Programming-Model Centric Debugging for OpenMP/OMPss

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Nano2017-DEMA project

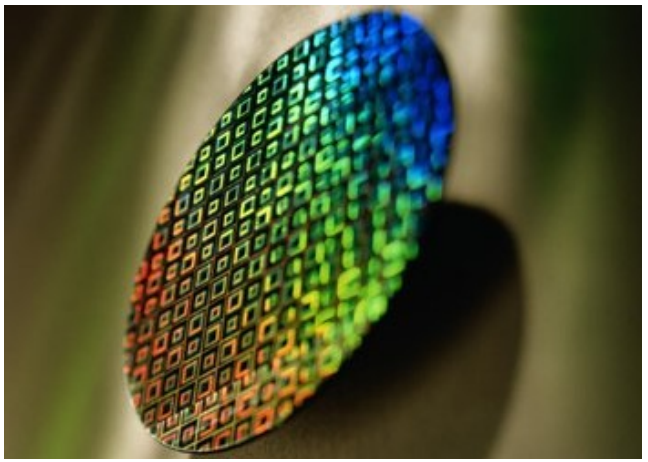
NANO2017/DEMA Workshop, Chamonix
December 14th, 2015

Introduction: Embedded Systems and MPSoC

Compiler Optimization and Runtime SystEms

Convergence of Embedded and HPC

- HPC in embedded systems
  - high-def. multimedia
  - augmented reality
  - video games on smartphones
- Embedded systems in HPC
  - dedicated hardware accelerators
  - energy efficiency
    - ★ e.g. Mont-Blanc projects

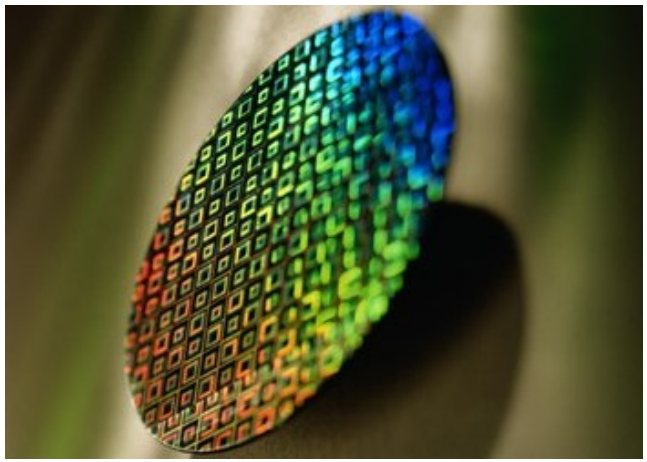


informatics mathematics

Introduction: Embedded Systems and MPSoC

⇒ important demand for:

- Powerful parallel architectures
- High-level development methodologies
- Efficient verification & validation tools



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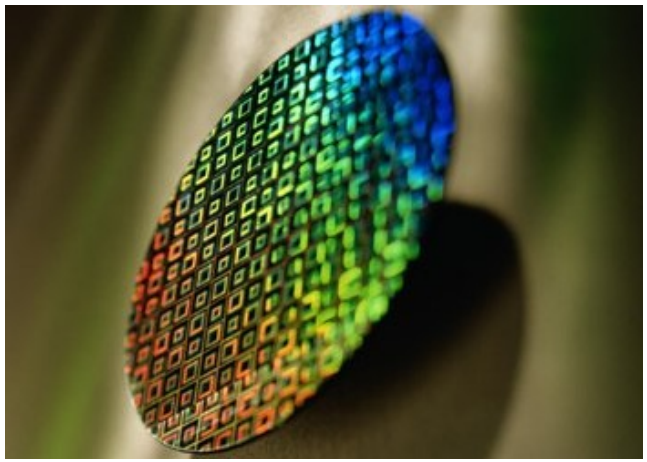

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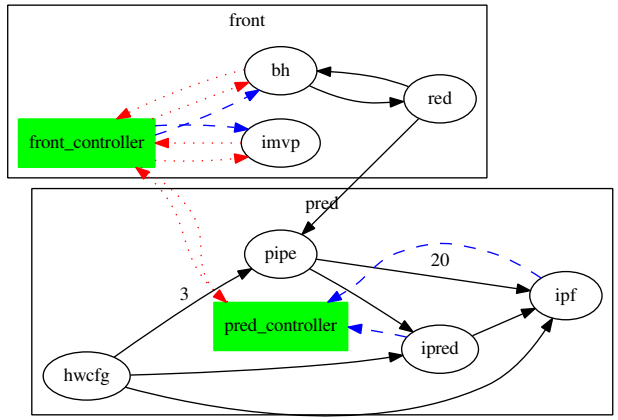

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⇒ important demand for:

- Powerful parallel architectures
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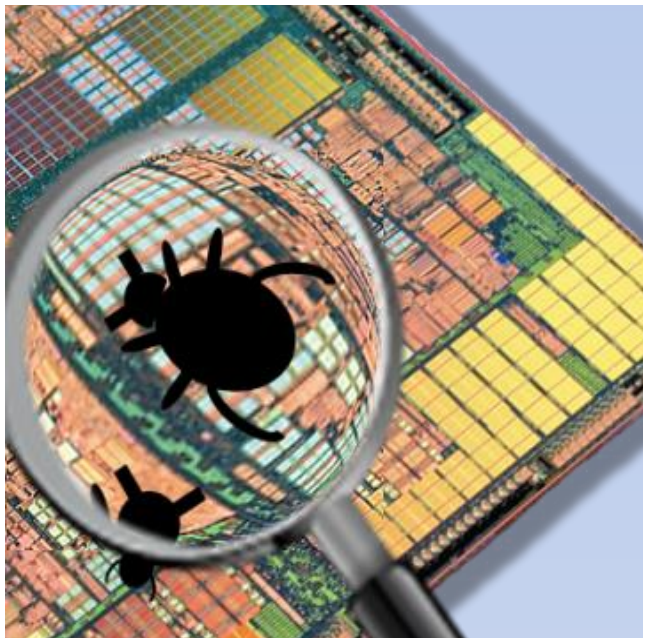
- High-level development methodologies
  - Programming models & environments
- Efficient verification & validation tools
  - Our research effort



informatics mathematics

Agenda

Compiler Optimization and Runtime SystEms

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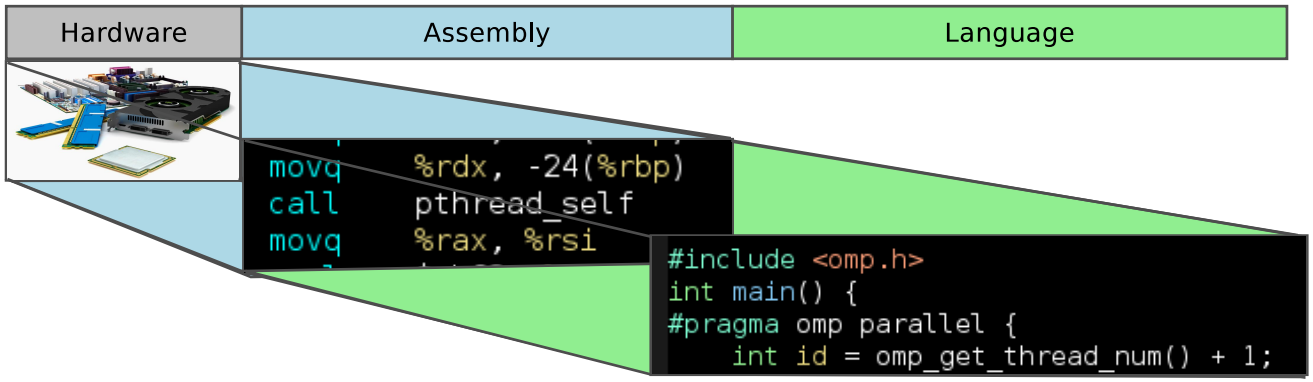
Compiler Optimization and Runtime SystEms

Verification and Validation: Debugging

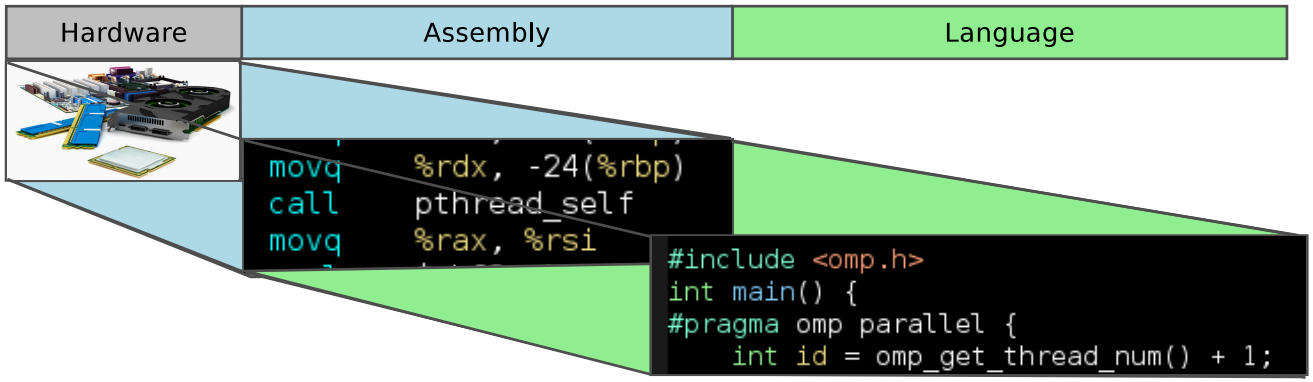


Source-Level Interactive Debugging (e.g. GDB)

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

Verification and Validation: Debugging

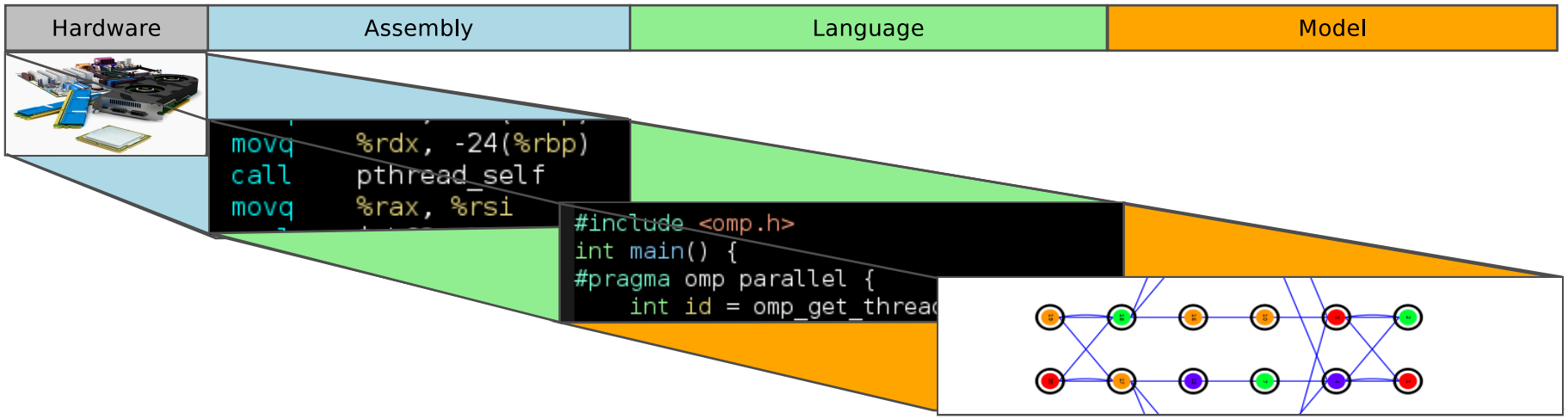
Compiler Optimization and Runtime SystEms



What about programming models?

