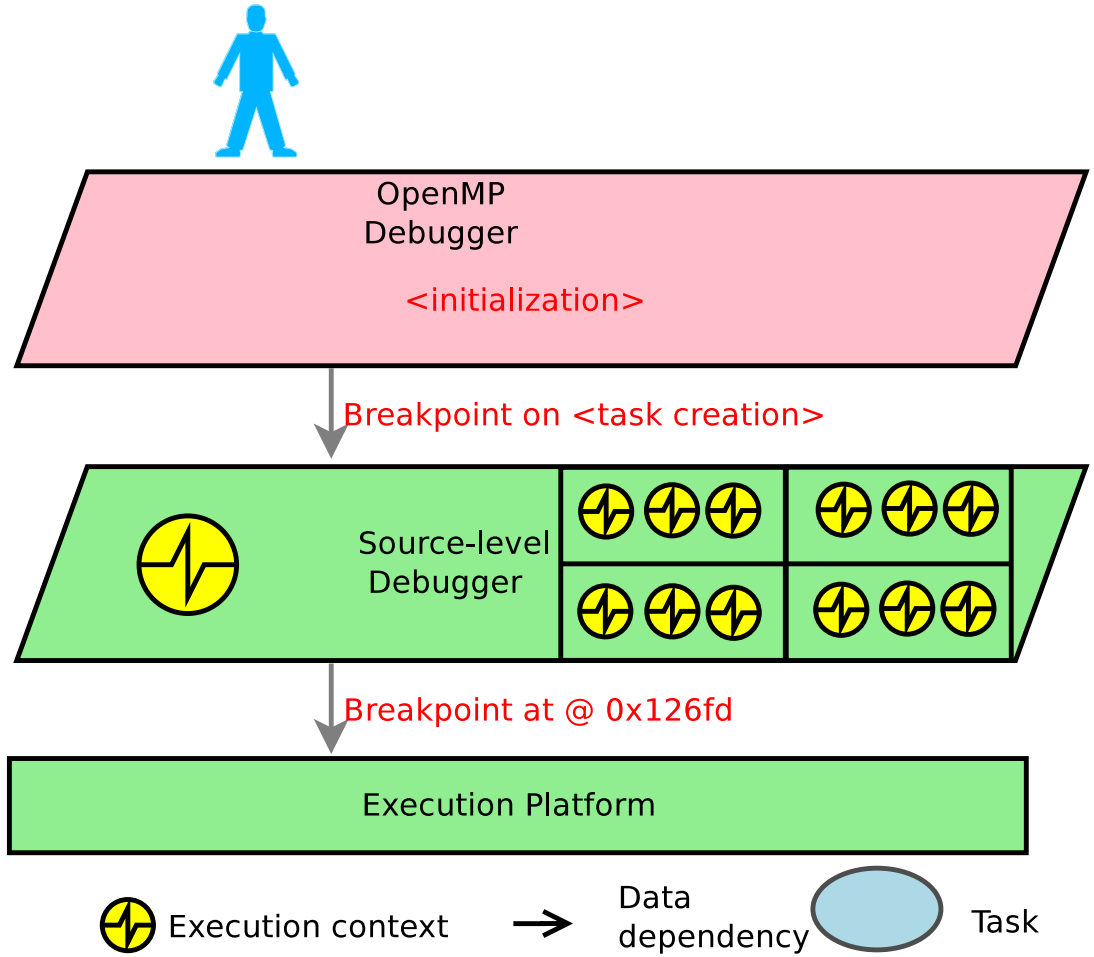
$\Rightarrow$ Detect and interpret the exec. events of the runtime framework

Building Blocks of a Model-Centric Debugger

⇒ Detect and interpret the exec. events of the runtime framework



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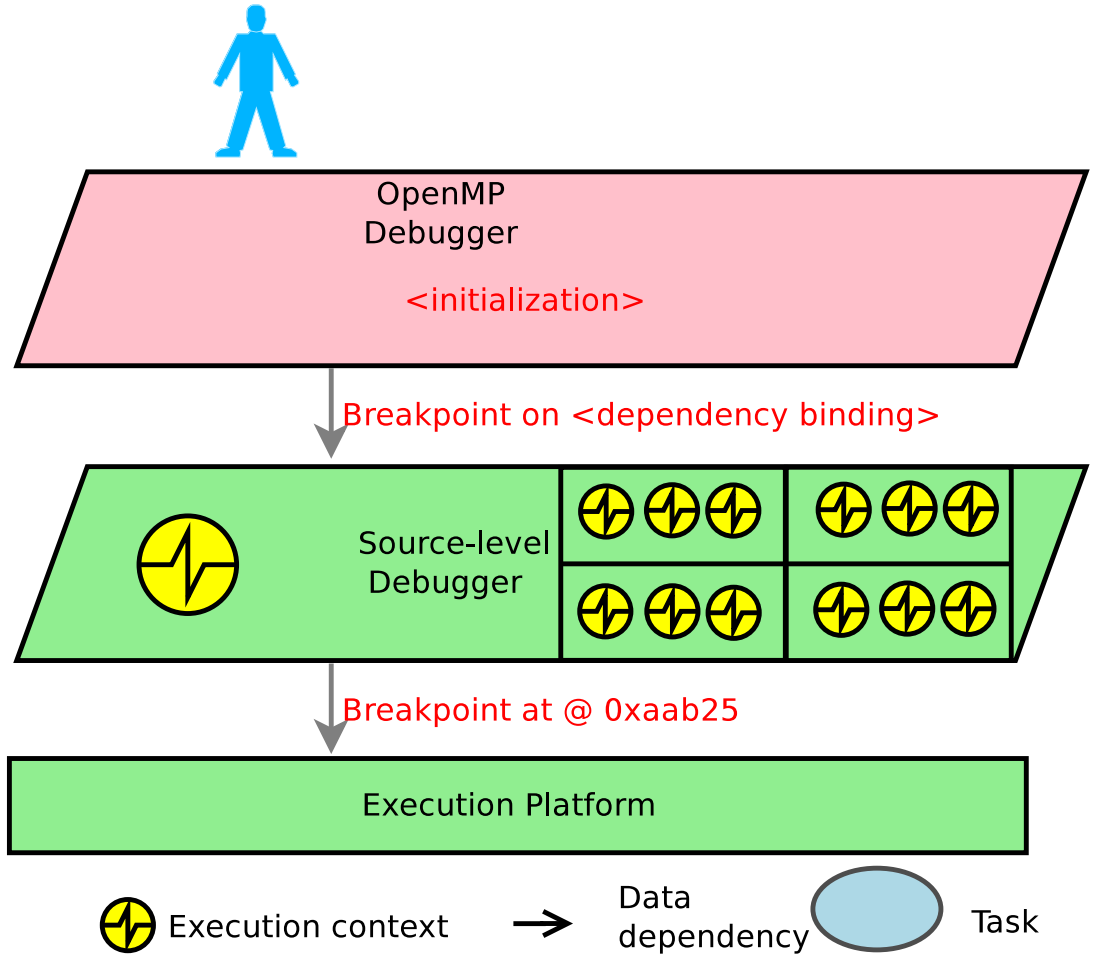

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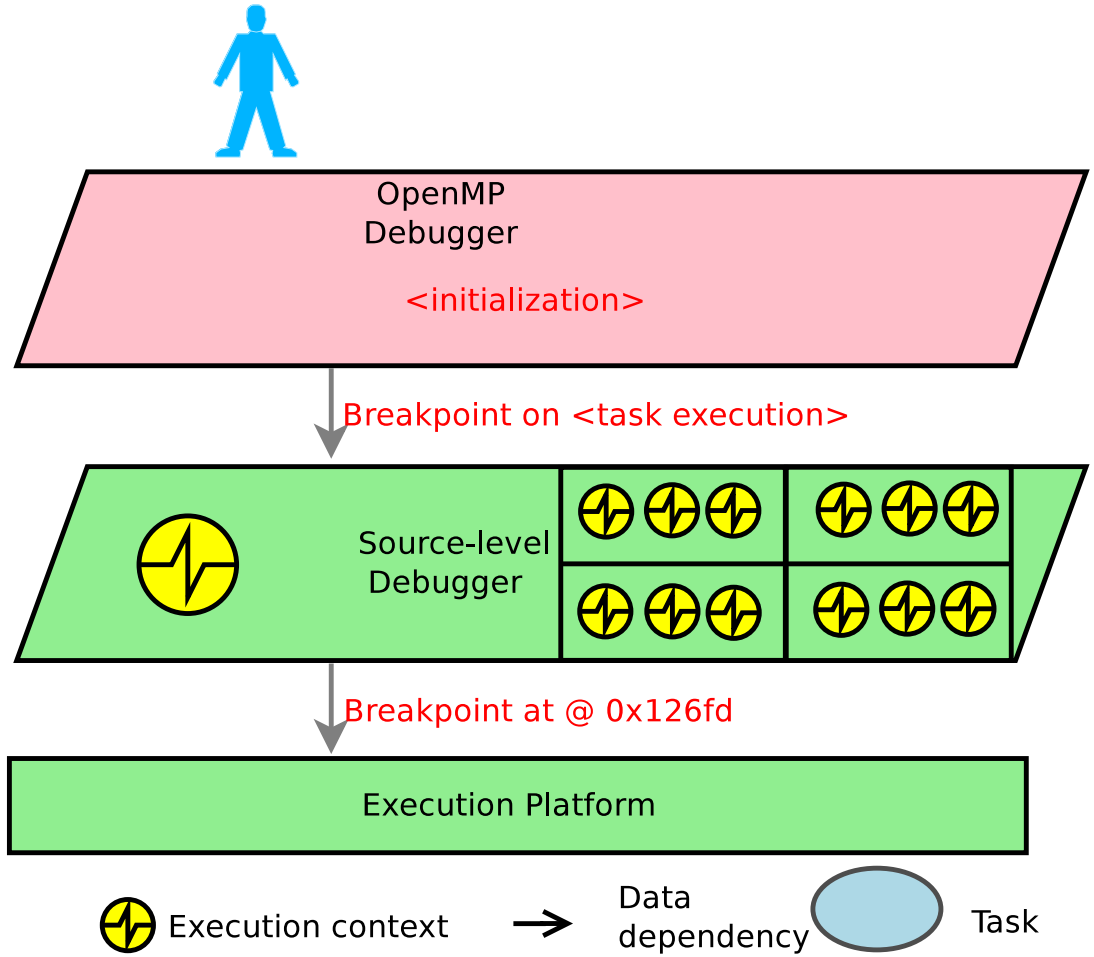

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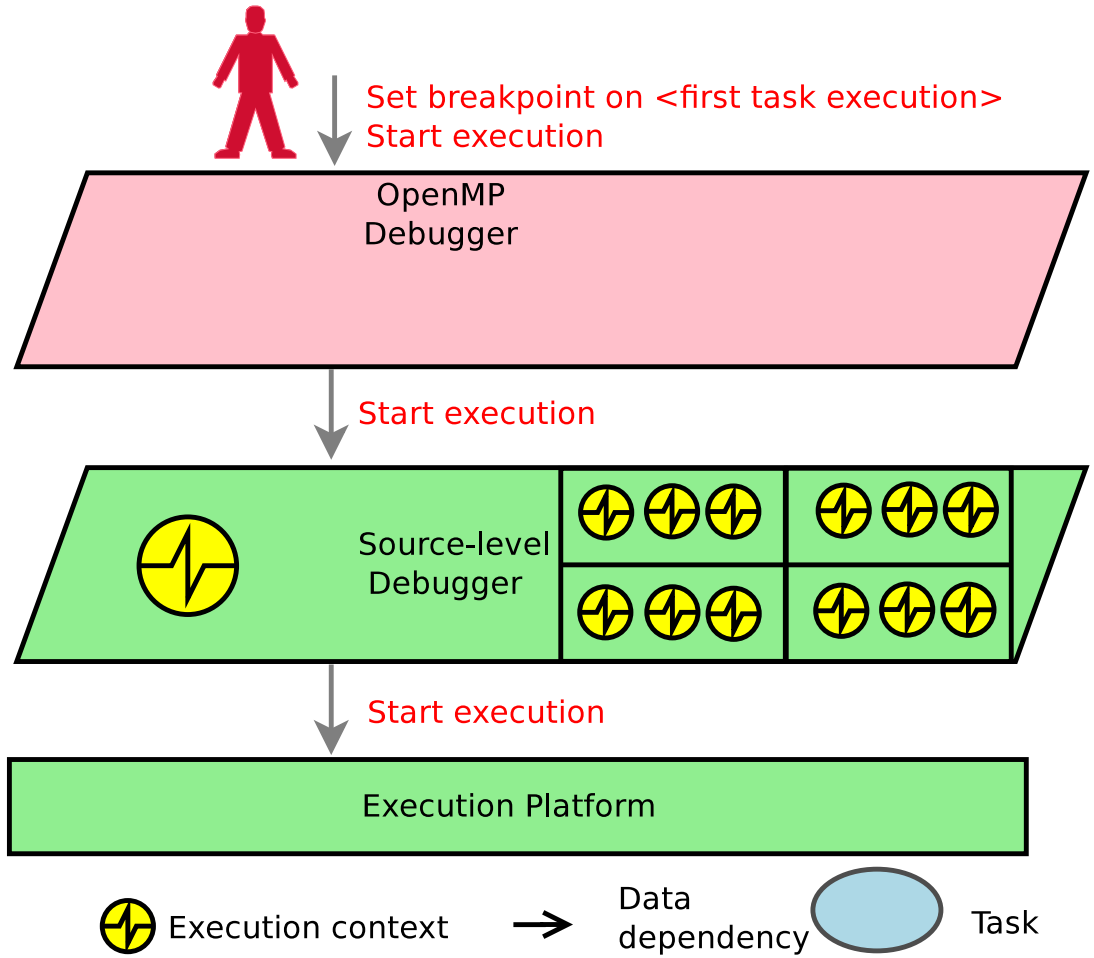