Verification and Validation: Debugging

Compiler Optimization and Runtime SystEms



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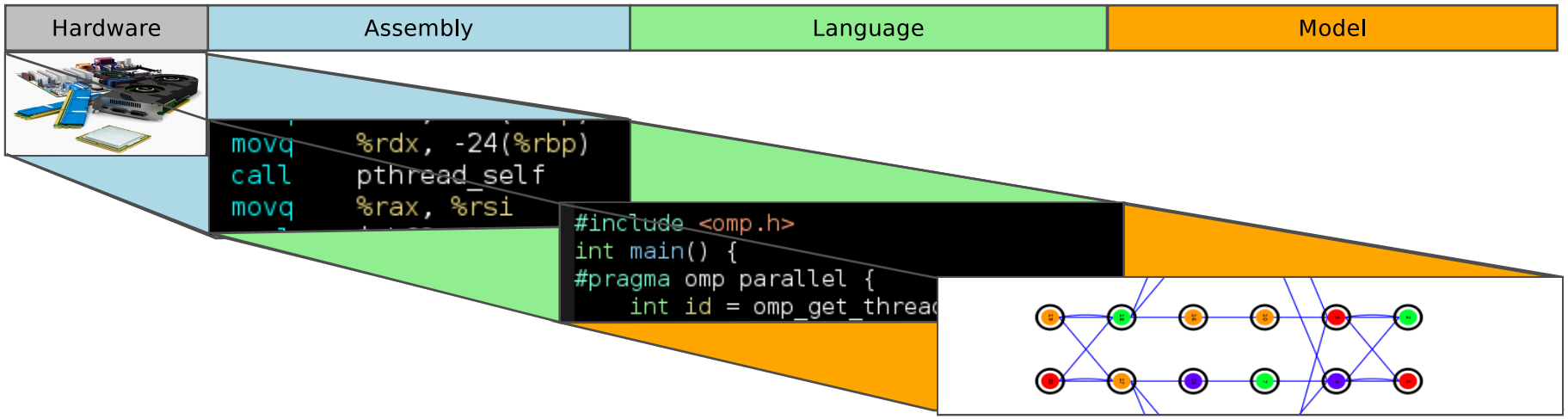

What about programming models?

Source-level Interactive Debuggers operate at language-level.

Verification and Validation: Debugging

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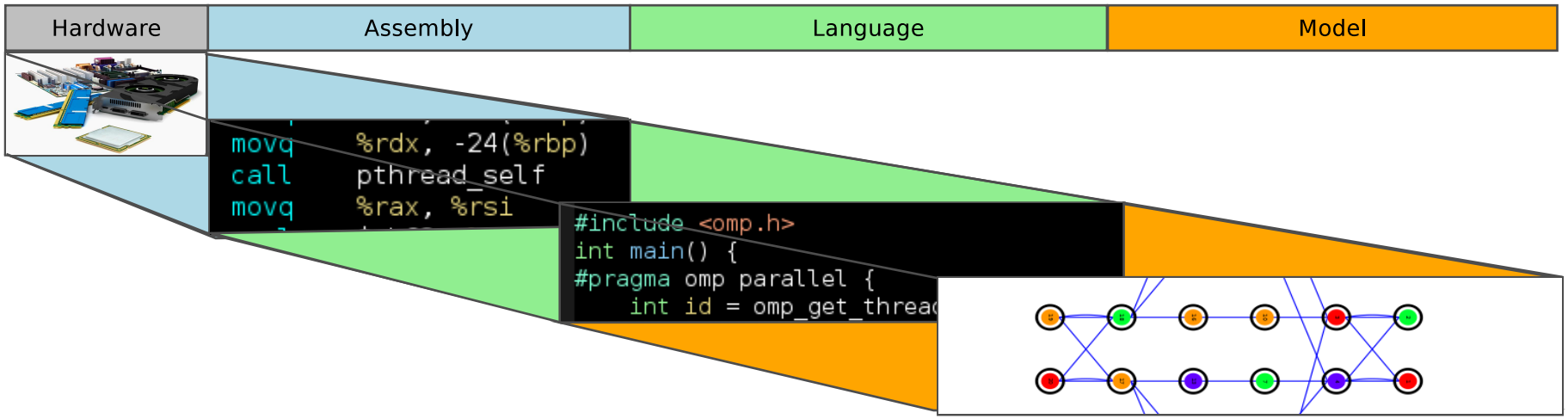

What about programming models?

Source-level Interactive Debuggers operate at language-level.

They have no knowledge about
high-level abstract machines!

Research Context

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.

Agenda

Compiler Optimization and Runtime SystEms

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

Programming Model Centric Debugging

Compiler Optimization and Runtime SystEms

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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Let's apply to OpenMP!

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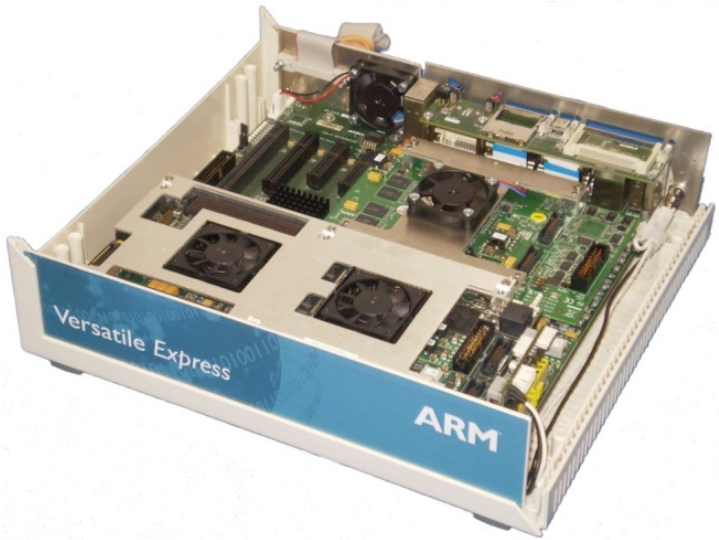
Compiler Optimization and Runtime SystEms

Nano2017/Dema project (with STMicroelectronics)

Compiler Optimization and Runtime SystEms

Debugging Embedded and Multicore Applications

ARM Juno



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

OpenMP Parallel Programming

- fork/join multithreading
- tasks with dependencies
- industrial standard for HPC

mcGDB debugger

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

OpenMP and GDB

$\Rightarrow$ No high-level vision of the application by GDB

```
(gdb) list
17  // <==== current thread is here
18  #pragma omp critical
19  {
20     printf("@%d Inside critical zone", id);
21  }
(gdb) next
@4 Inside critical zone
@2 Inside critical zone
20  printf("@%d Inside critical zone", id);
(gdb) # I wanted to be the first :‘-(
```

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OpenMP/OMPss: Problems with GDB

Compiler Optimization and Runtime SystEms

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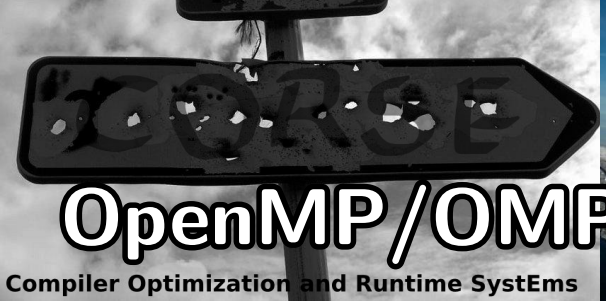

OpenMP/OMPss: mcGDB Execution Control

Compiler Optimization and Runtime SystEms

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

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2. omp start
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4. omp next barrier
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```
int main() {
  ①// beginning of main function
  #pragma omp parallel {
    // beginning of parallel zone

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

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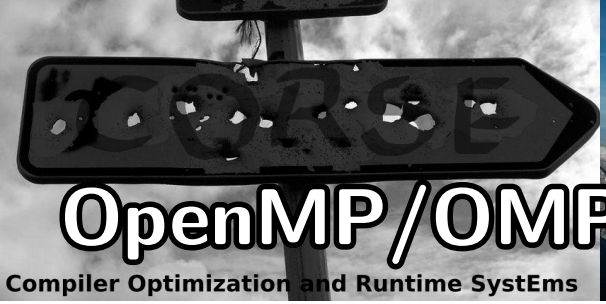

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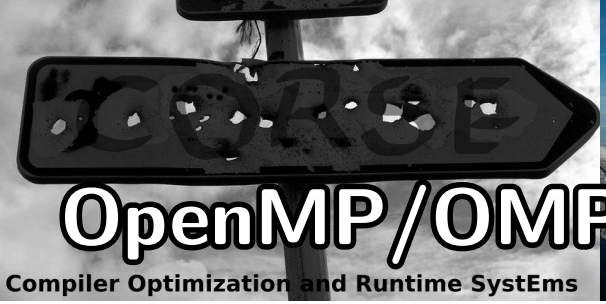

OpenMP/OMPss: structural representation

Compiler Optimization and Runtime SystEms

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

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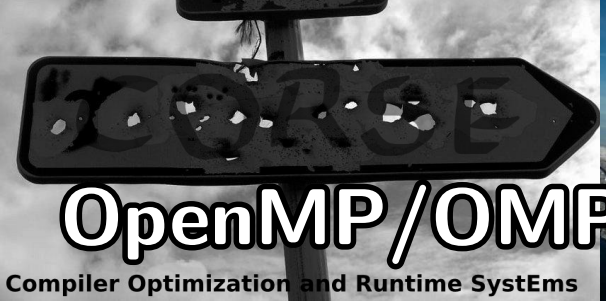
OpenMP/OMPss: mcGDB sequence diagram
Compiler Optimization and Runtime SystEms

DEMO



OpenMP/OMPss: mcGDB sequence diagram

Compiler Optimization and Runtime SystEms

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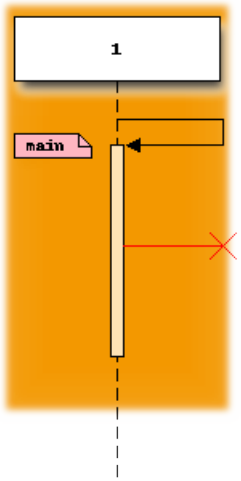

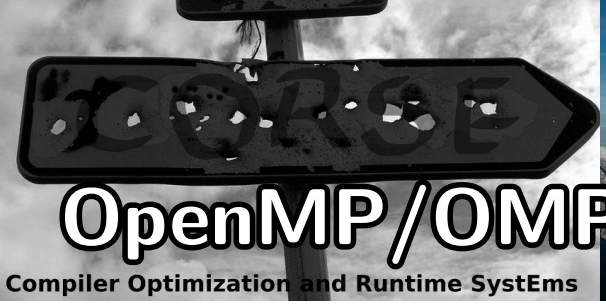

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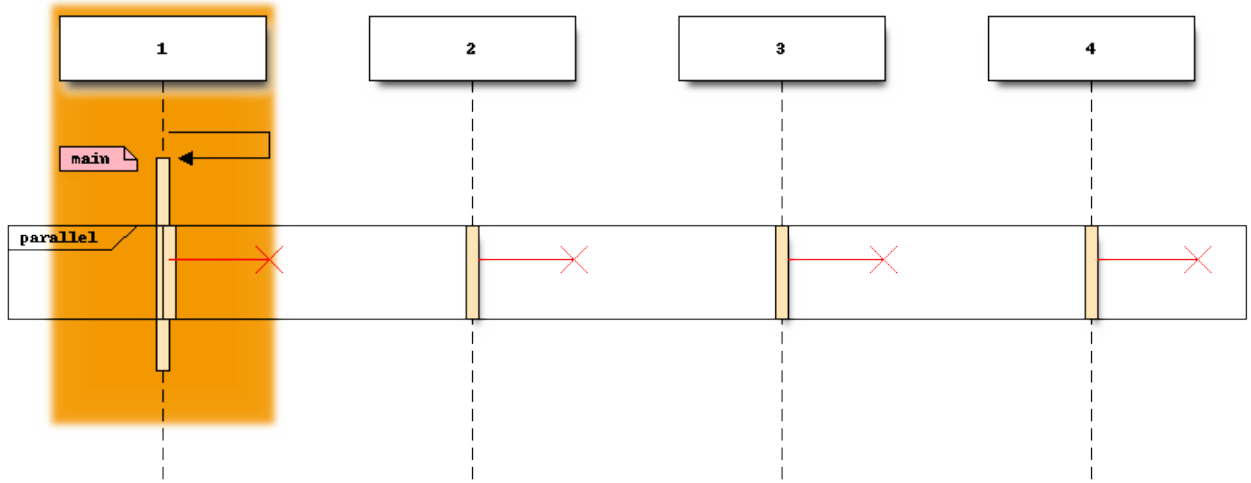

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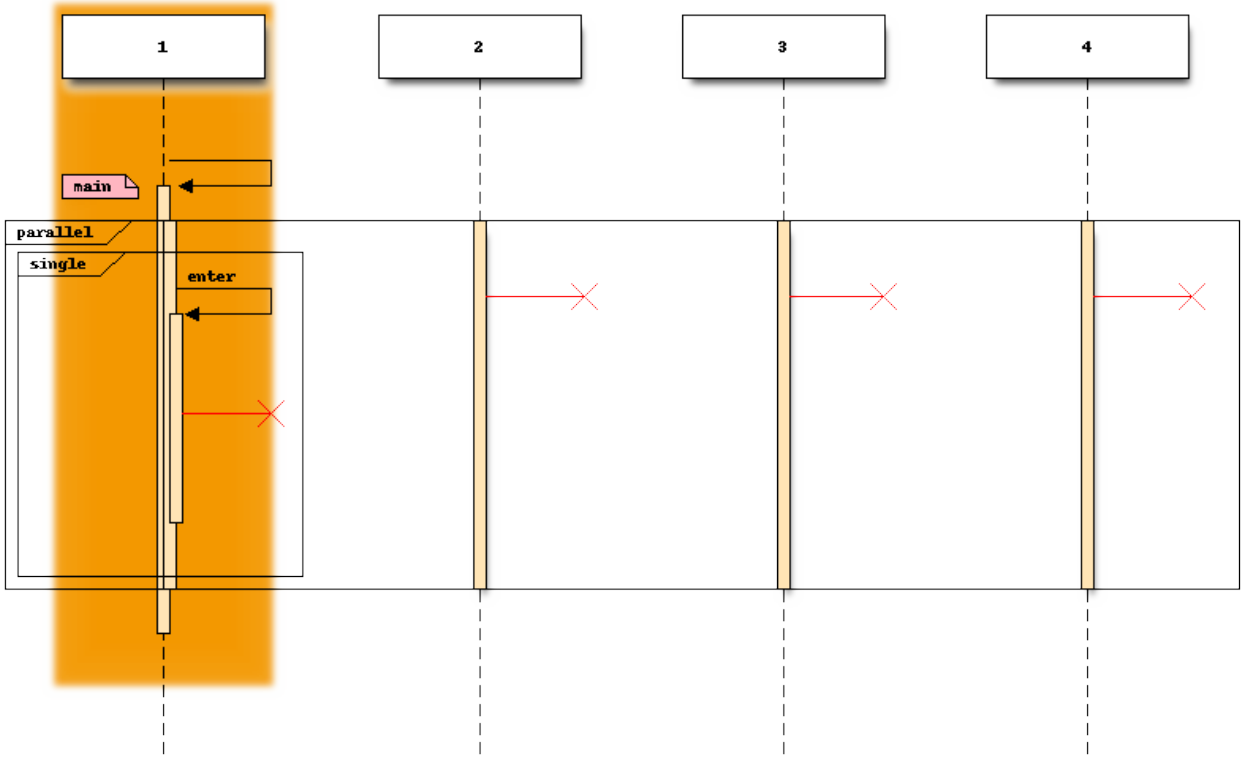

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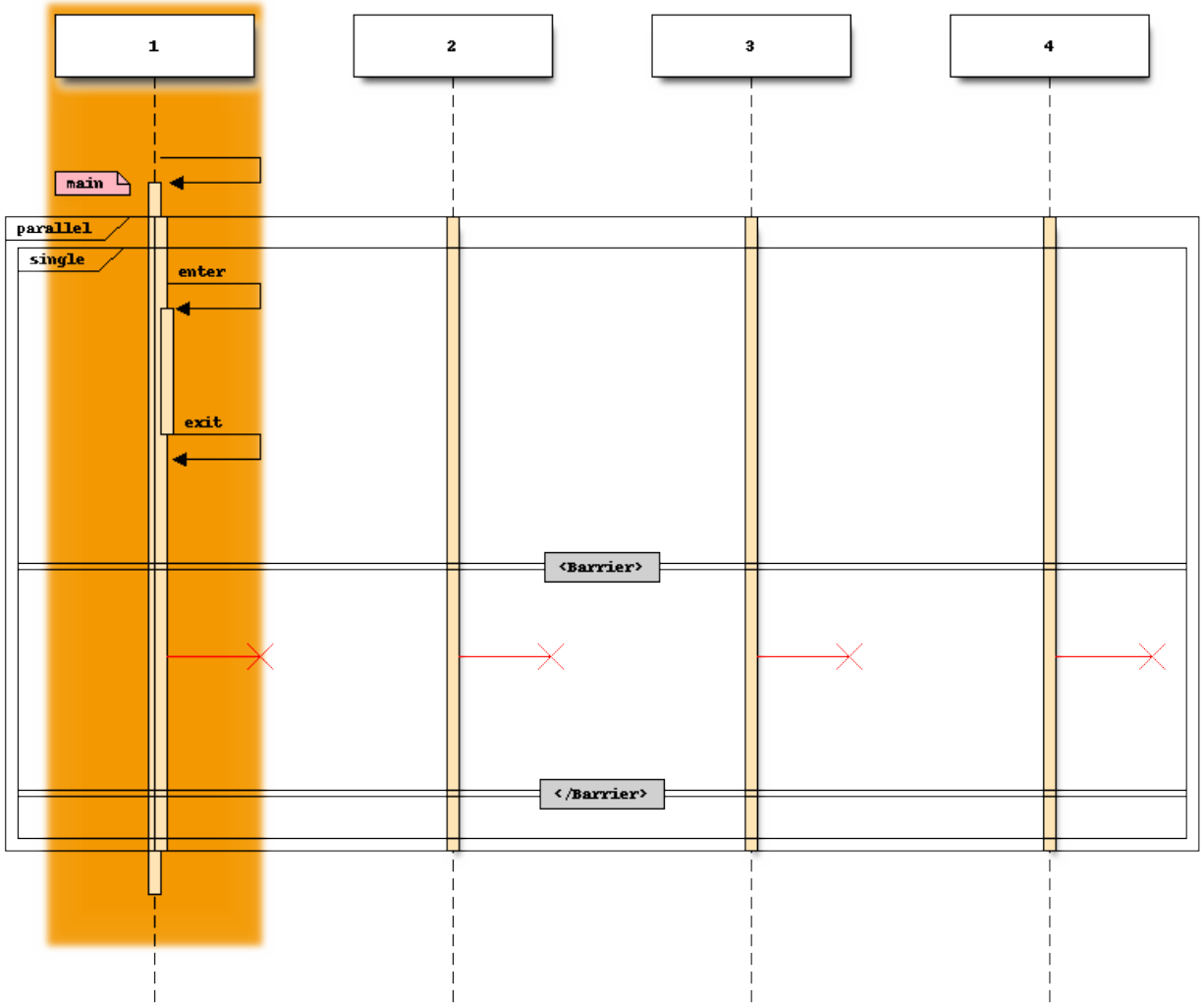

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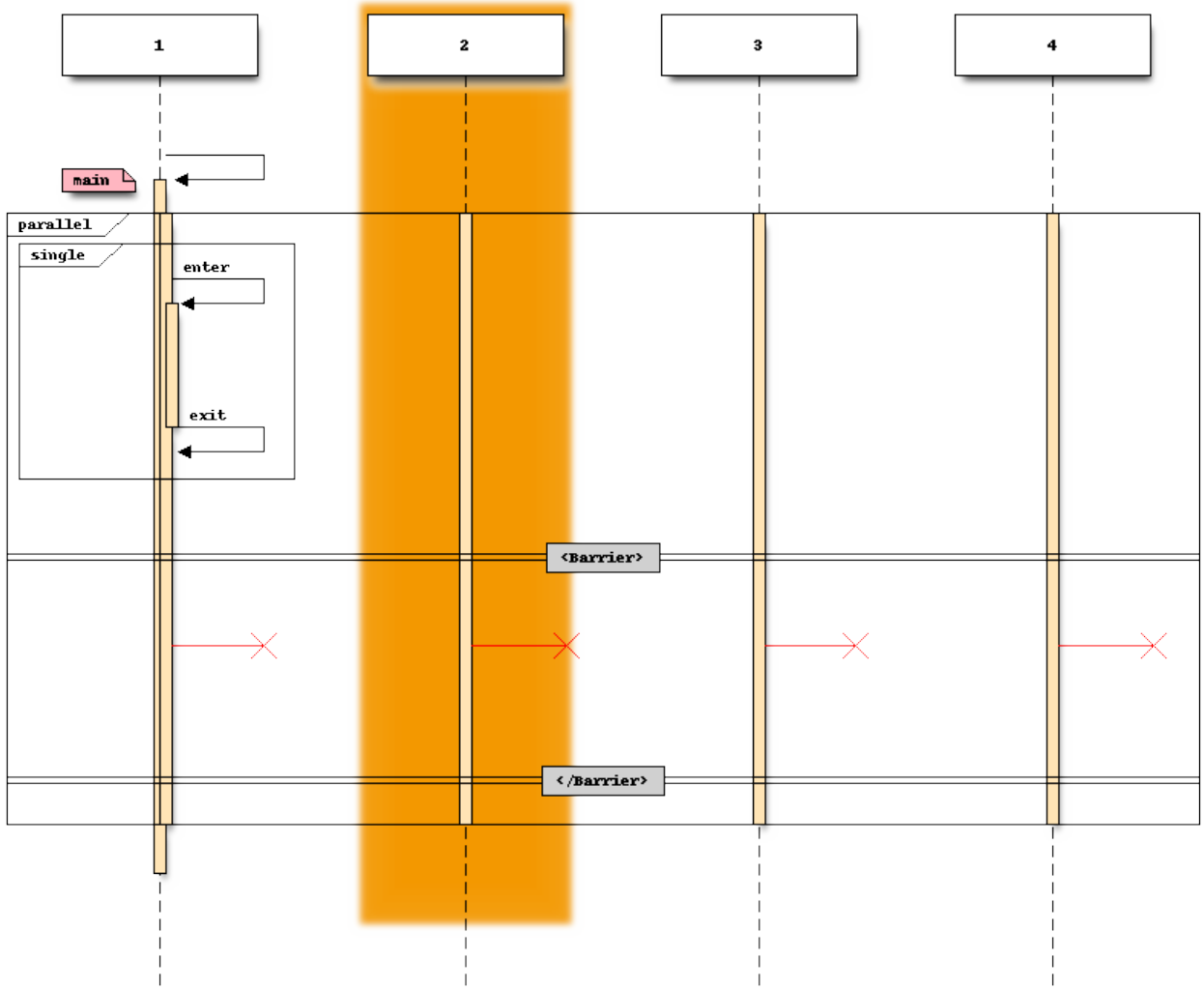