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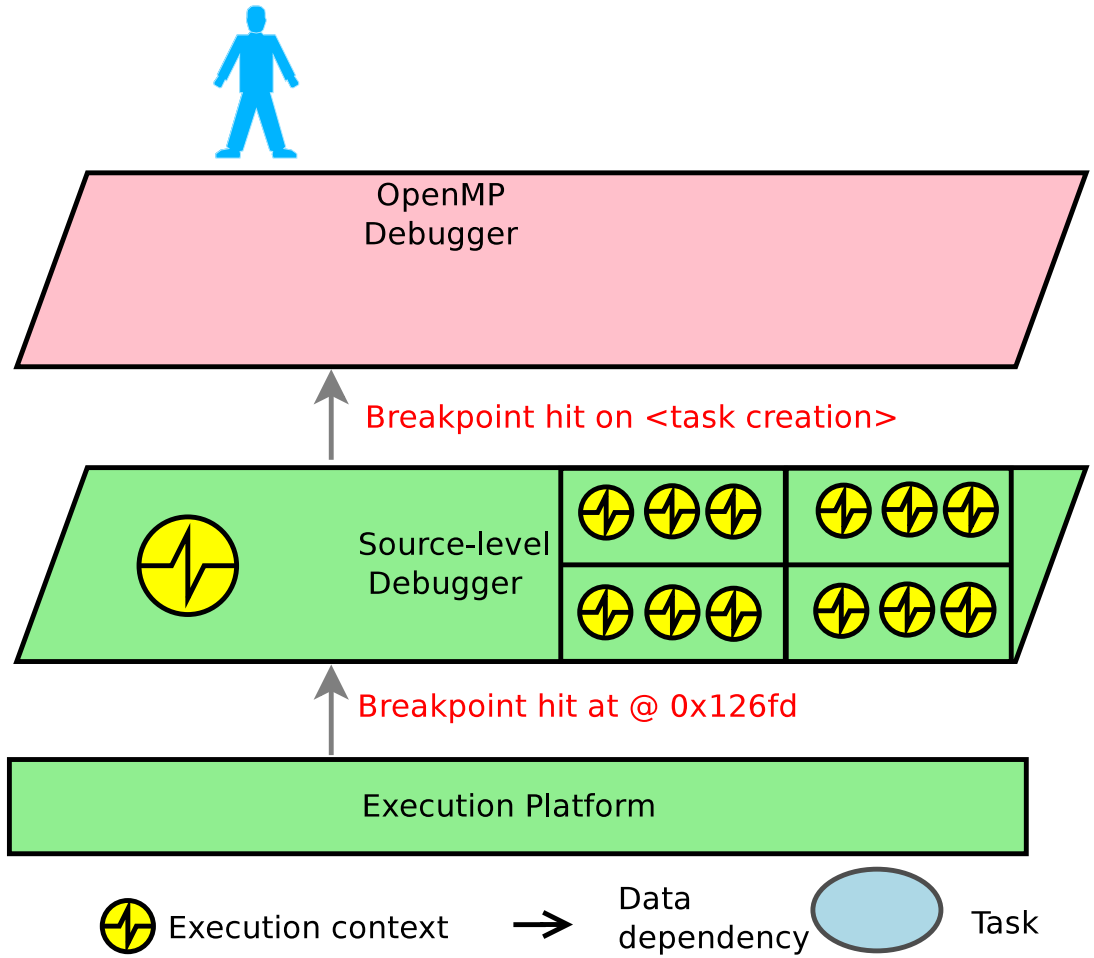

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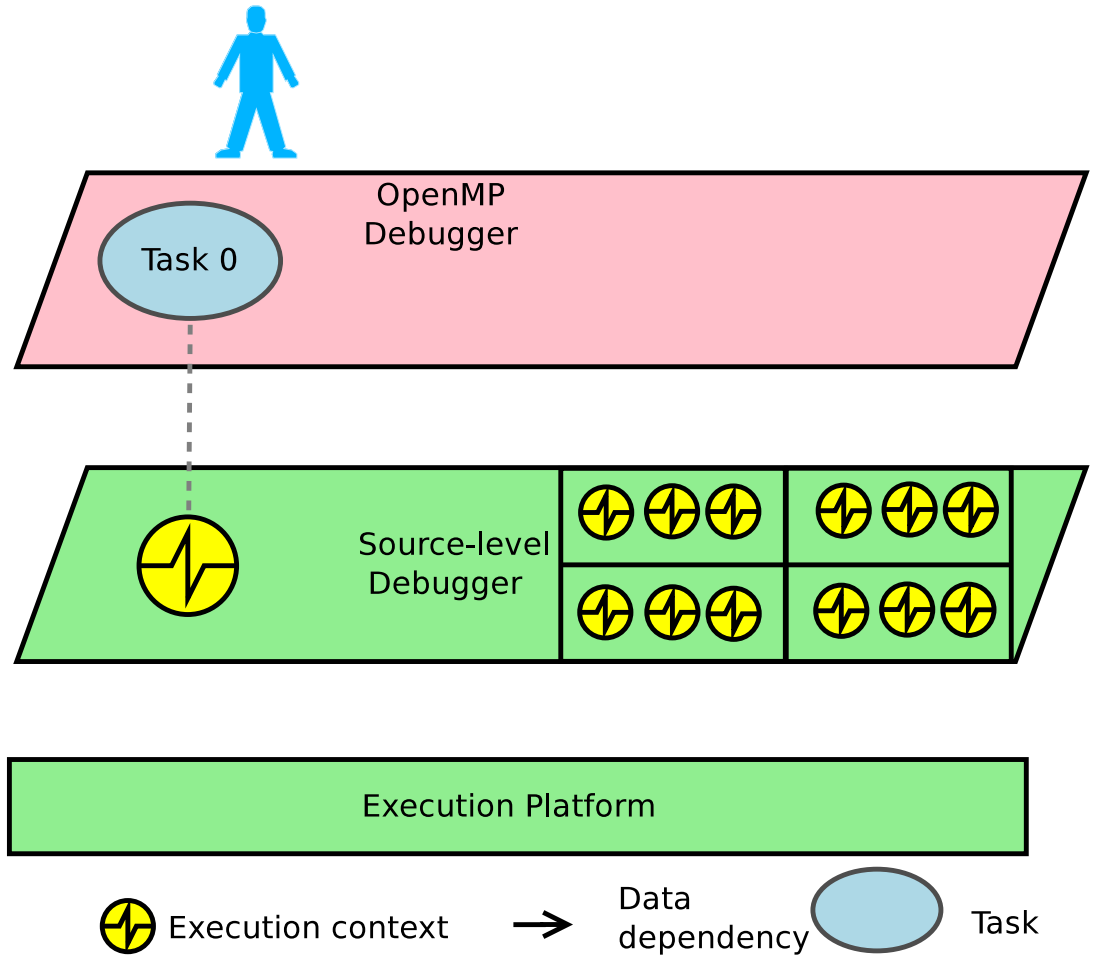

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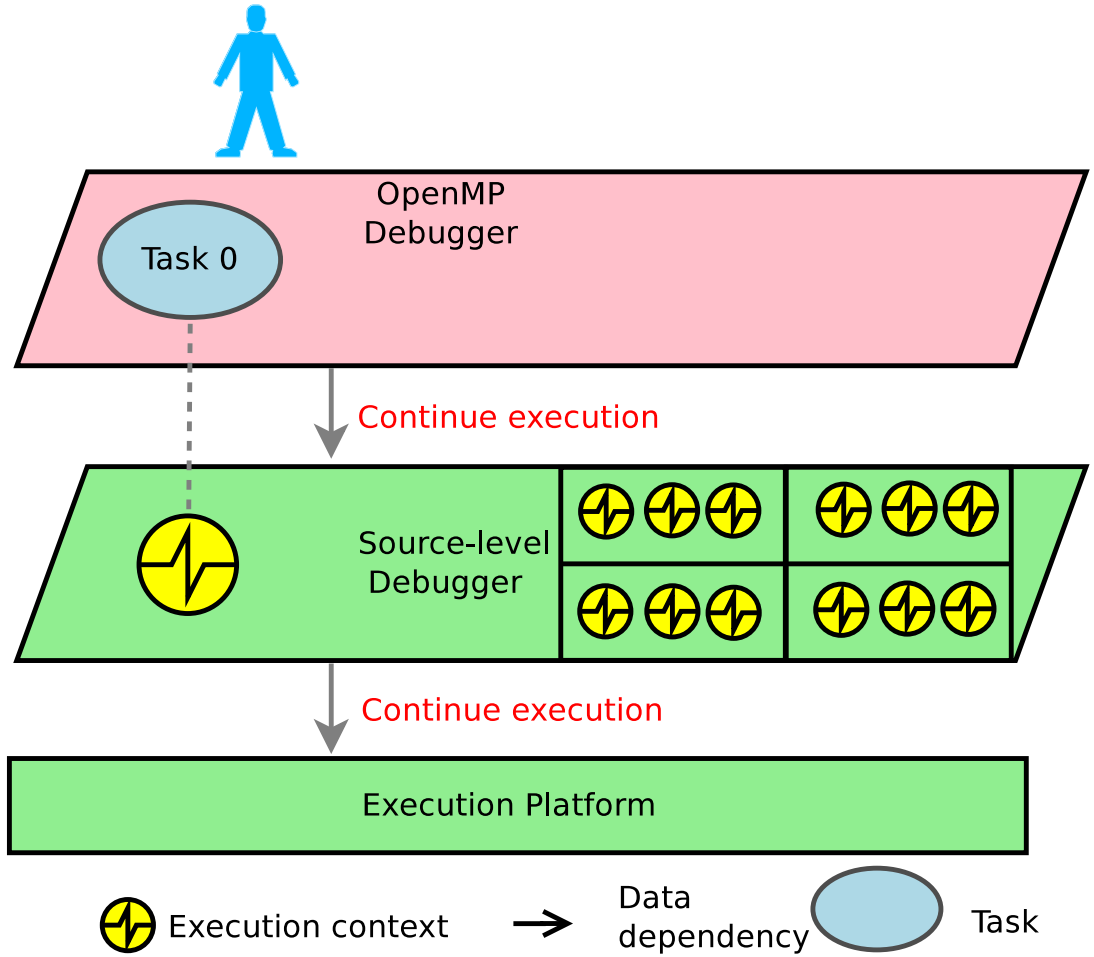

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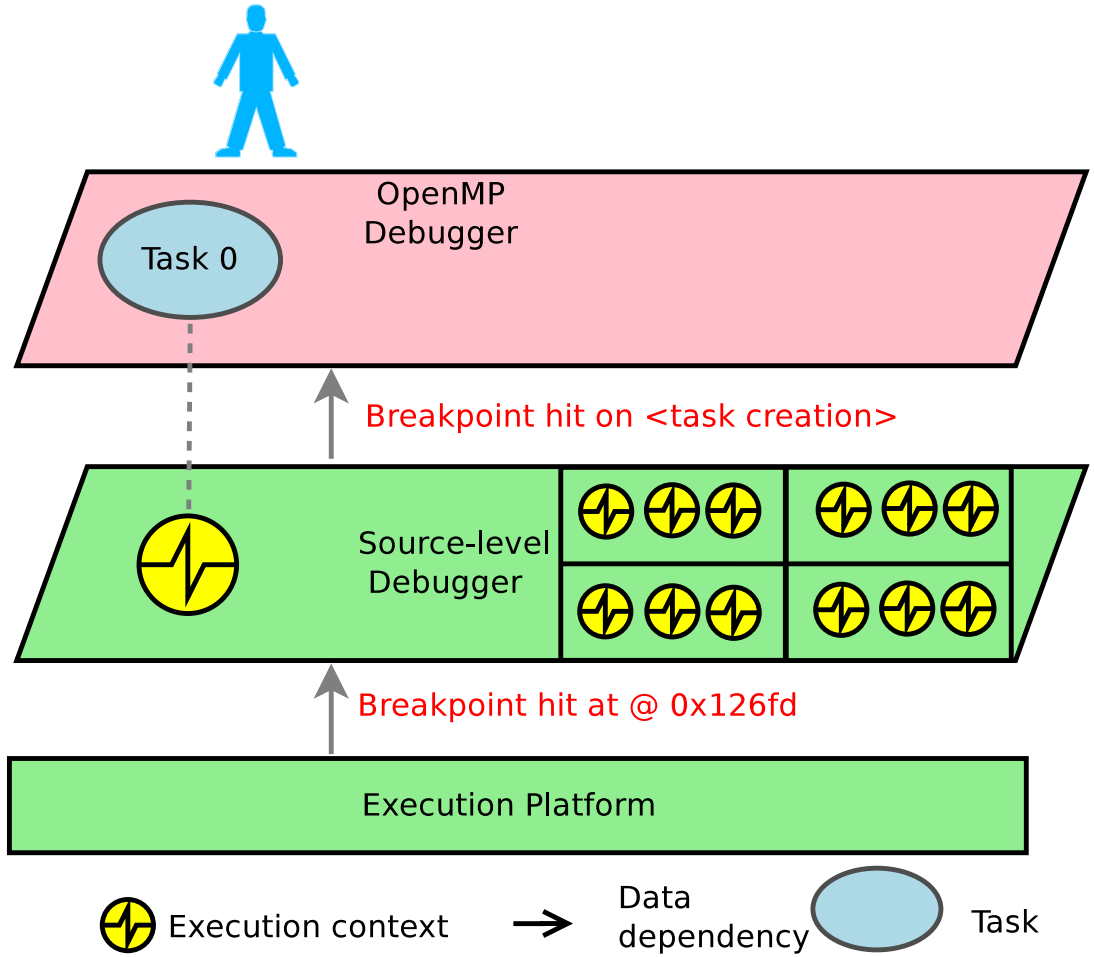

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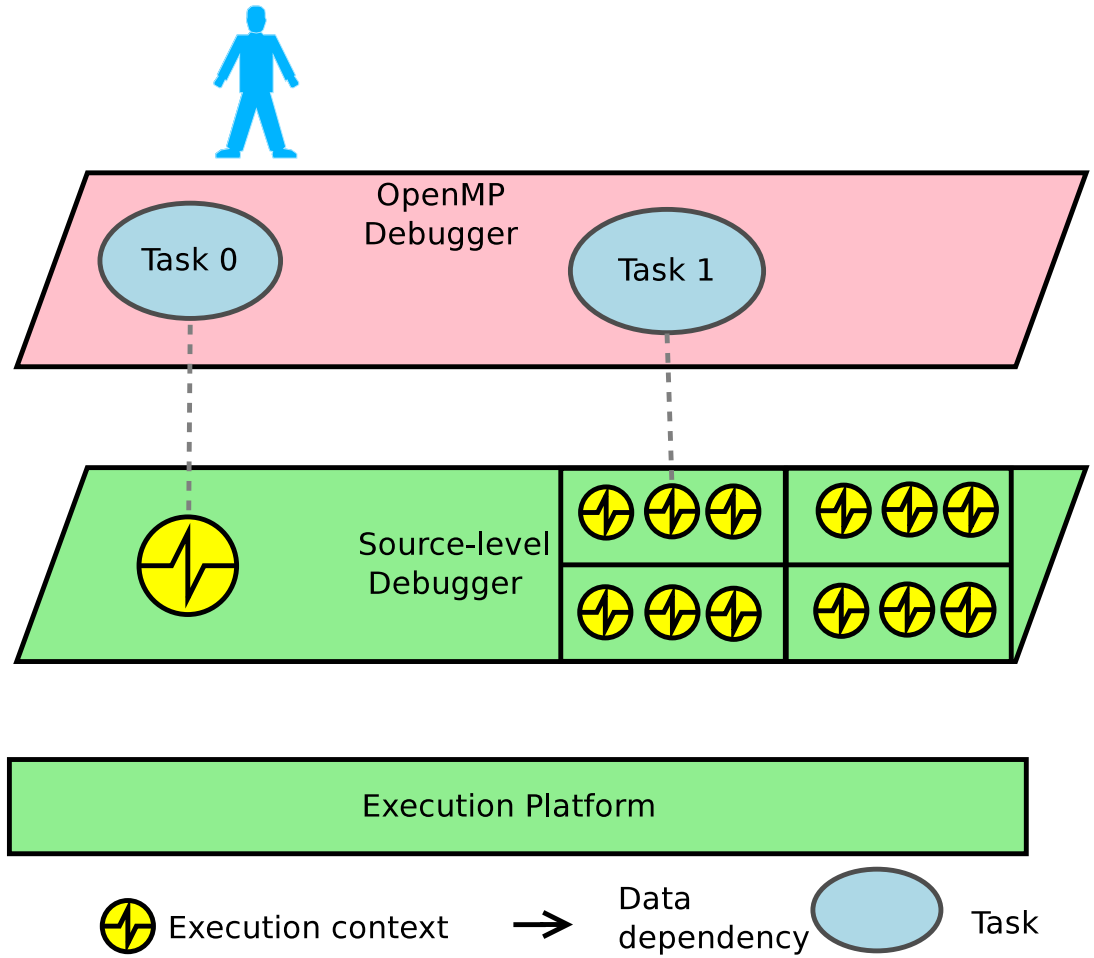

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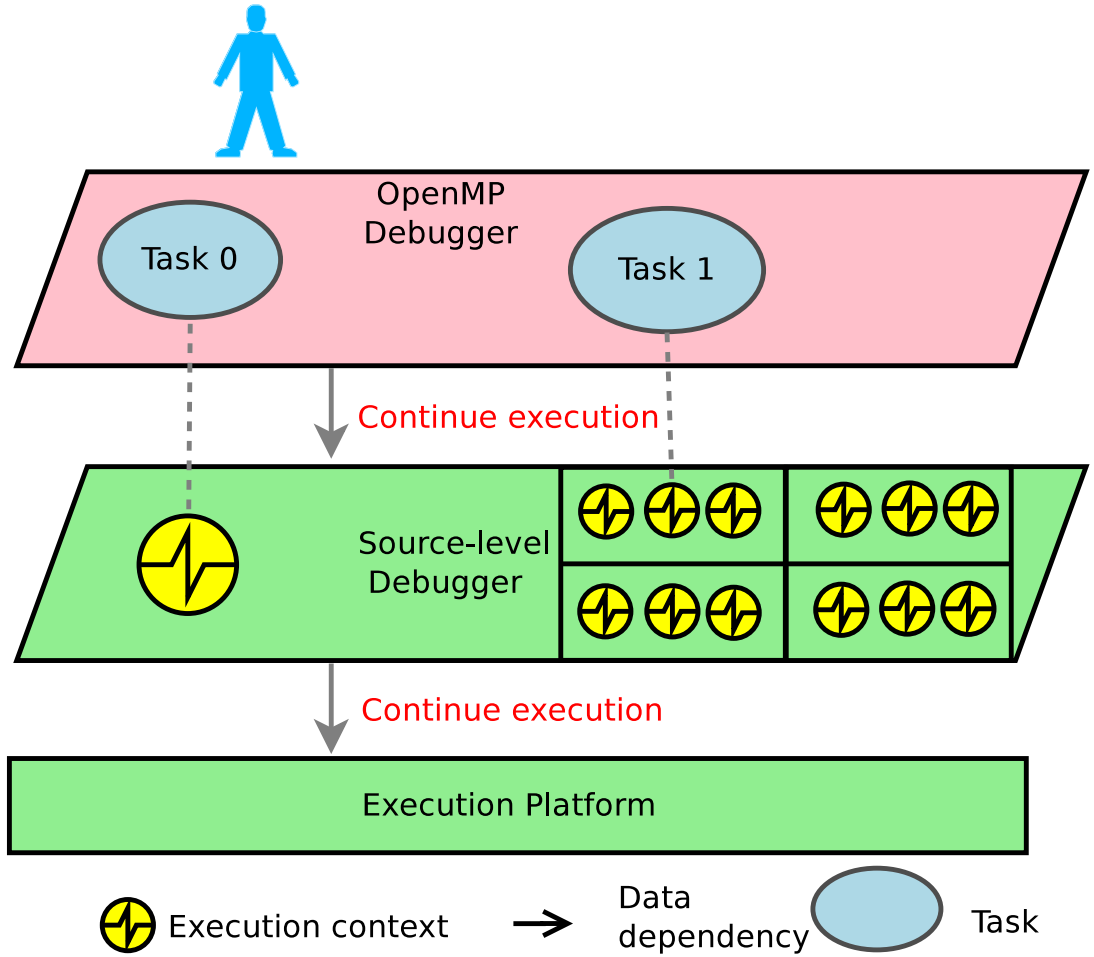

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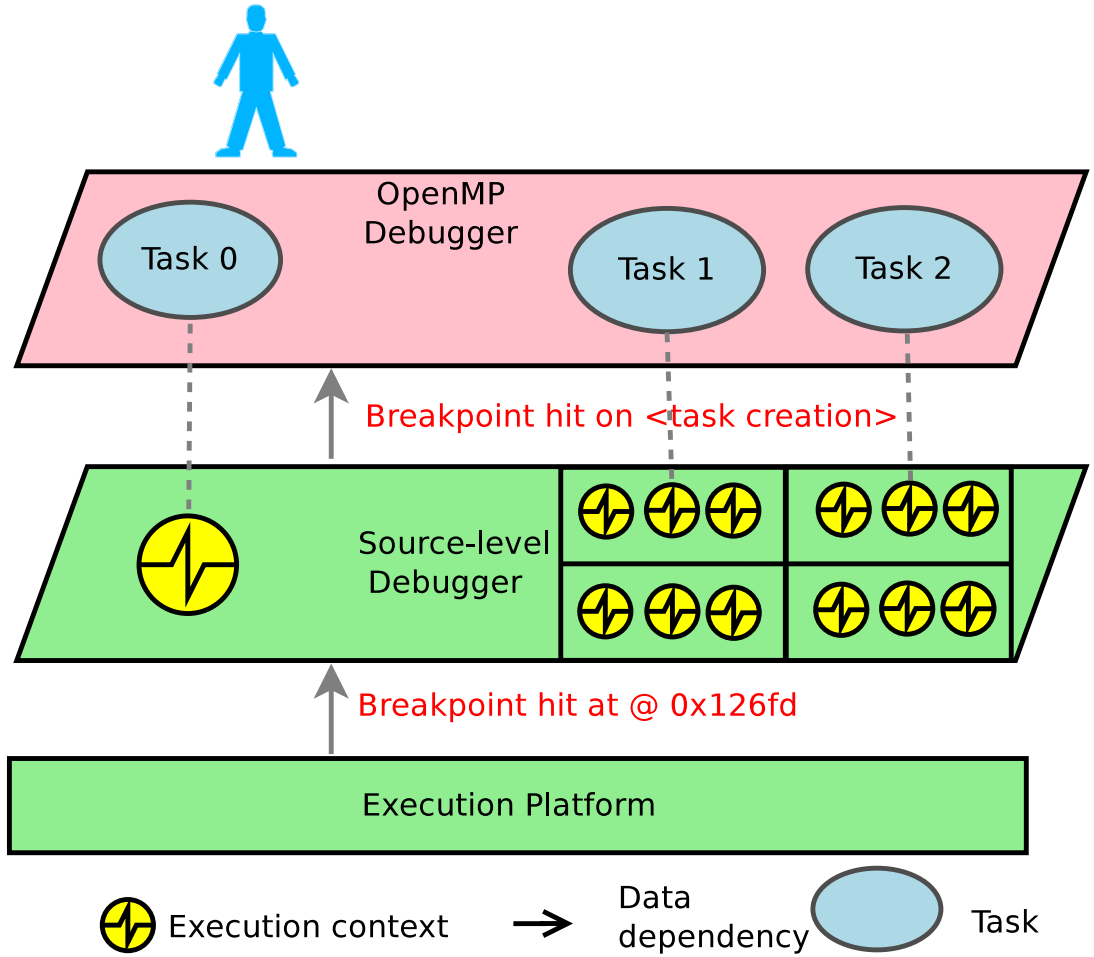

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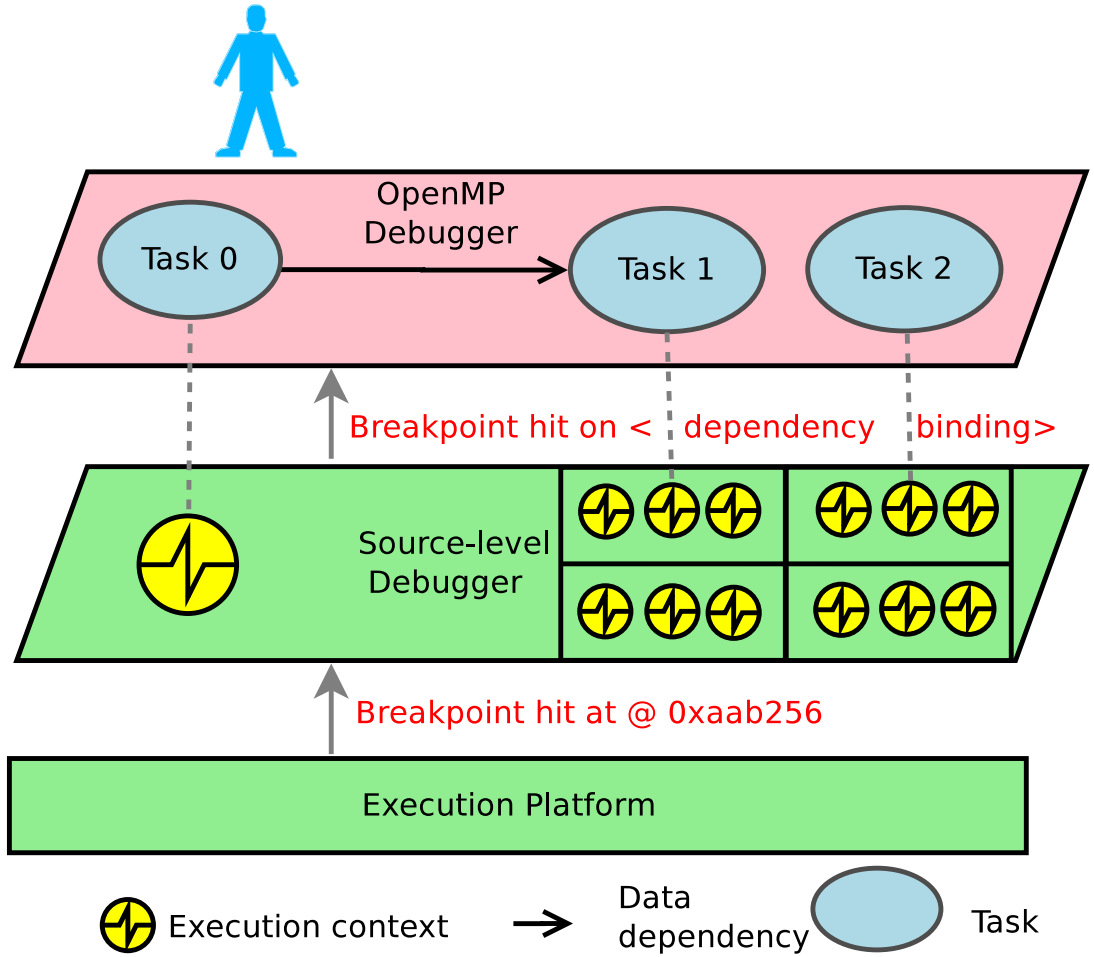