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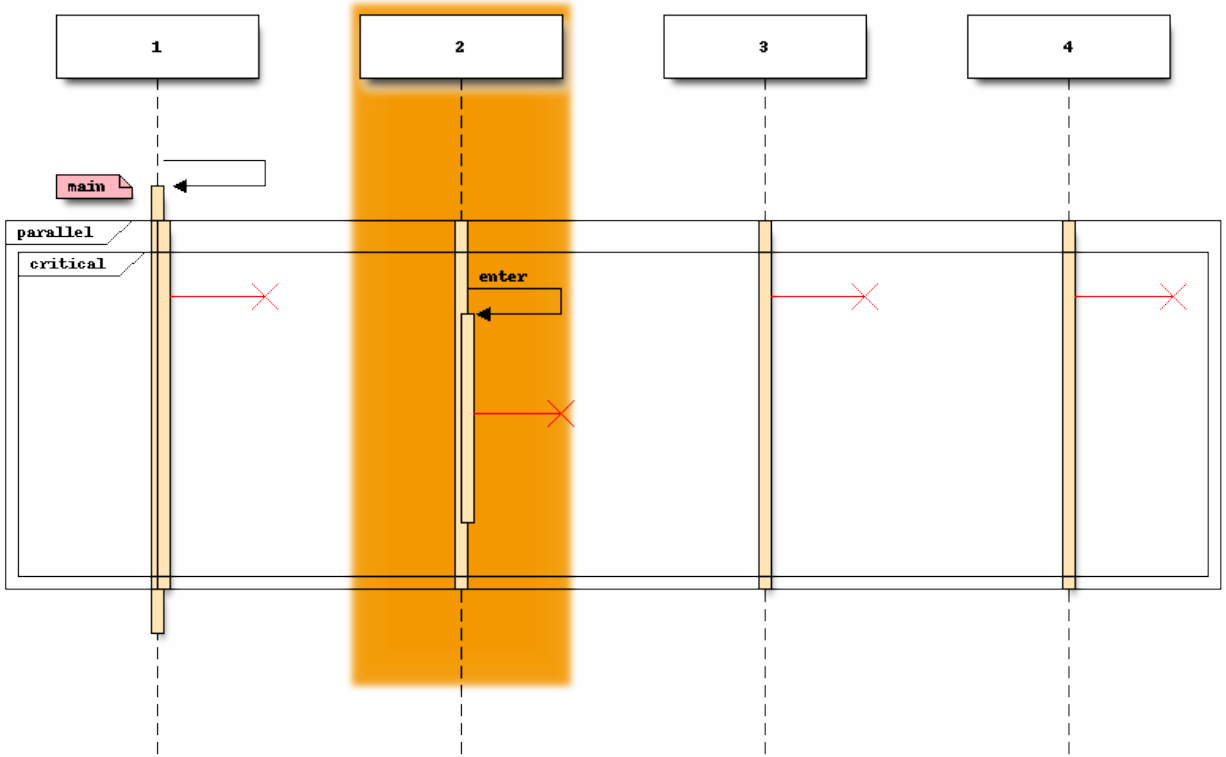

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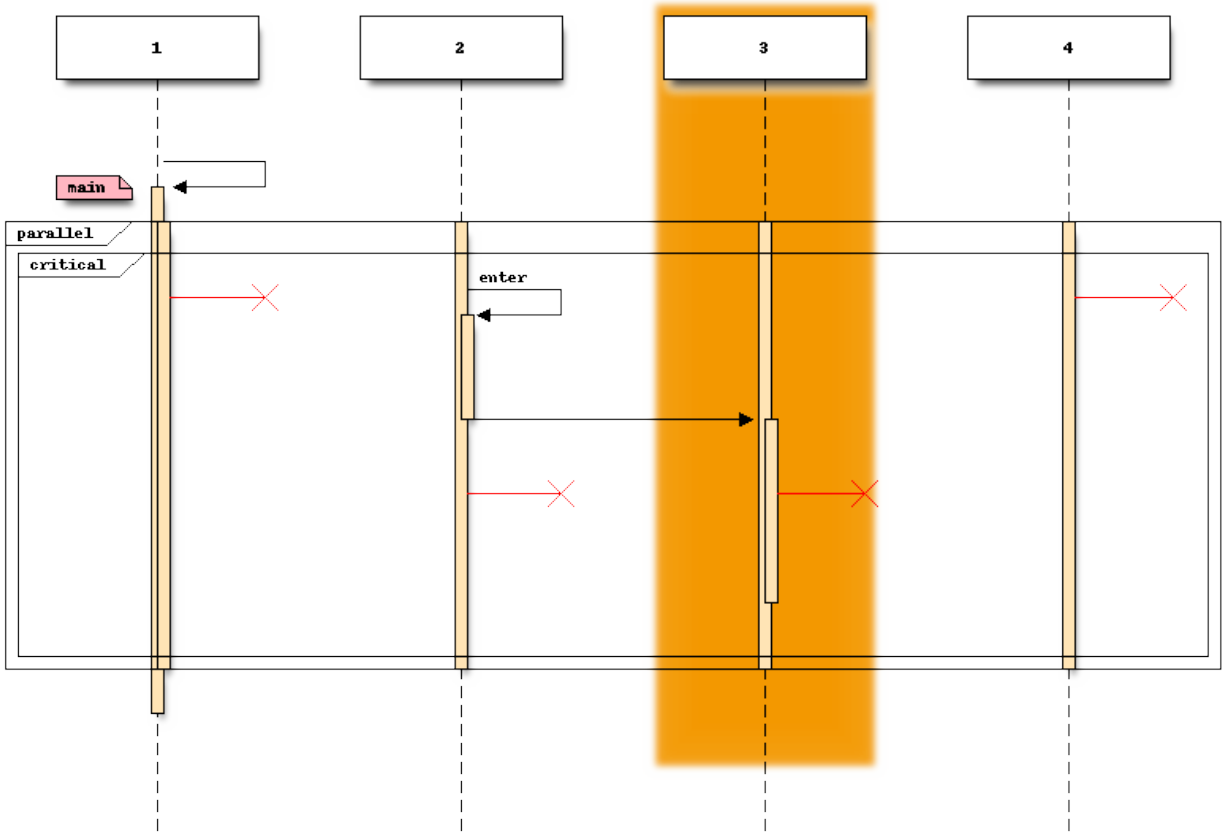

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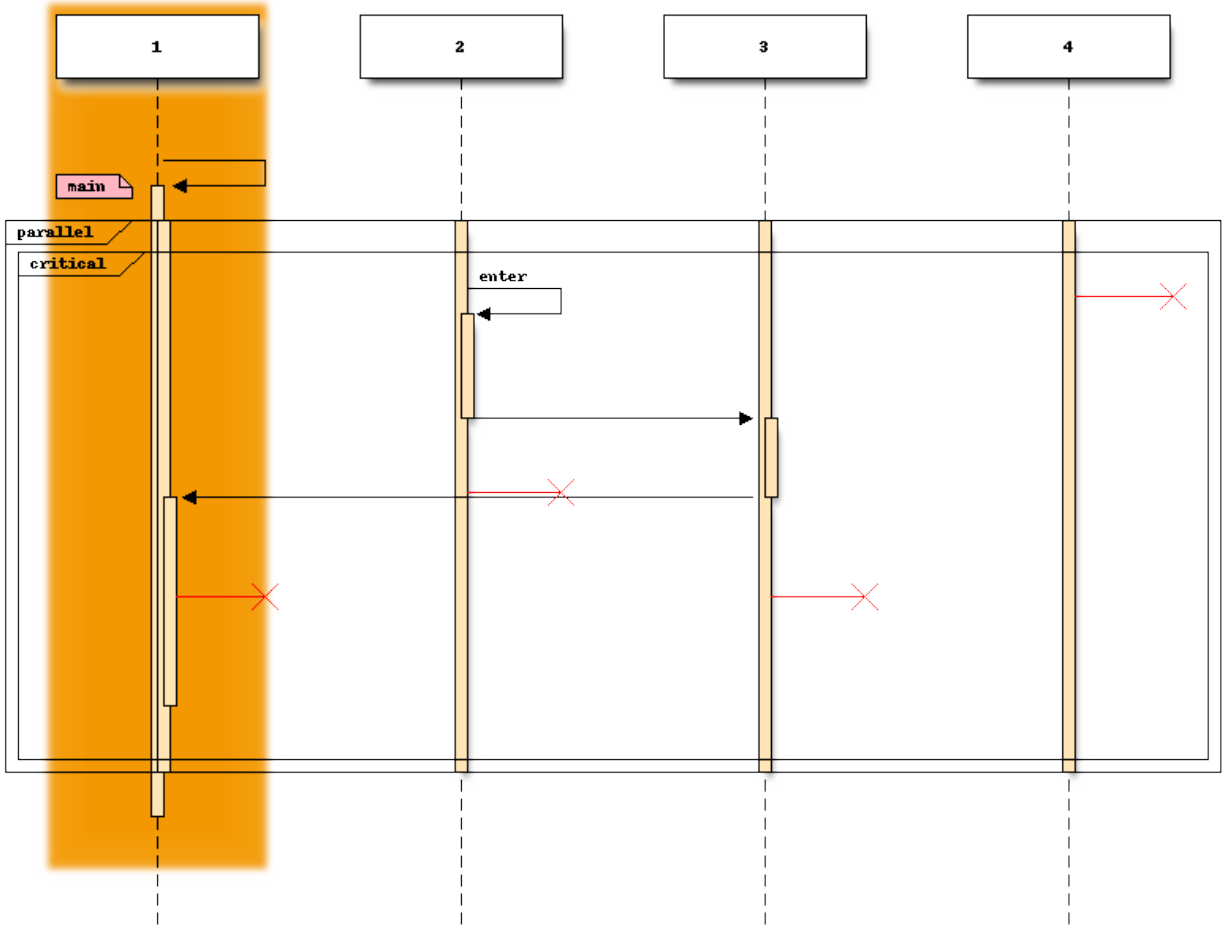

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Compiler Optimization and Runtime SystEms

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2. **task-based** $\Longrightarrow$ mcGDB+Temanejo cooperation

OpenMP 4.0 task dependencies

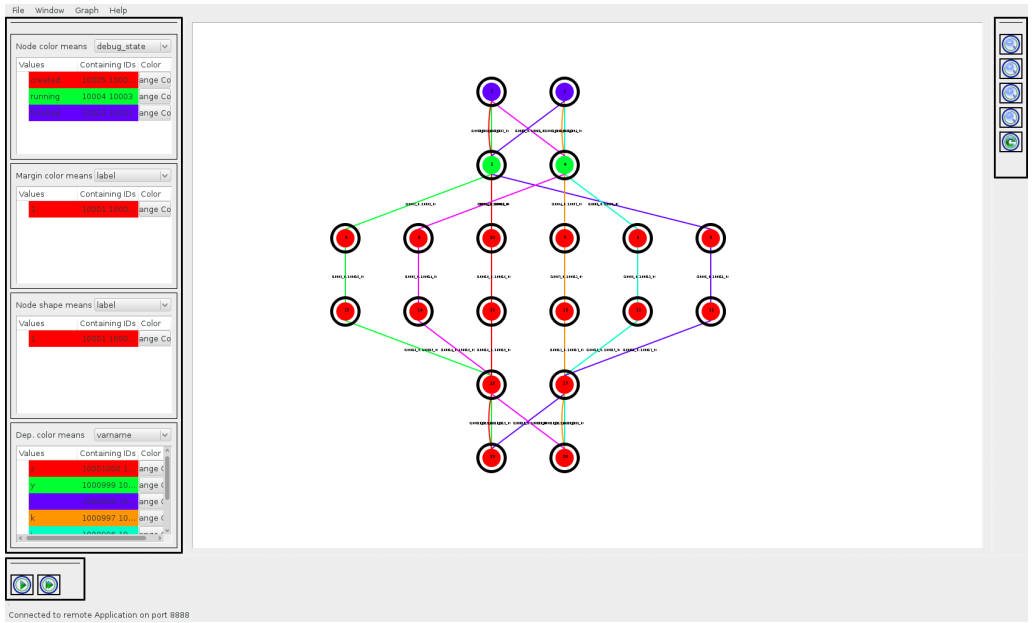
```
#pragma omp task depend(in: i,j) depend(out:i,j)
update_1(&i, &j);

#pragma omp task depend(in: i)   depend(out:i)
update_2a(&i);

#pragma omp task depend(in: j)   depend(out:j)
update_2b(&j);
```

(HLRS Stuttgart) Temanejo ...

✓ is a great visualization tool for task debugging,
✗ and does not support source-level debugging.



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mcGDB ...

✗ has no visualization engine,

✓ but provides source debugging at language (gdb) and model level.

OpenMP/OMPss: mcGDB + Temanejo

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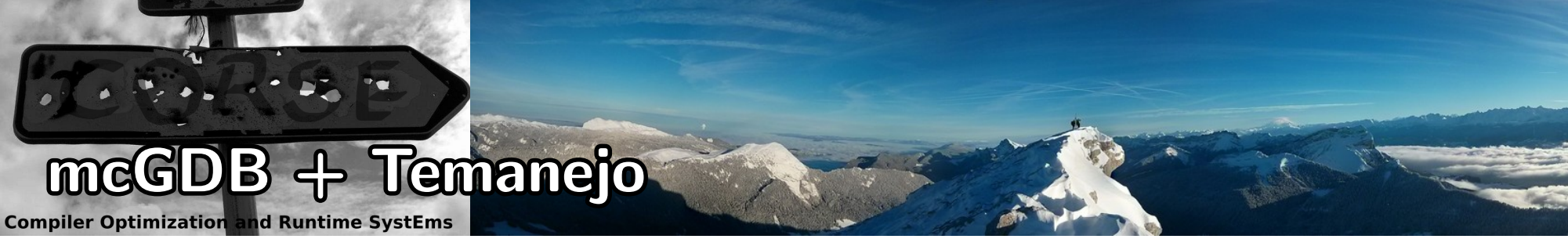
So let's do both!



mcGDB – Temanejo cooperation:

Temanejo

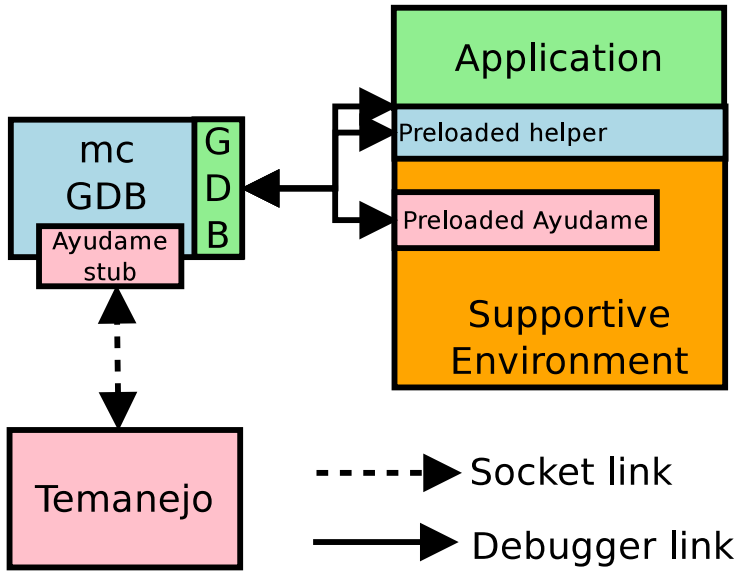
- task graph visualization
- simple model-level execution control.
- sequence diagram visualization.

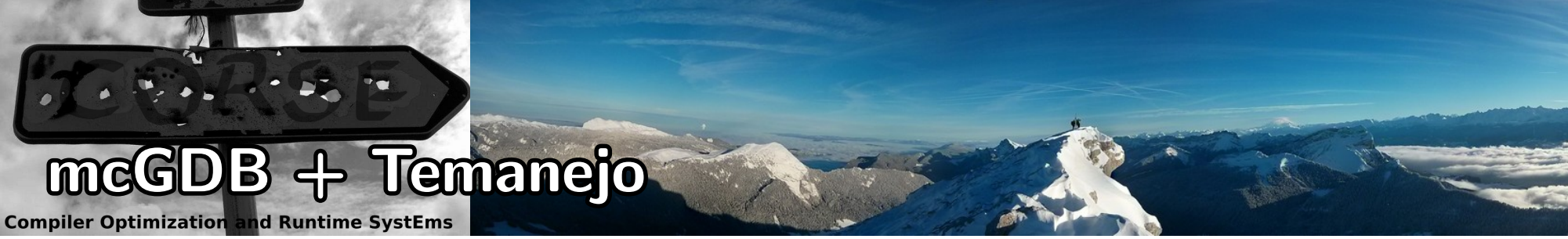
mcGDB

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

GDB

- language and assembly level
  execution control, memory inspection.





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mcGDB

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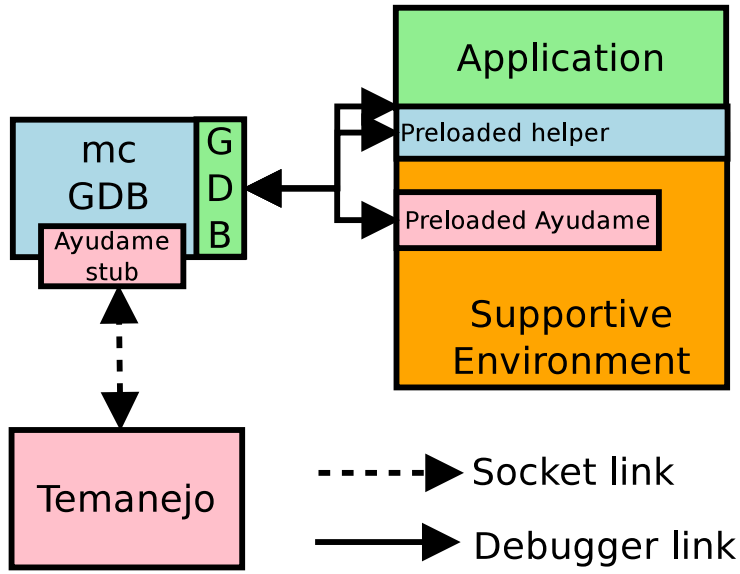

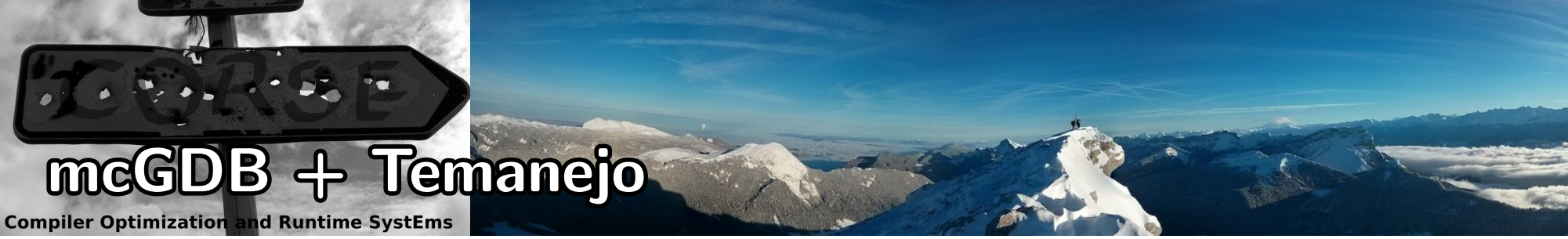

mcGDB – Temanejo cooperation:

Temanejo

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

mcGDB

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

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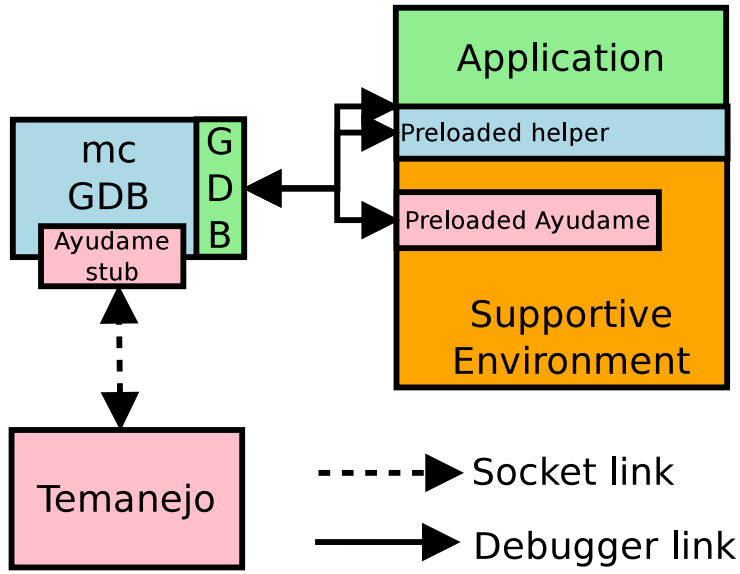