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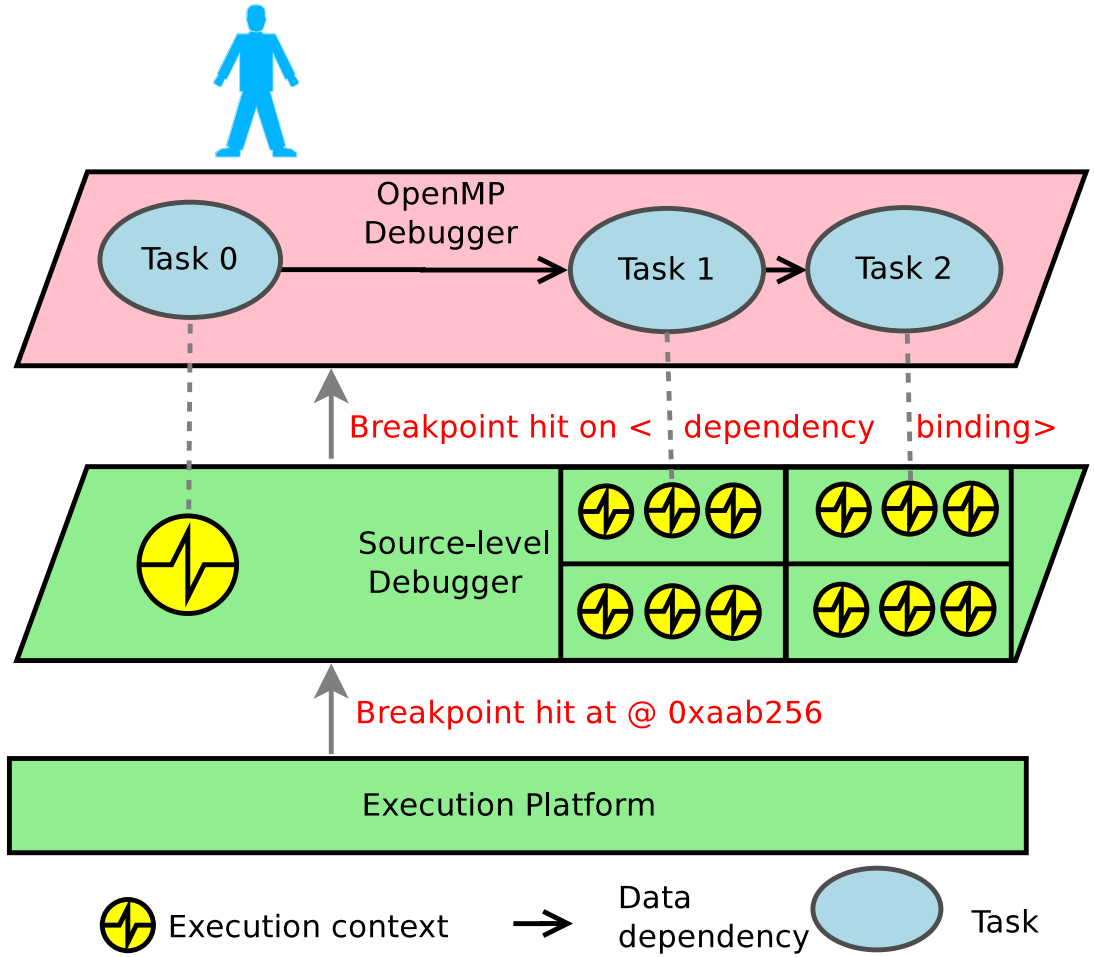

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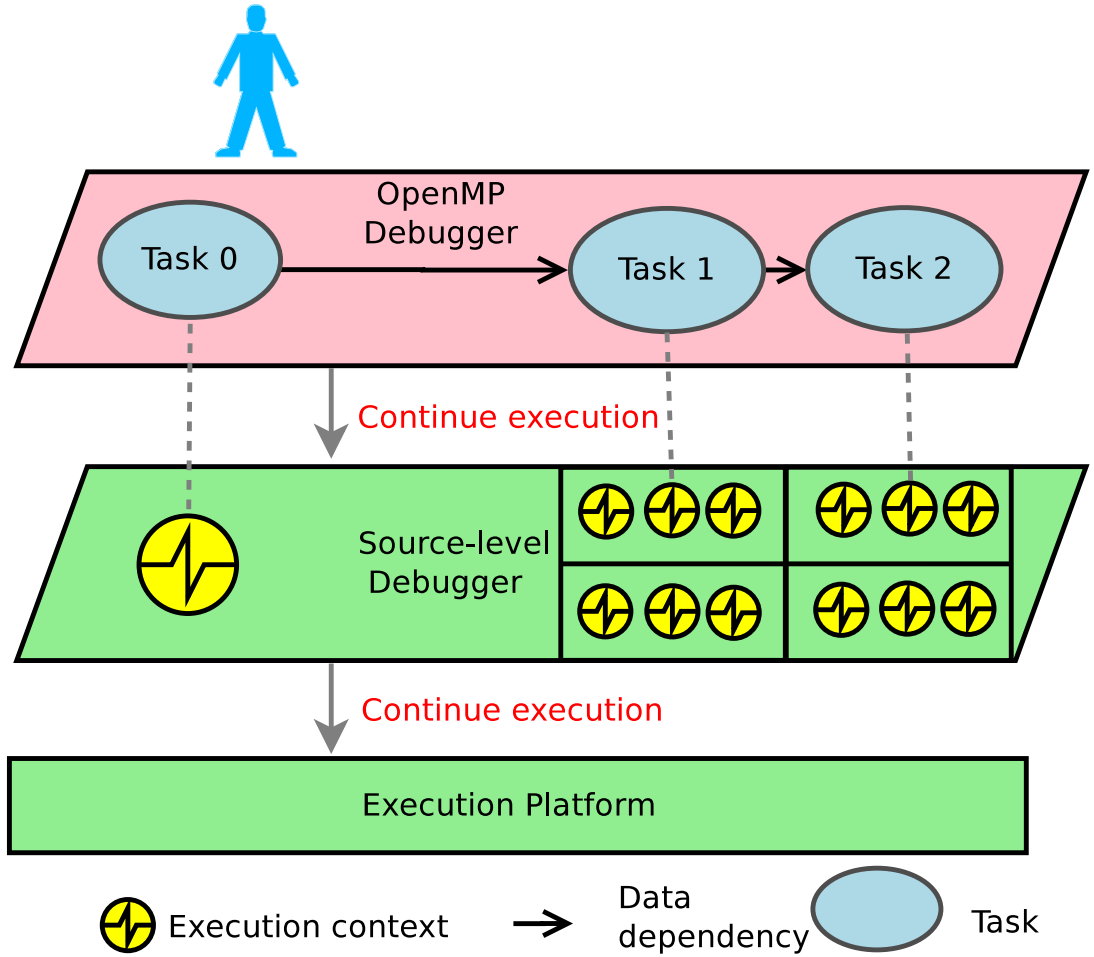

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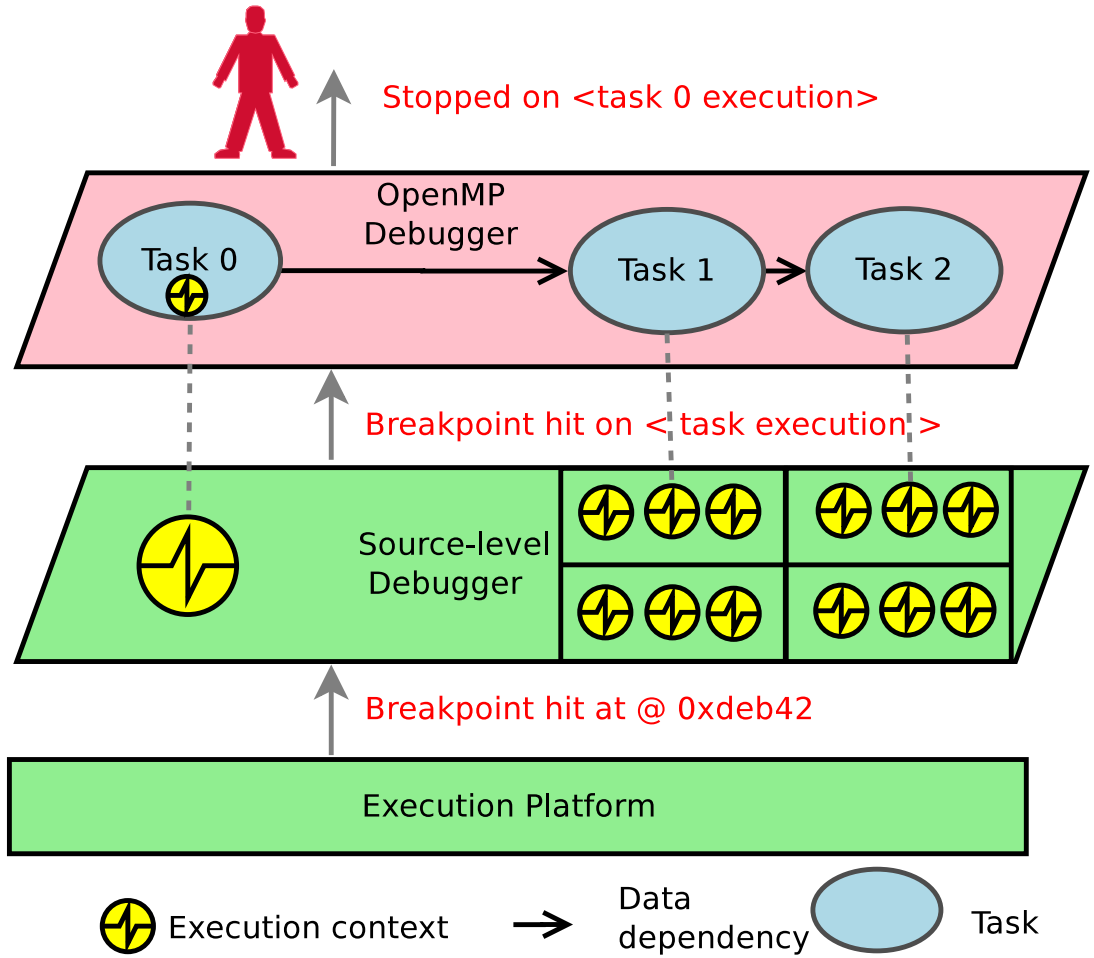

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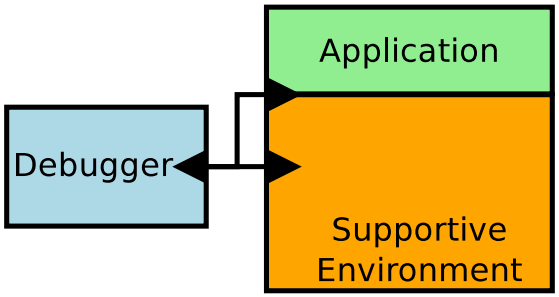
Compiler Optimization and Runtime SystEms



	Breakpoints and Debug Information
Capturable Info.	**High**
Execution Overhead	Significant
Cooperation btw. Debug and Env.	**None**
Portability	Low

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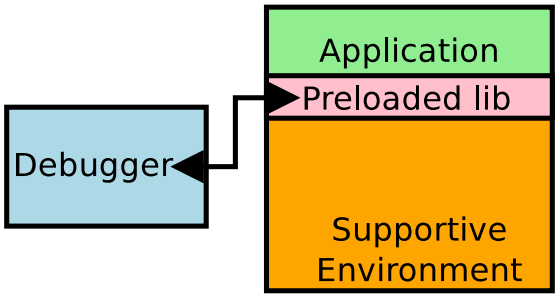

	Breakpoints and Debug Information	**Preloaded Library**
Capturable Info.	**High**	Limited to API
Execution Overhead	Significant	Limited
Cooperation btw. Debug and Env.	**None**	Low
Portability	Low	**Very Good**

Building Blocks of a Model-Centric Debugger

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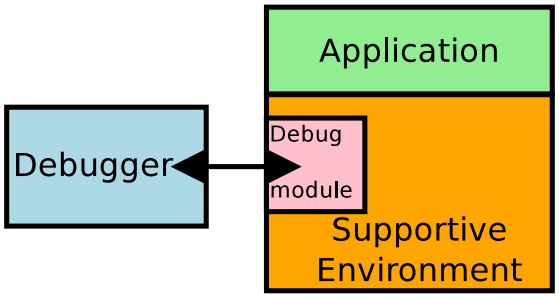


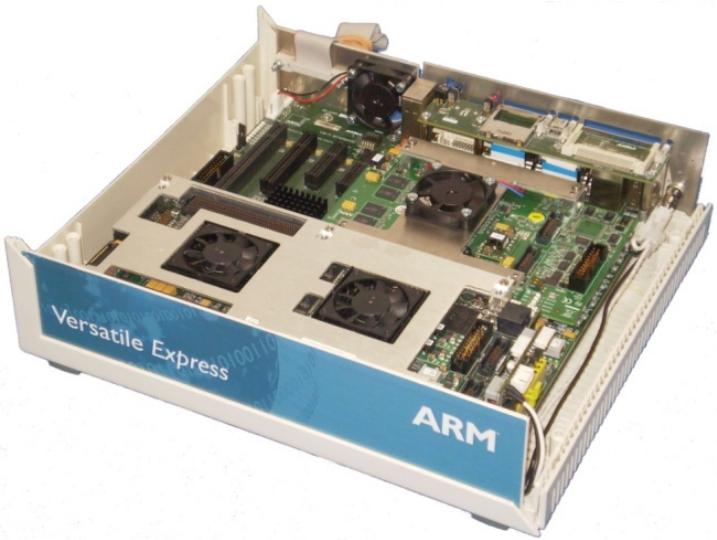
	Breakpoints and Debug Information	Preloaded Library	Specialized Debug Module
Capturable Info.	**High**	Limited to API	**Full**
Execution Overhead	Significant	Limited	Limited
Cooperation btw. Debug and Env.	**None**	Low	Strong
Portability	Low	**Very Good**	Vendor Specific

Agenda

Compiler Optimization and Runtime SystEms

Debugging Embedded and Multicore Applications

ARM Juno



- asymmetric archi.
- ARM big.LITTLE + Mali GPU

OpenMP Parallel Programming

- fork/join multithreading
- tasks with dependencies
- GNU Gomp, Intel OpenMP, ...

mcGDB debugger

- Python extension of GDB
- support for dataflow, components, ...
- developed in partnership with ST

OpenMP: mcGDB execution control

Compiler Optimization and Runtime SystEms

... control the execution of the entities ...