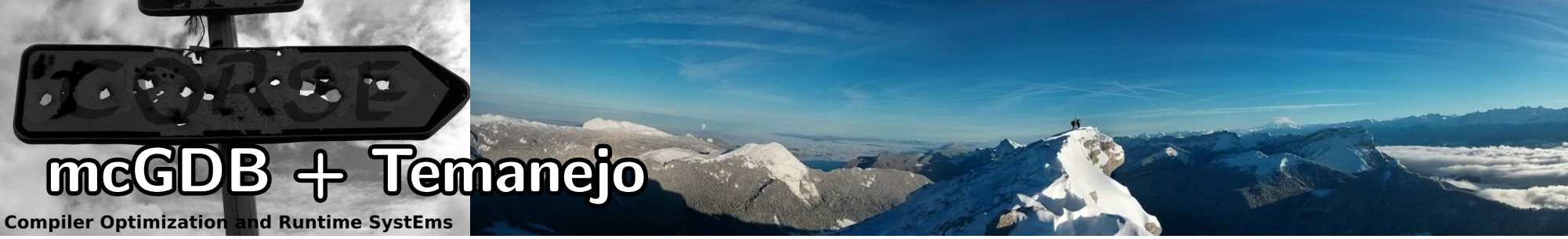

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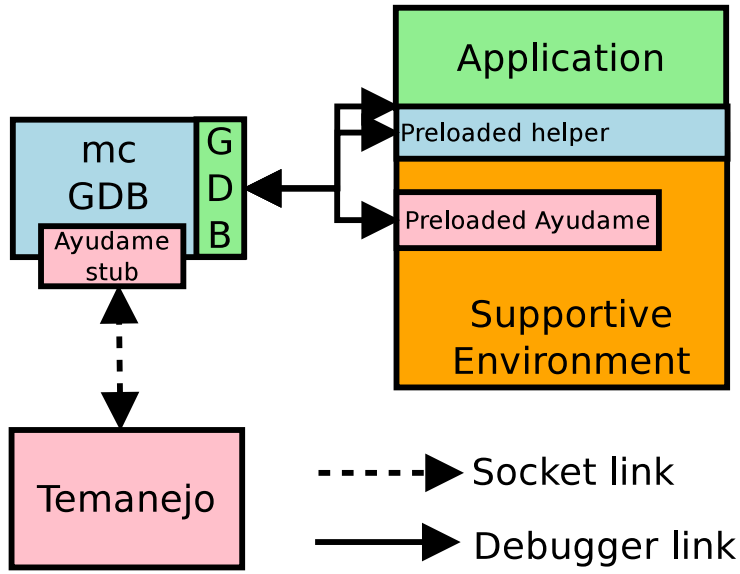
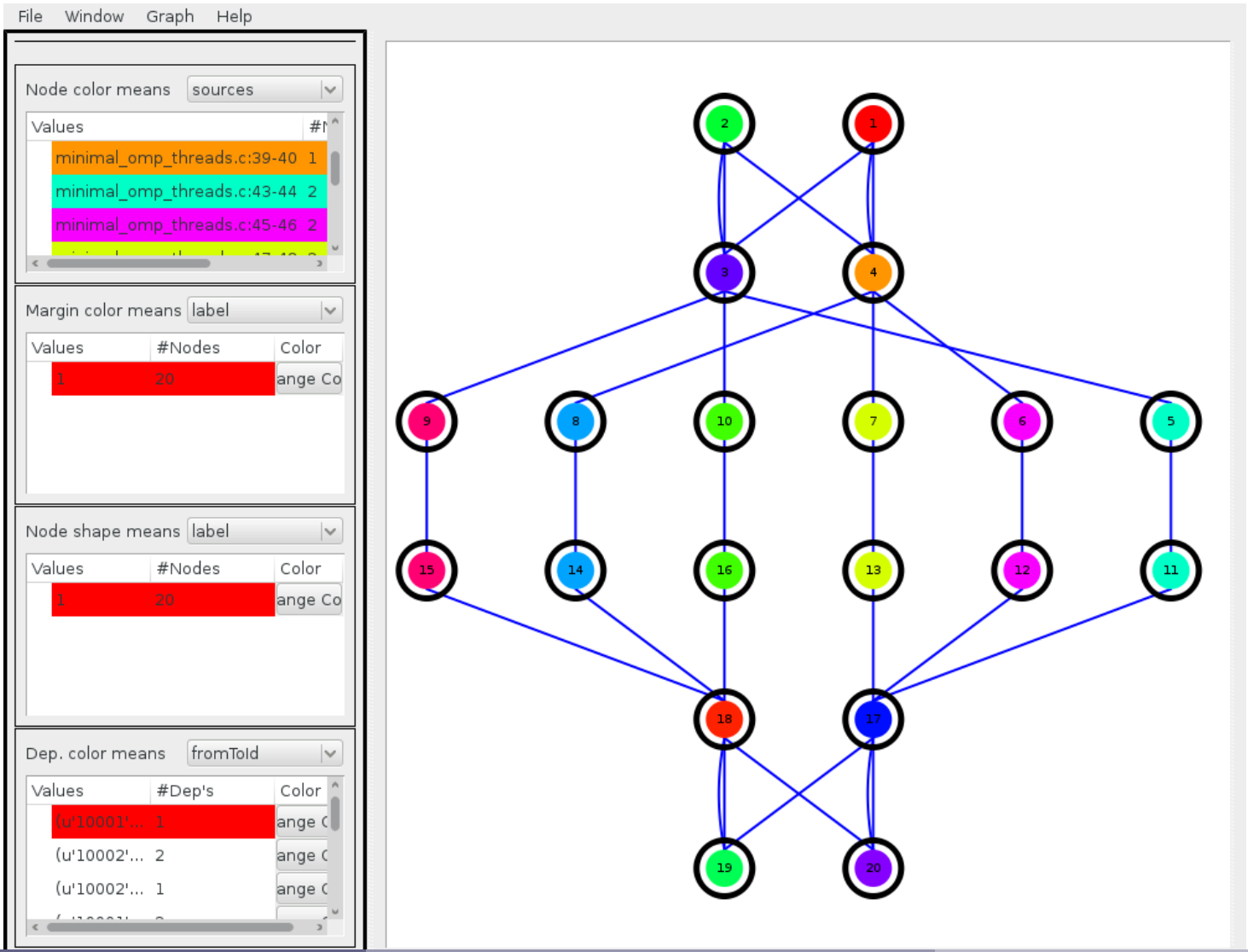



OpenMP/OMPss: structural representation
Compiler Optimization and Runtime SystEms

DEMO

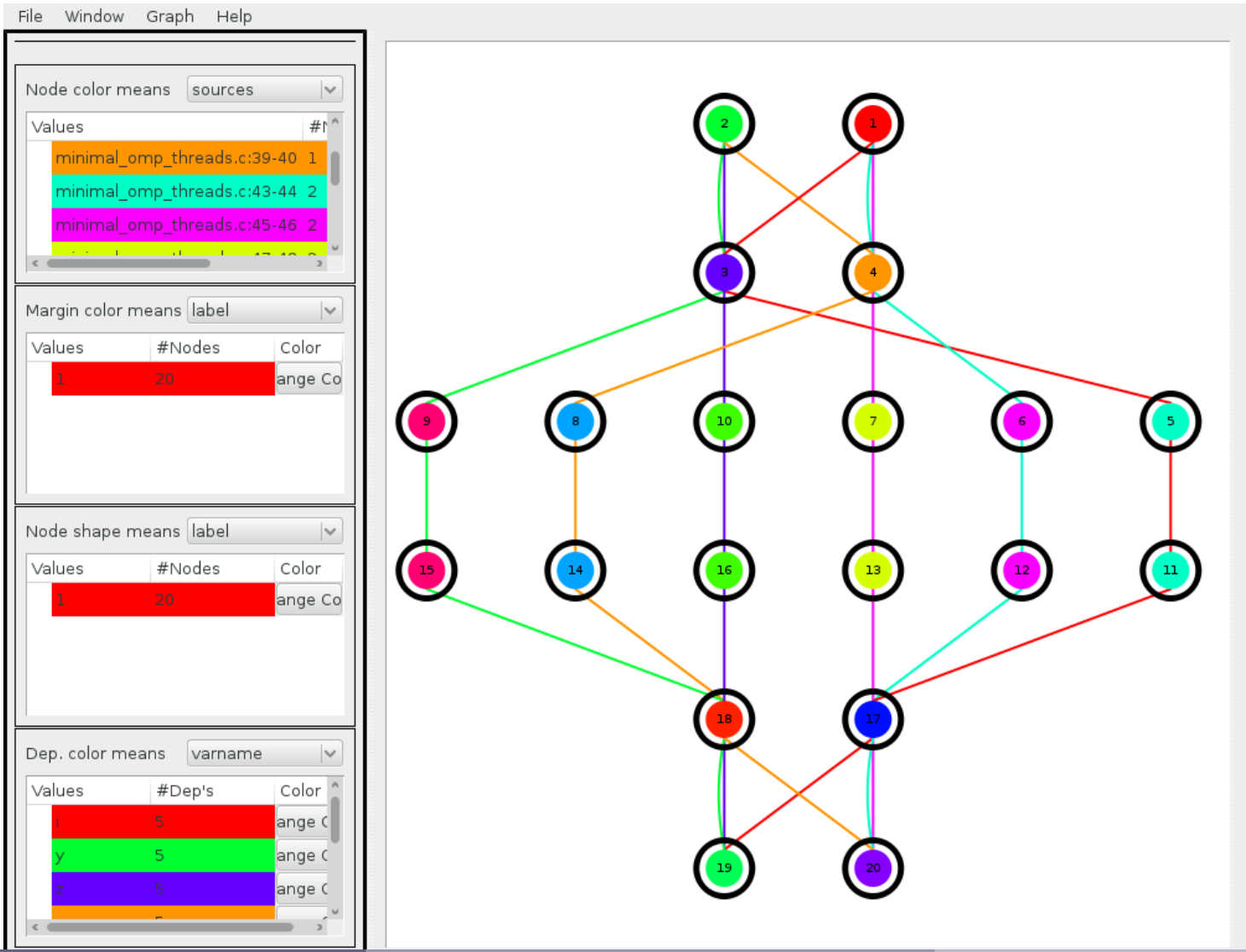
mcGDB + Temanejo: Node color means sources