1. start
2. omp start
3. omp step
4. omp next barrier
5. omp critical next
6. omp critical next
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```
int main() {
  ①// beginning of main function
  #pragma omp parallel {
    // beginning of parallel region

    #pragma omp single {
      // execute single
    }//implicit barrier

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OpenMP: structural representation

Compiler Optimization and Runtime SystEms

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... provide details about entity state

1. **fork-join** $\Longrightarrow$ OpenMP sequence diagrams
2. **task-based** $\Longrightarrow$ mcGDB+Temanejo cooperation

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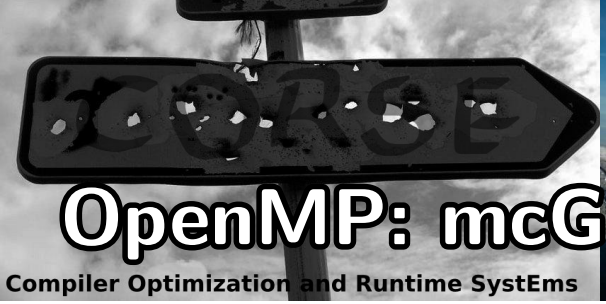

OpenMP: mcGDB sequence diagram

Compiler Optimization and Runtime SystEms

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5. thread 2
6. omp critical next
7. omp critical next
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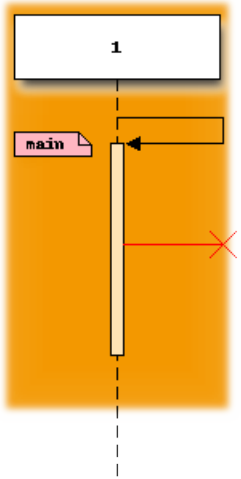

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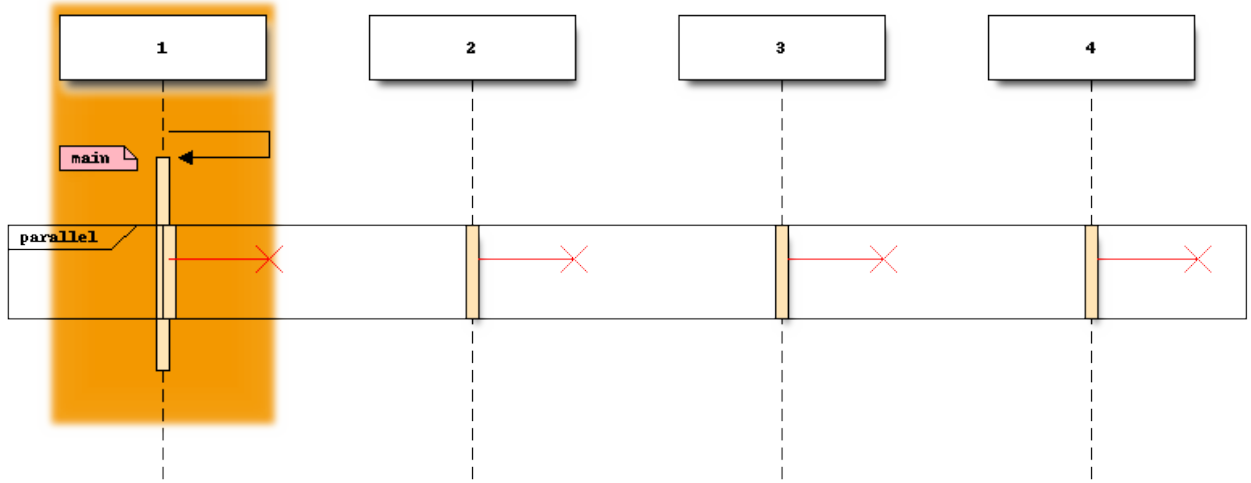

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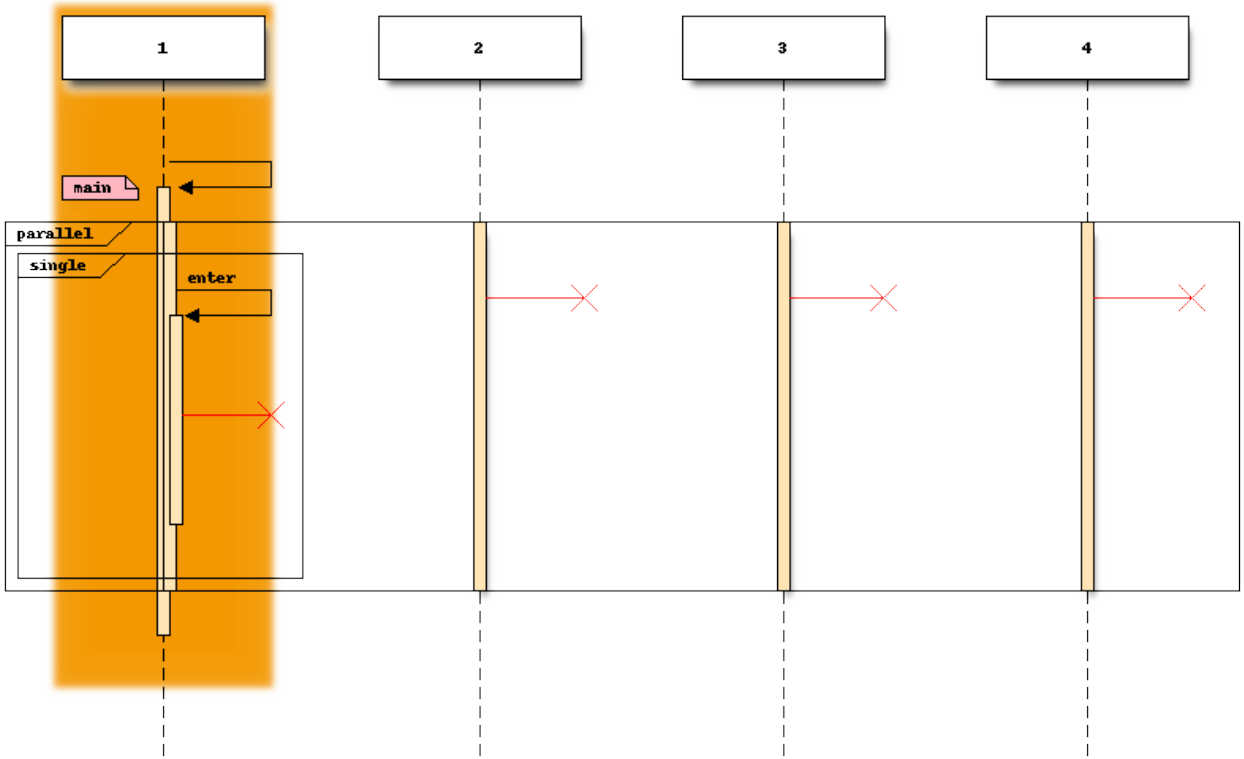

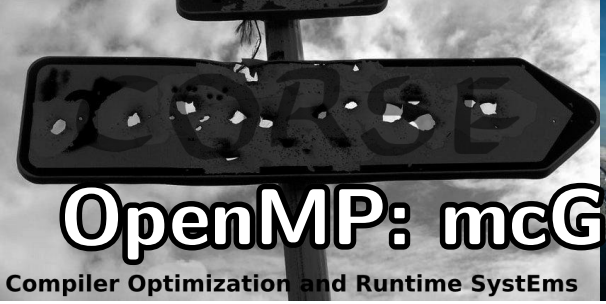

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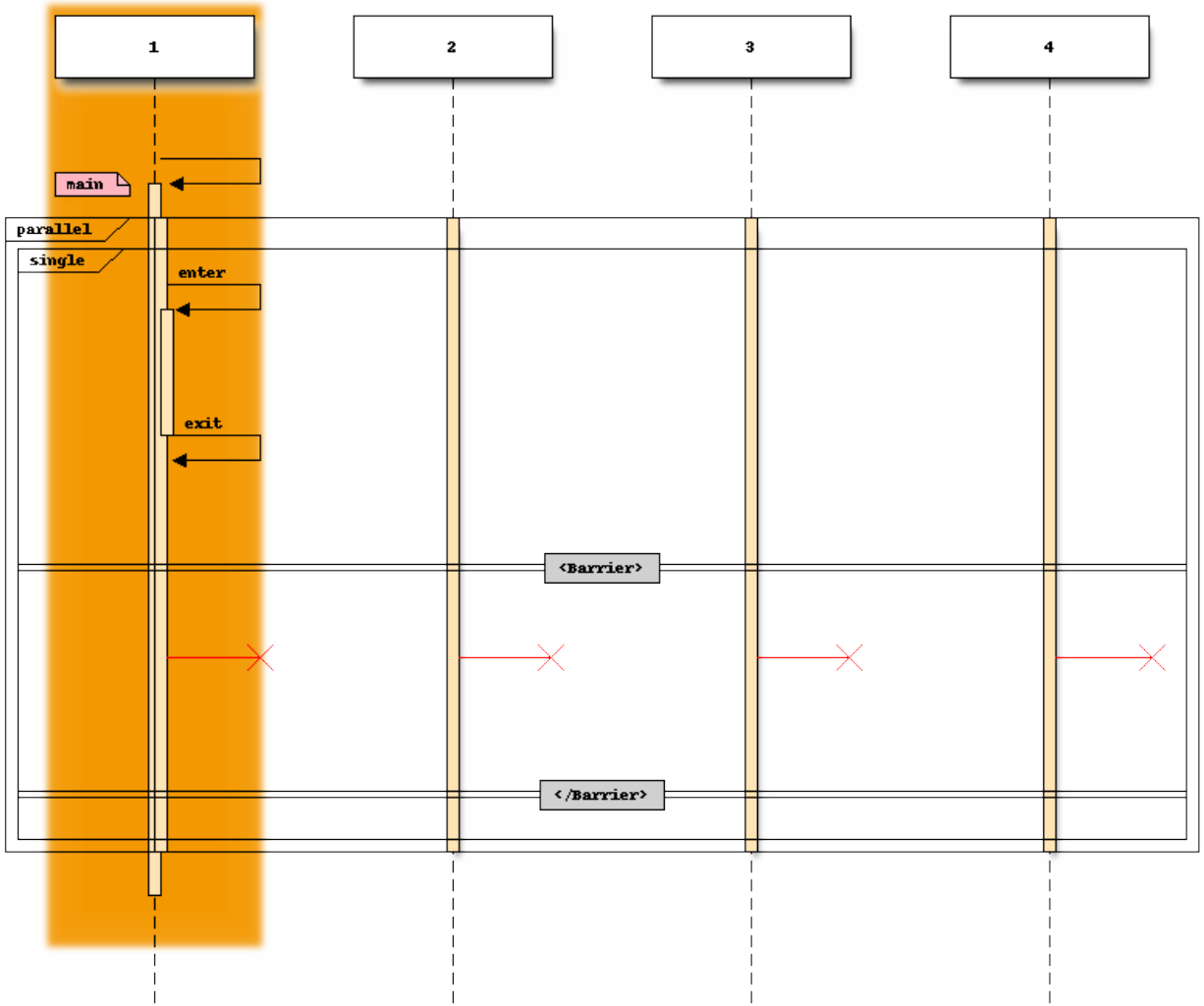
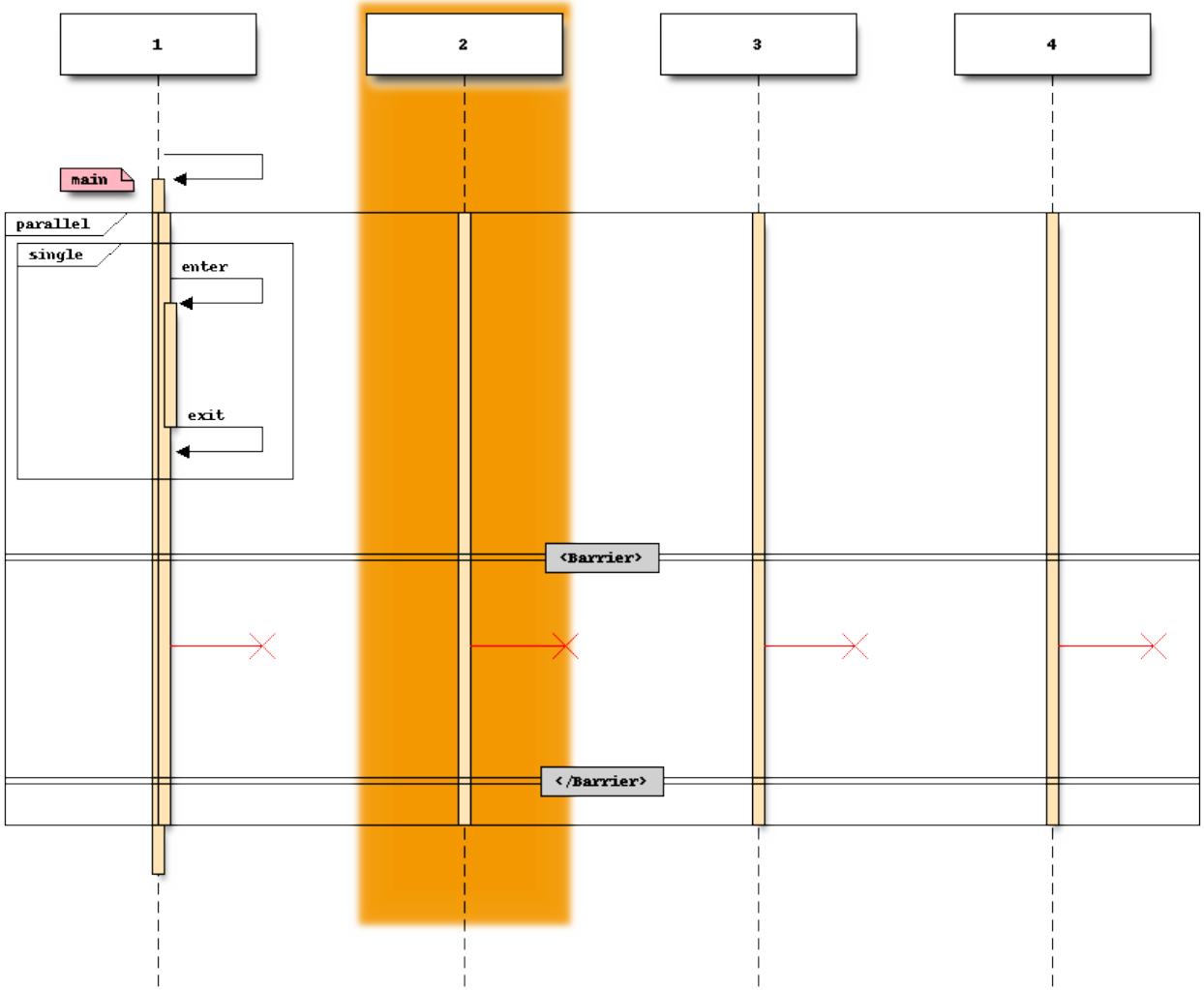


OpenMP: mcGDB sequence diagram

Compiler Optimization and Runtime SystEms

1. start
2. omp start
3. omp step
4. omp next barrier
5. thread 2
6. omp critical next
7. omp critical next
8. omp critical next



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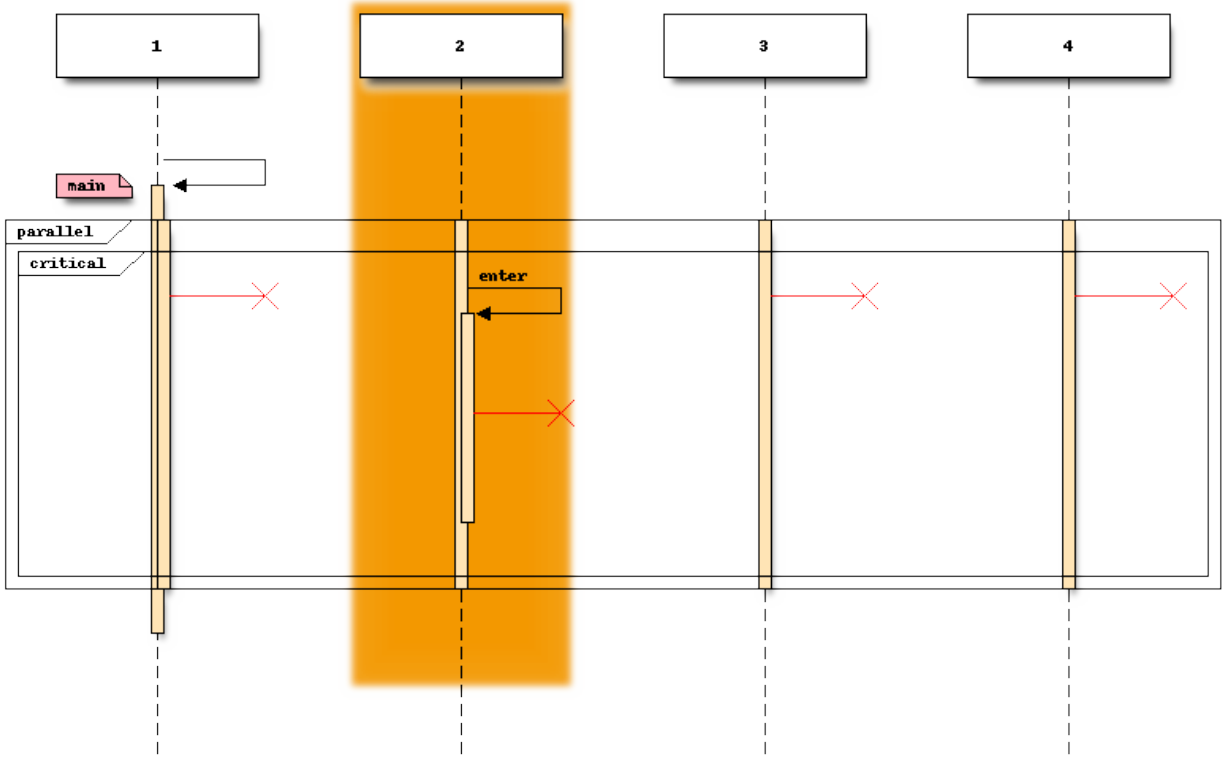

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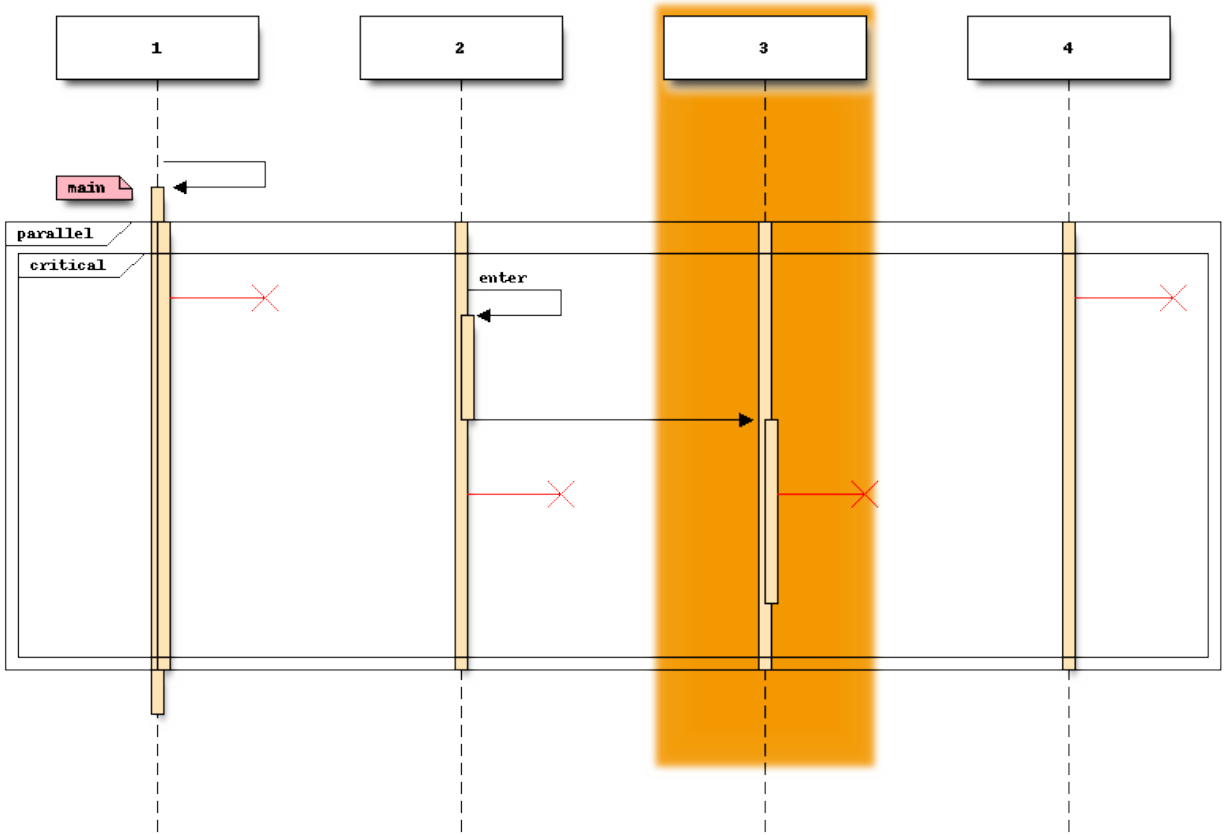

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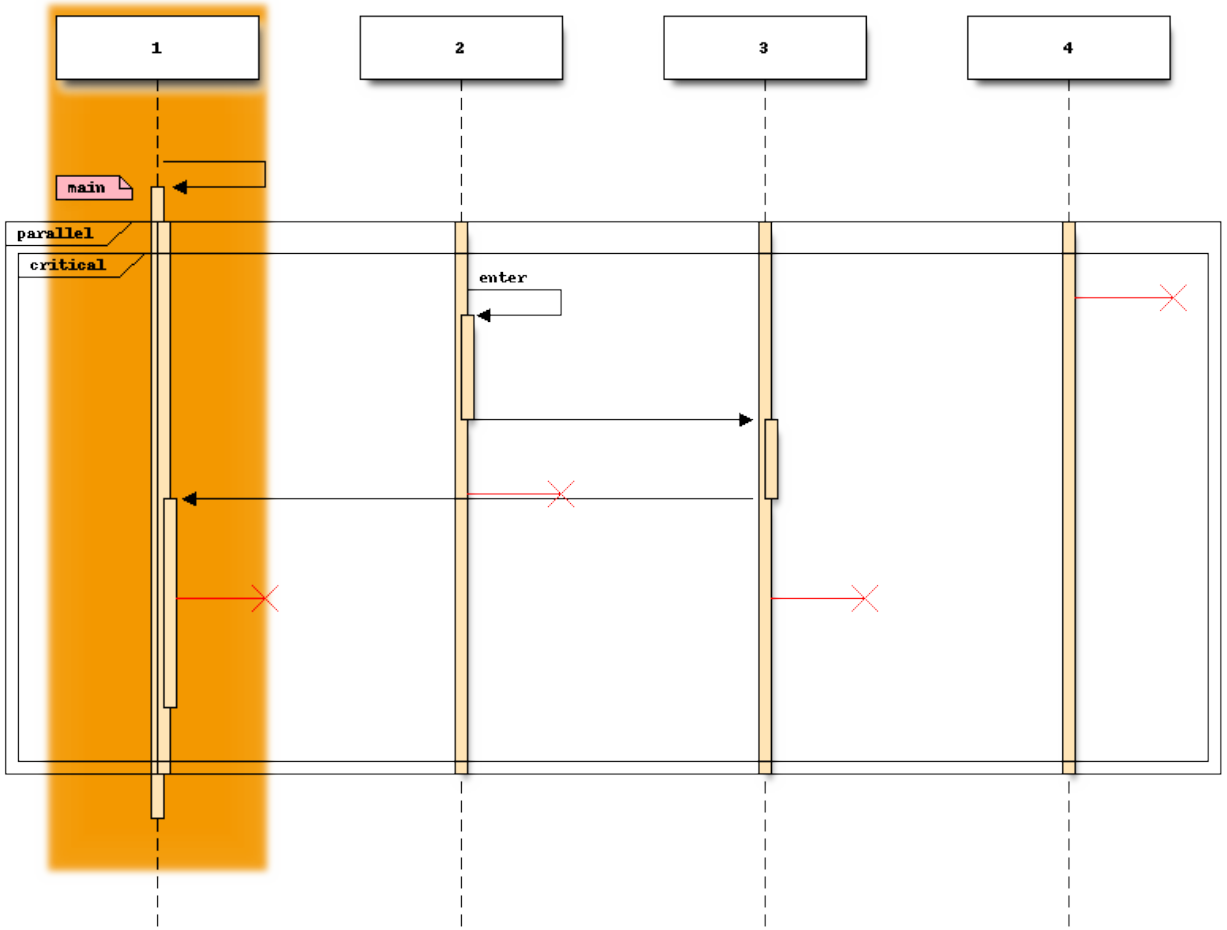


OpenMP: structural representation

Compiler Optimization and Runtime SystEms

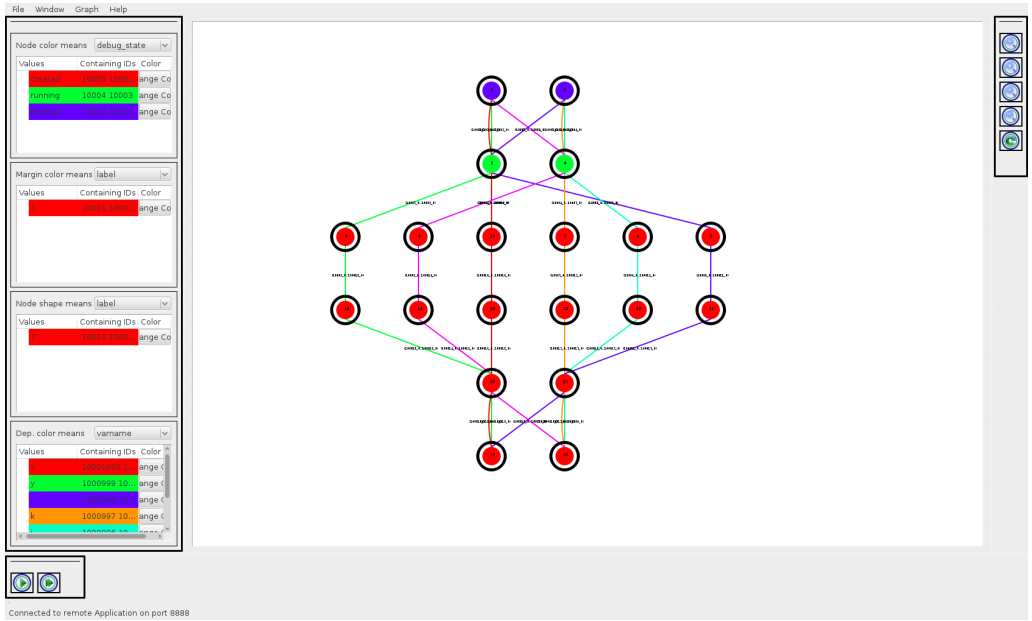
... provide a structural representation
... provide details about entity state

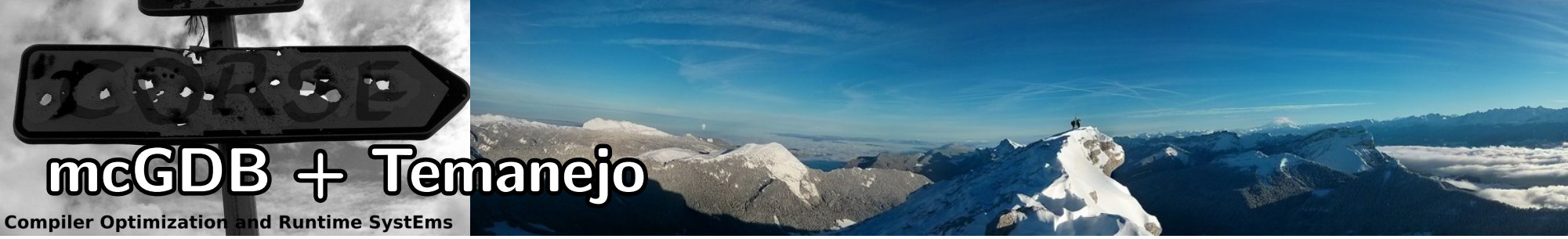
1. **fork-join** $\Longrightarrow$ OpenMP sequence diagrams
2. **task-based** $\Longrightarrow$ mcGDB+Temanejo cooperation

(HLRS Stuttgart) Temanejo ...

✓ is a great visualization tool for task debugging,

✗ and does not support source-level debugging.