Compiler Optimization and Runtime SystEms



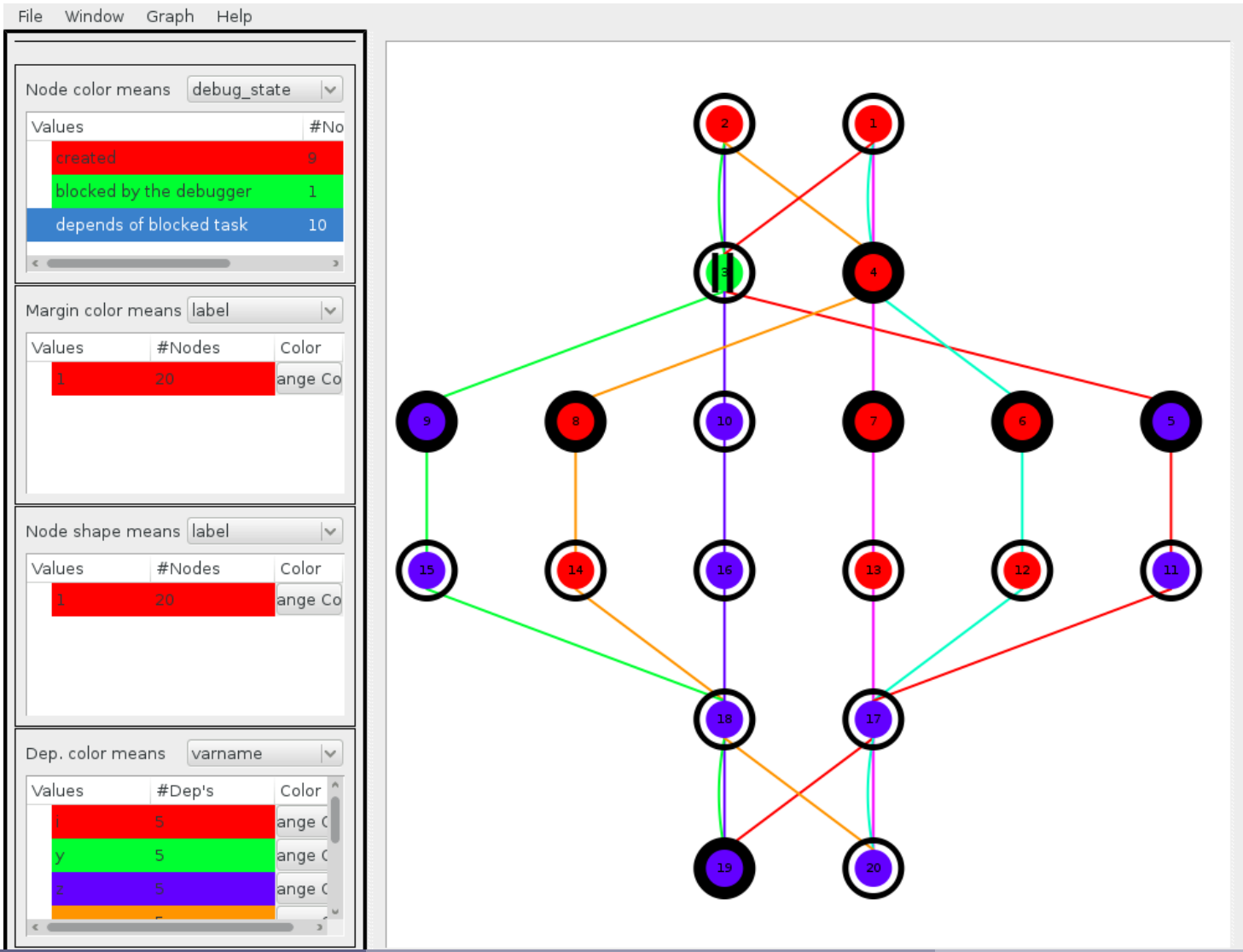
mcGDB + Temanejo: Dep. color means varname

Compiler Optimization and Runtime SystEms



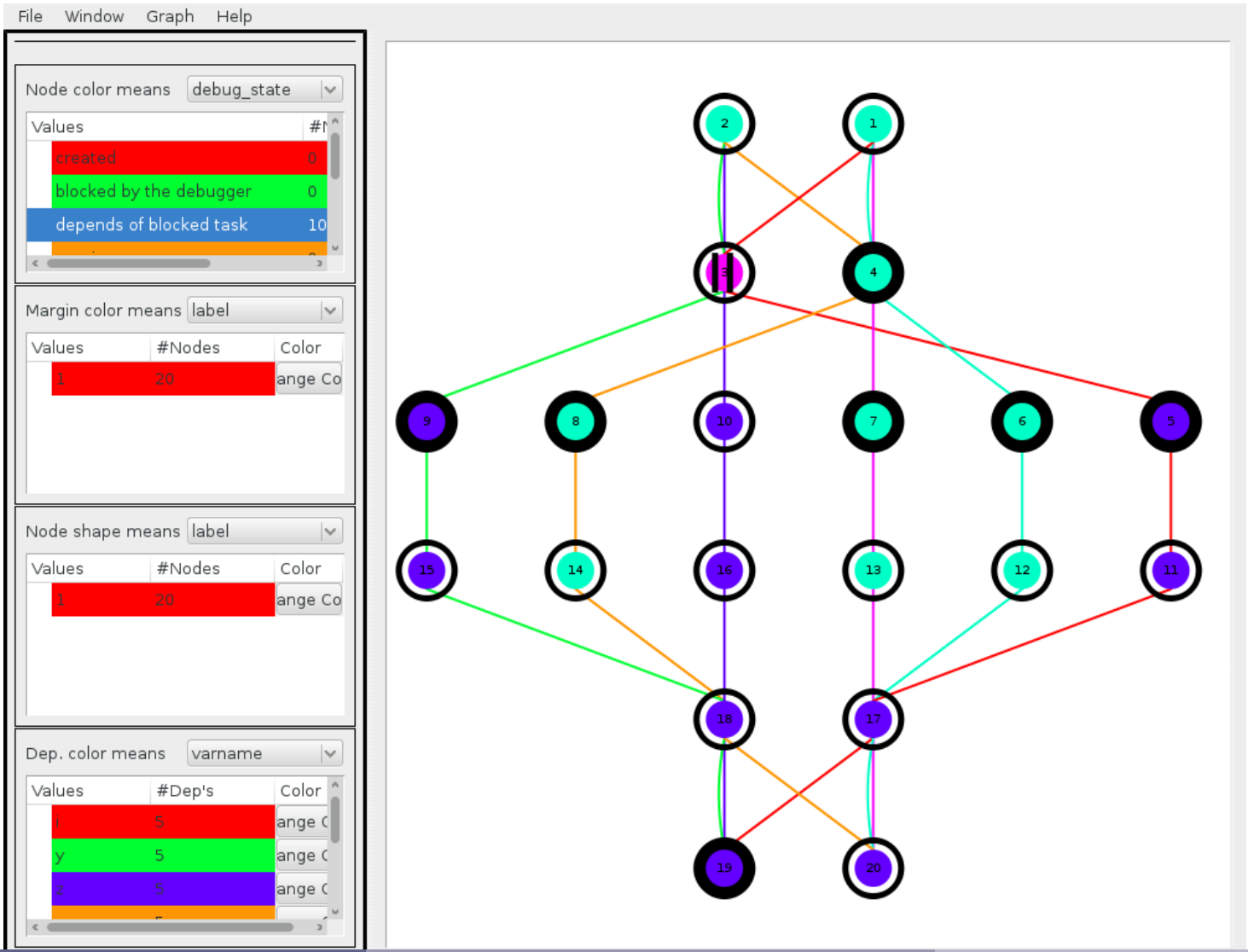
mcGDB + Temanejo: Task 3 blocked.

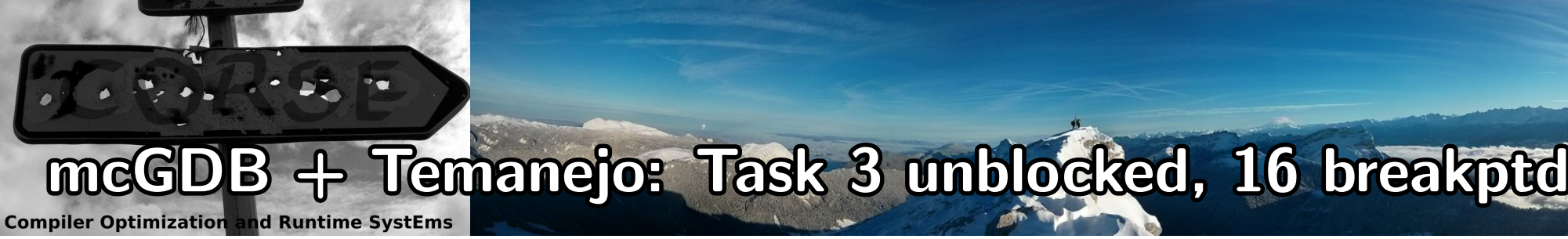
Compiler Optimization and Runtime SystEms



mcGDB + Temanejo: Execution continued til locked

Compiler Optimization and Runtime SystEms





File Window Graph Help

Node color means debug_state

Values	#N
finished	9
actively blocked by the debu...	0
created (unblocked)	11

Margin color means label

Values	#Nodes	Color
1	20	ange Co

Node shape means label

Values	#Nodes	Color
1	20	ange Co

Dep. color means varname

Values	#Dep's	Color
i	5	ange C
y	5	ange C
z	5	ange C

File Window Graph Help

Node color means executed_by

Values	#N
Worker #1	7
Worker #2	7
Worker #3	2

Margin color means label

Values	#Nodes	Color
1	20	ange Co

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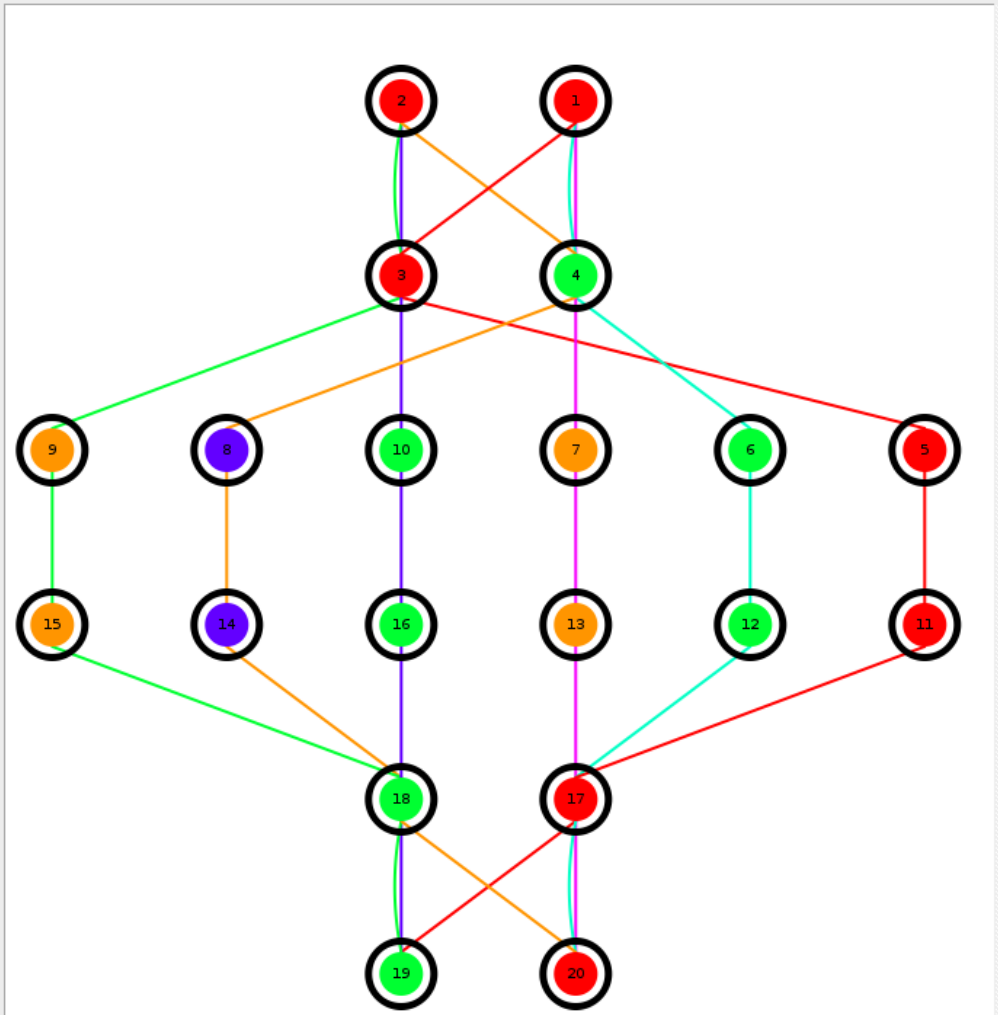