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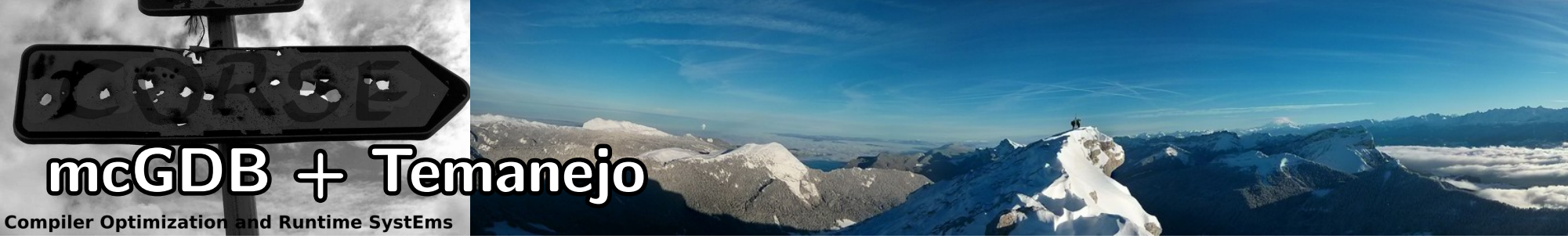
GDB/mcGDB ...

- ✗ has no visualization engine,
- ✓ but provides source debugging at language (gdb) and model level.



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So let's combine them!

mcGDB – Temanejo cooperation:

Temanejo

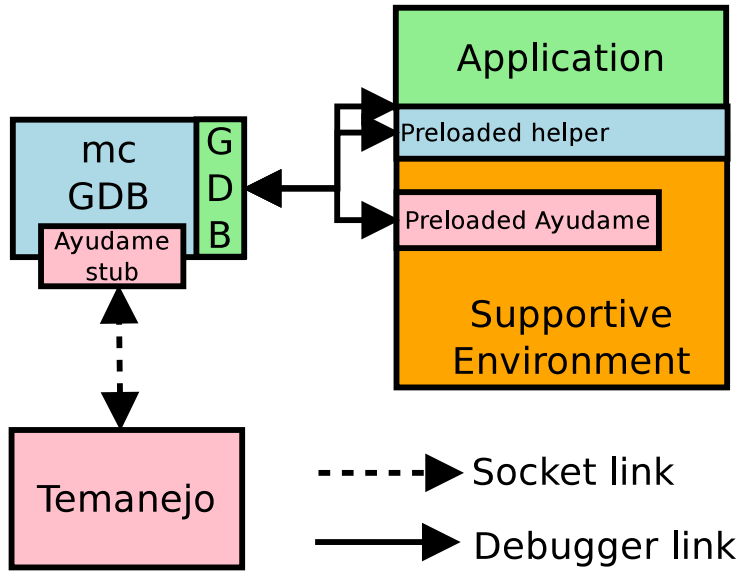
- task graph visualization
- simple model-level execution control.
- sequence diagram visualization.

mcGDB

- task graph and exec. events capture,
- advanced model-level exec. control.

GDB

- language and assembly level
  execution control, memory inspection.



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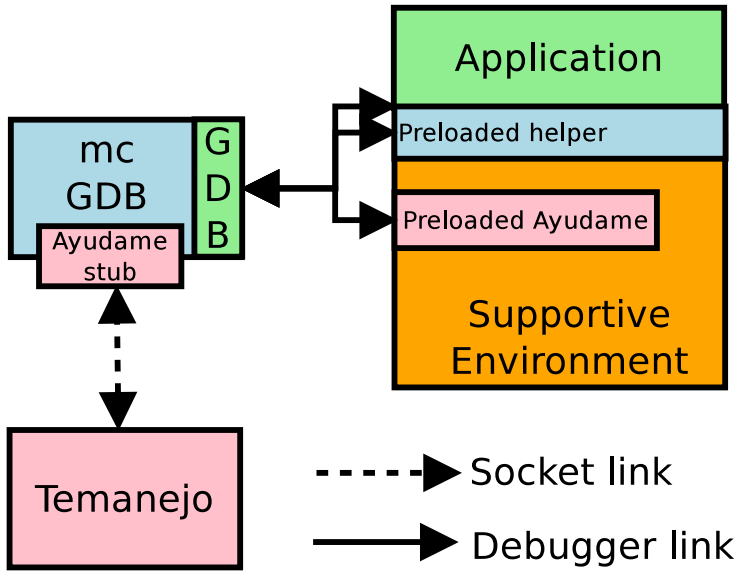

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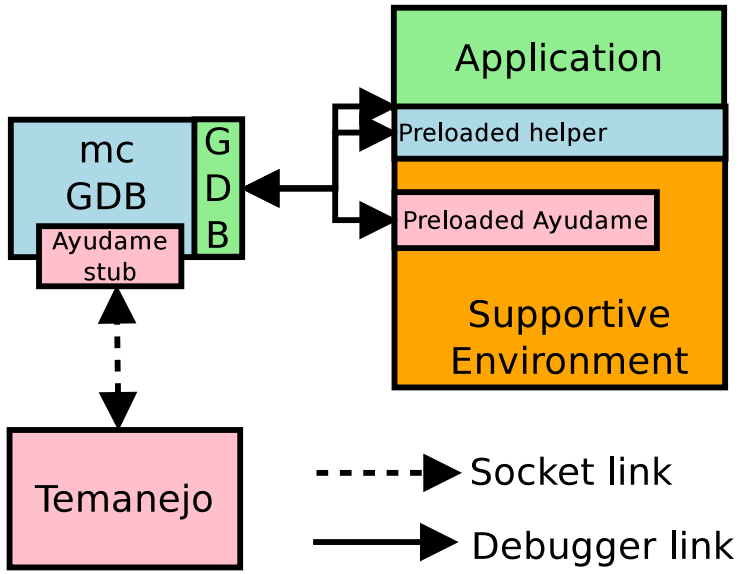

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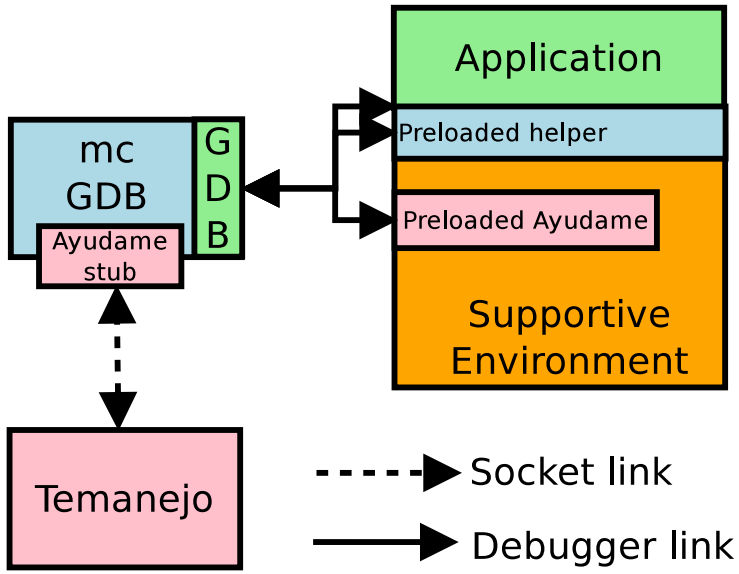
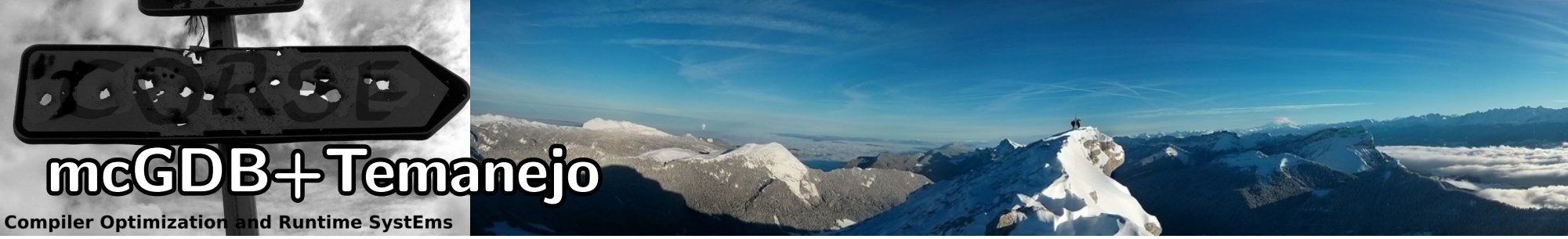
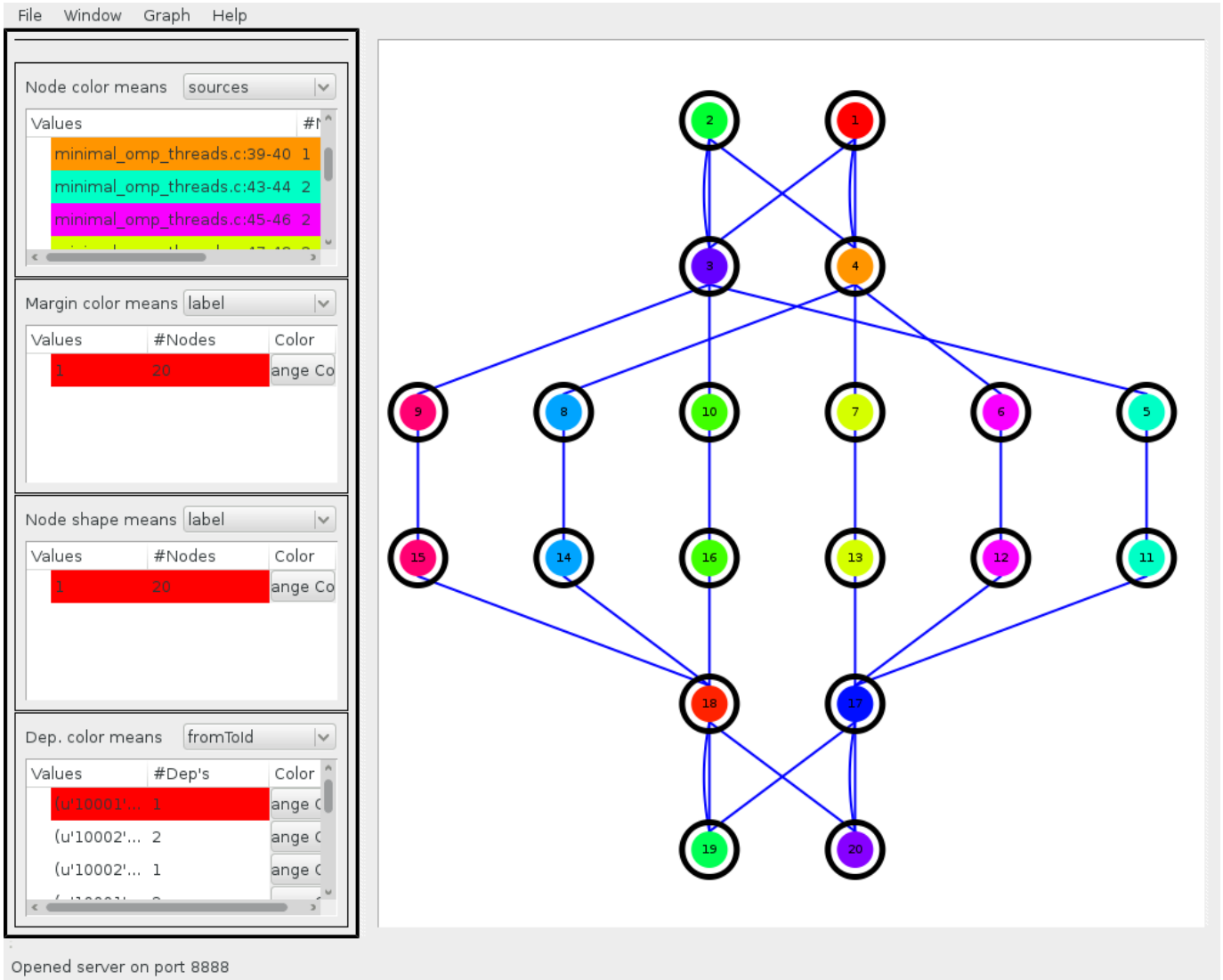
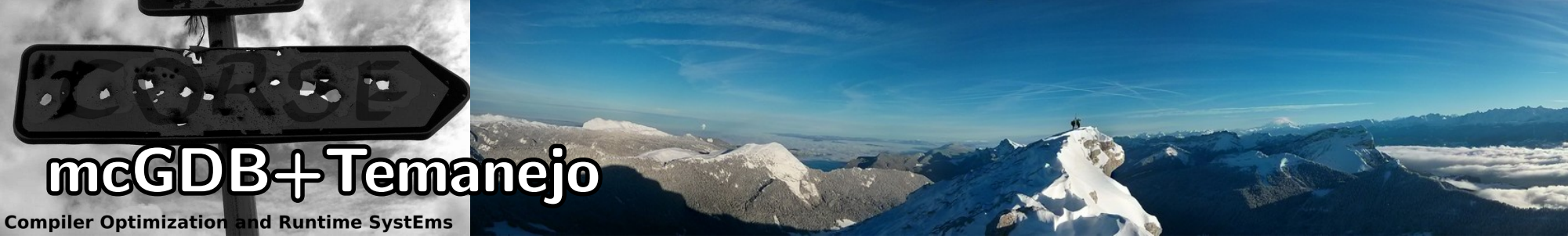
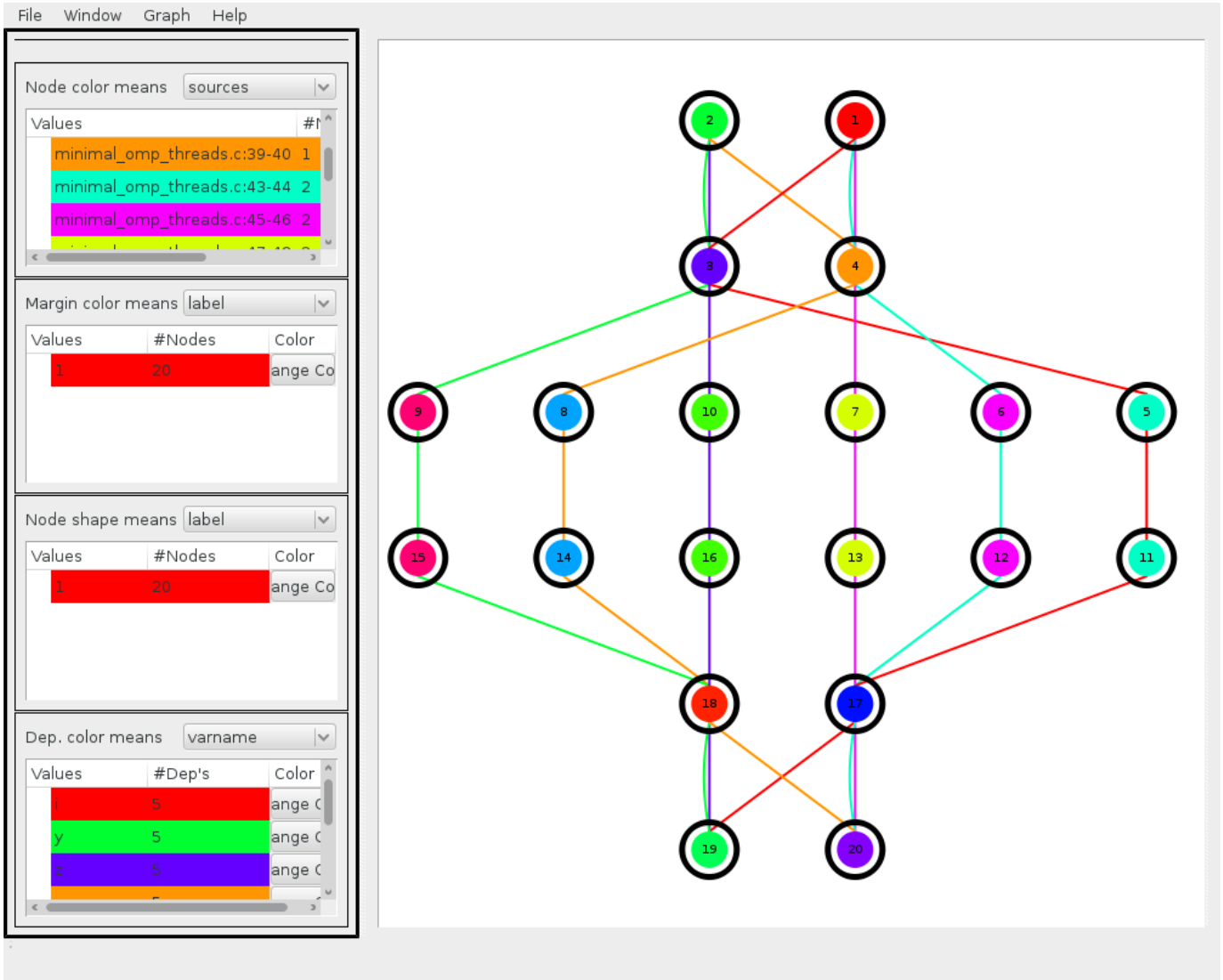