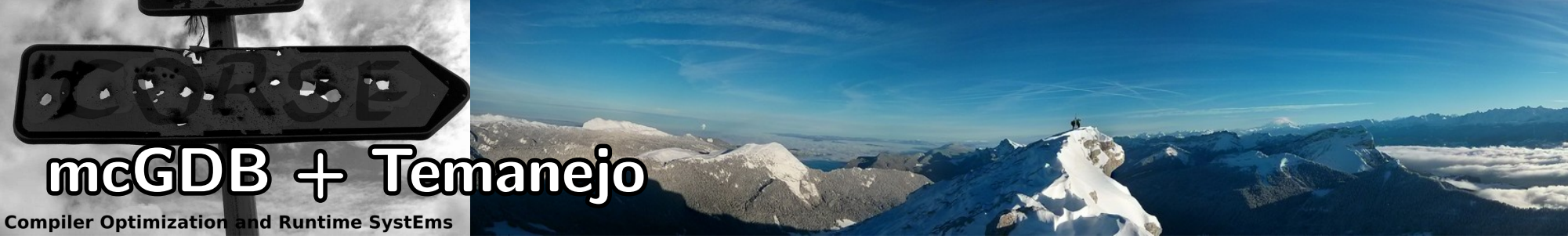

More on OMP tasks

```
#pragma omp task depend(in: i,j)
```

Support on-going:

```
//arrays and matrix
#pragma omp task depend(in: array[i])
#pragma omp task depend(in: matrix[i][j])

//ranges (*not* overlapping)
#pragma omp task depend(in: array[i:j])
#pragma omp task depend(in: matrix[i:11][j:12])
```

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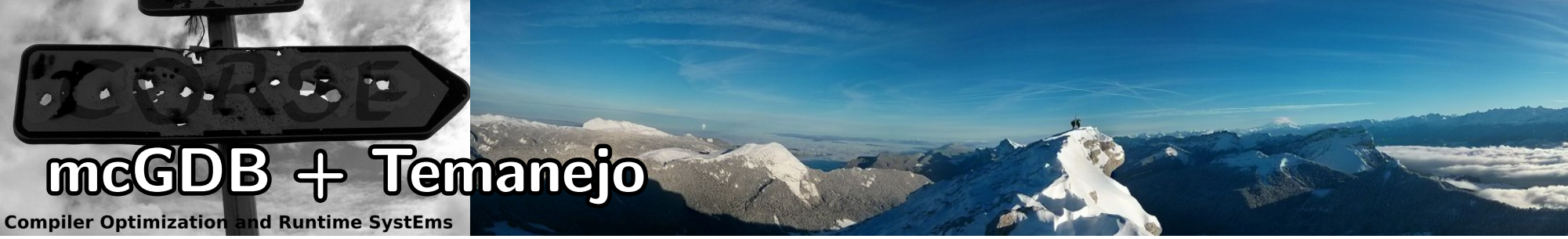
- dynamic, so good match for interactive debugging
- but debugger unfriendly compilation:
  - array/index merged, `len` disappears



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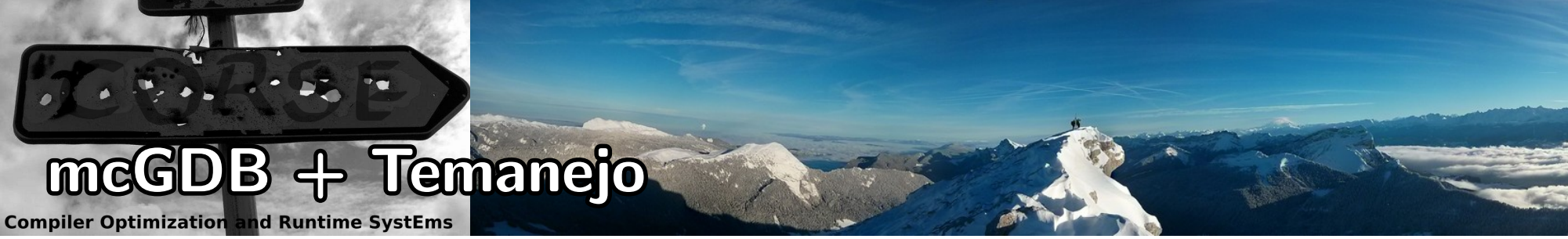

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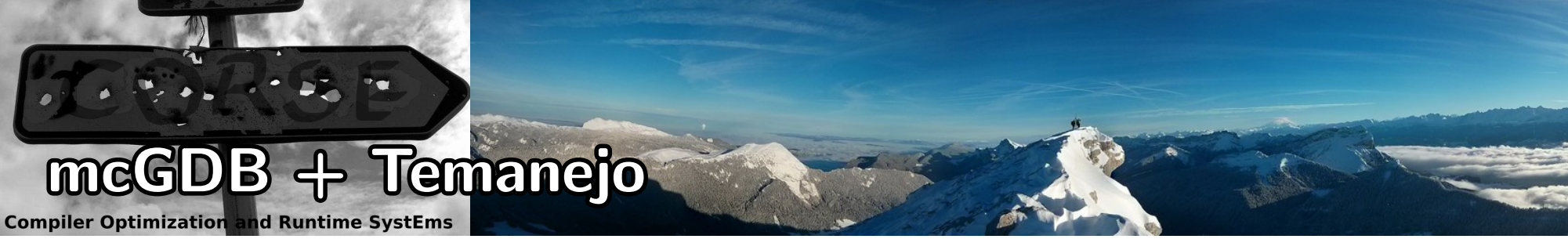

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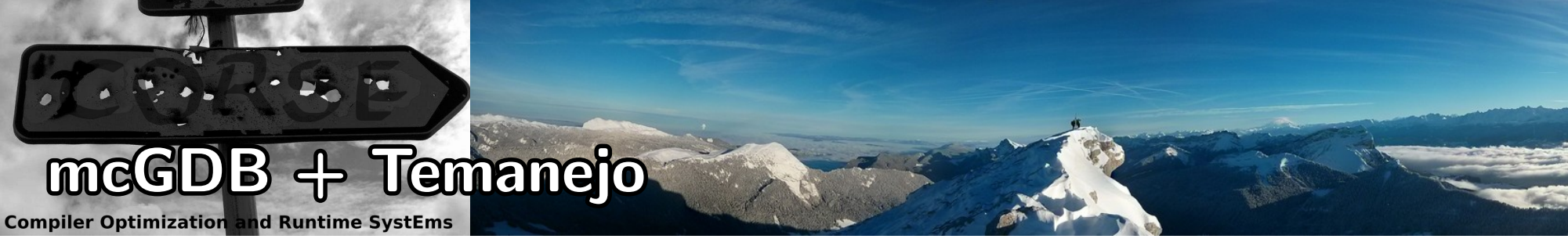

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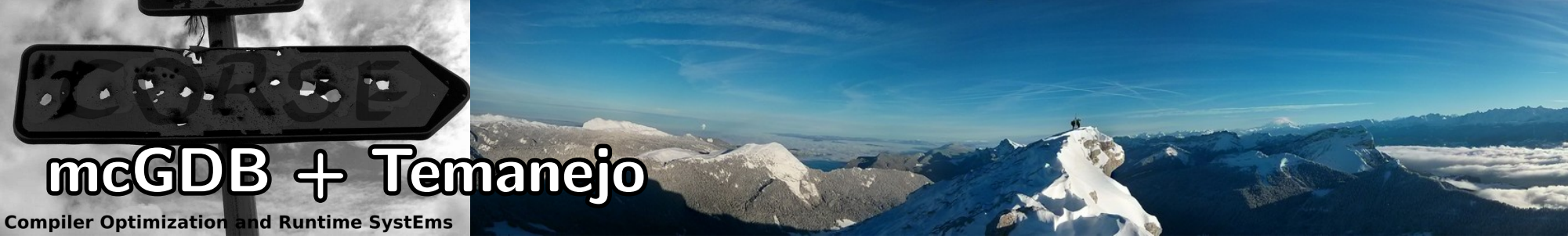

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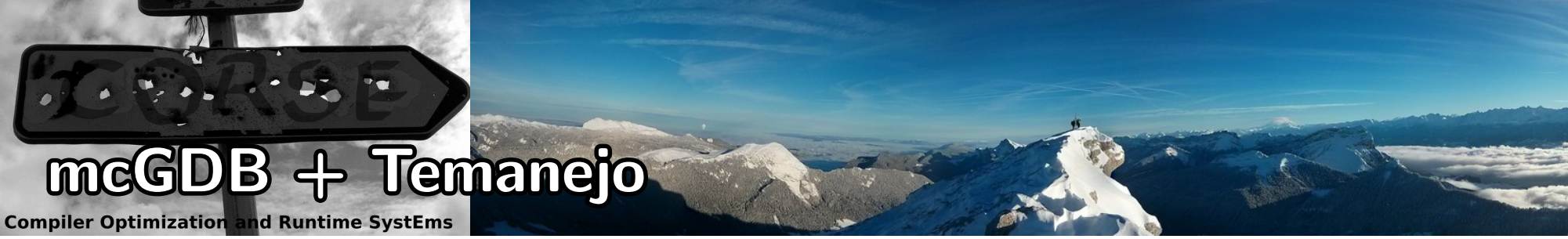

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OpenMP callstack

bad callstack of the threads `where`

```
Thread 3
#0 gomp_mutex_lock (mutex=0x7ffff7bd6748 <default_lock>)
#1 GOMP_critical_start ()
#2 in main._omp_fn.0 () at parallel-demo.c:17
#3 in GOMP_parallel_trampoline (arg=0x602060)
#4 in gomp_thread_start (xdata=<optimized out>)
#5 in pthread_create_trampoline (arg=0x602b10)
#6 in start_thread (
#7 in clone ()
Thread 2
#0  main._omp_fn.0 () at parallel-demo.c:17
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OpenMP/OMPss: OpenMP callstack

Compiler Optimization and Runtime SystEms

OpenMP callstack

bad	callstack of the threads	`where`
better	OpenMP aware thread callstack	`where no-filter`

```
Thread 3
#0  gomp_mutex_lock (...)
#1  #pragma omp critical_start ()
#2  #parallel zone 1 of main () at parallel-demo.c:17
Thread 2
#0  #parallel zone 1 of main () at parallel-demo.c:17
Thread 1
#0  #parallel zone 1 of main () at parallel-demo.c:19
#2  #pragma omp parallel ()
#4  main () at parallel-demo.c:5
```

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```

OpenMP/OMPss: OpenMP callstack

Compiler Optimization and Runtime SystEms

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bad	callstack of the threads	`where`
better	OpenMP aware thread callstack	`where no-filter`
best	OpenMP tree callstack	`omp where`

```
   main () at parallel-demo.c:5
      #pragma omp parallel
         #parallel zone #1 of main
-->      + at parallel-demo.c:17                [Thread 1, 4]
            #pragma omp critical_start ()
-->            gomp_mutex_lock (...)            [Thread 3]
-->      + at parallel-demo.c:19                [Thread 2]
```

OpenMP/OMPss: runtime support

Compiler Optimization and Runtime SystEms

- Intel OpenMP and GOMP:
  - breakpoints
  - `libmcgdb-omp` preloaded helper
    - ⋆ full support, main targets

- OMPss tasks:
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    - ⋆ only task support
  - Initial support of Ayudame helper
    - ⋆ HLRS Ayudame/Temanejo targets for free

- OMP Trace/Debugging Interfaces
  - No support :(task dependencies missing) but it looks promising!!
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Agenda

Compiler Optimization and Runtime SystEms

Conclusion

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  - tree-based callstack
  - task graph visualization
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  - ... and benchmark mcGDB slowdown
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