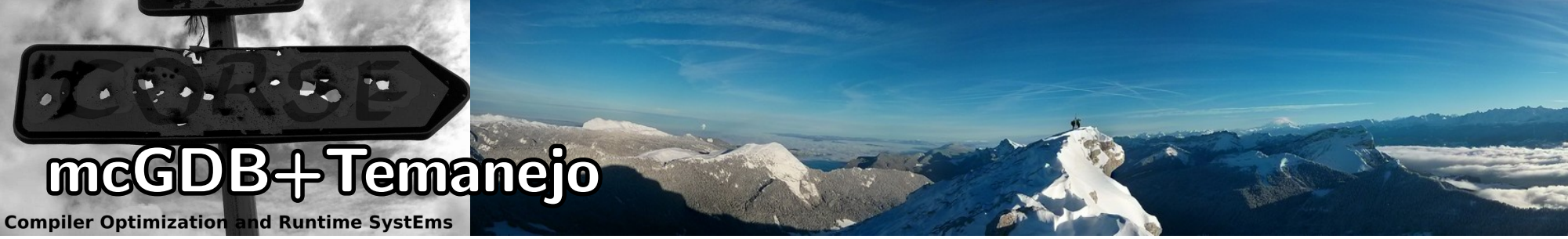


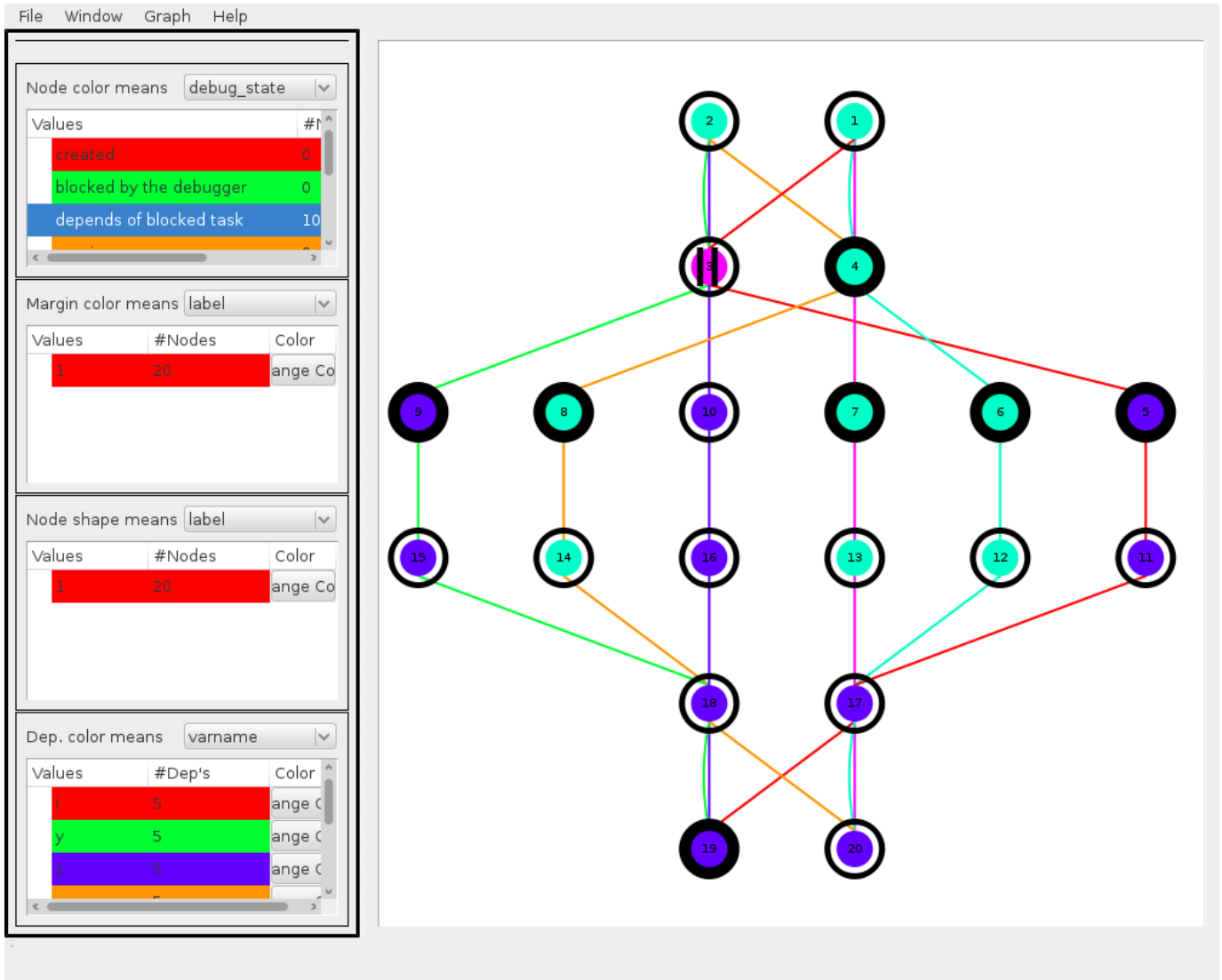
- Node color
  - sources files





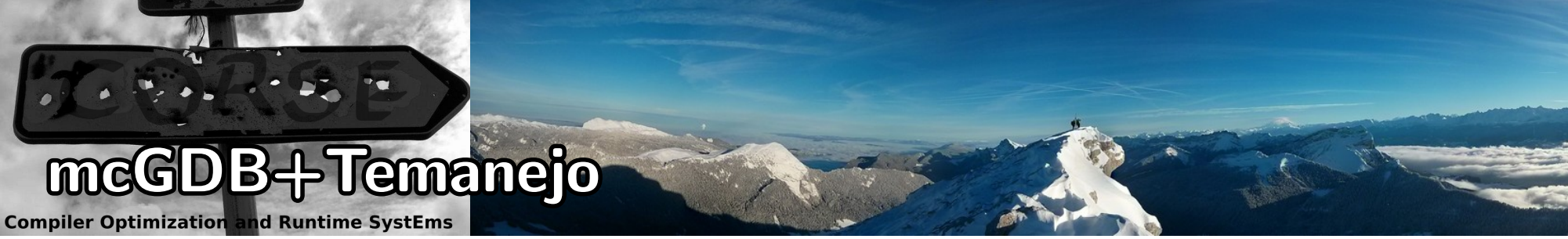
- Node color
  - sources files
- Links color
  - dependencies

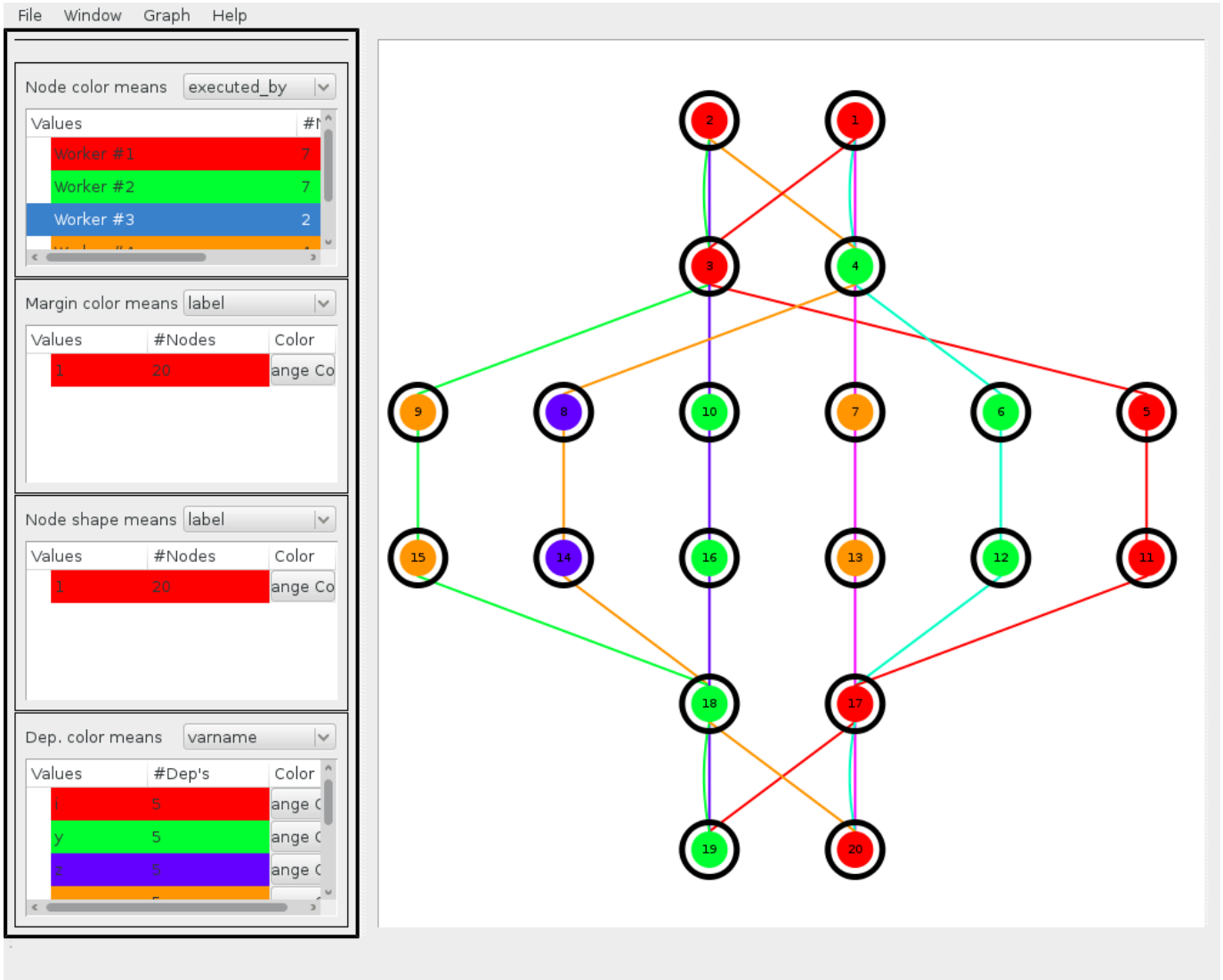




- Node color
  - ~~sources files~~
  - debug state
- Links color
  - dependencies
- Task 3 blocked

blue finished
purple blocked





- Node color
  - ~~sources files~~
  - ~~debug state~~
  - executed by
- Links color
  - dependencies
- Task 3 blocked

  blue finished

  purple blocked
- Exec. finished

Conclusion

Compiler Optimization and Runtime SystEms

- Debugging high-level applications is challenging
- Lack of information about programming models and frameworks

Our contribution: model-centric interactive debugging

- mcGDB extends GDB through its Python interface:
  - Framework for model-centric debugging
  - Py interface patches contributed to the community
  - Source code soon-to-be open source (Apache licence)
- mcGDB OpenMP support:
  - Developed for GNU GOMP and Intel OpenMP
  - Better control of fork-join and task-based execution
  - Better current-state understanding
    - ★ OpenMP sequence diagrams
    - ★ Temanejo graph visualization

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Programming-Model Centric Debugging for OpenMP

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Jean-François Méhaut, Miguel Santana

Université Grenoble Alpes / LIG, STMicroelectronics, France
Nano2017-DEMA project

OpenMPCon, Nara, Japan
October 3-5th, 2016