DE LA RECHERCHE À L'INDUSTRIE

Communication-Aware Task Scheduling Strategy in Hybrid MPI+OpenMP applications

IWOMP 2021 – 17th International Workshop on OpenMP – 16th September 2021

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Introduction (1/4)

Context

- HPC applications, **distributed** machines
  - Message Passing Interface (**MPI**)

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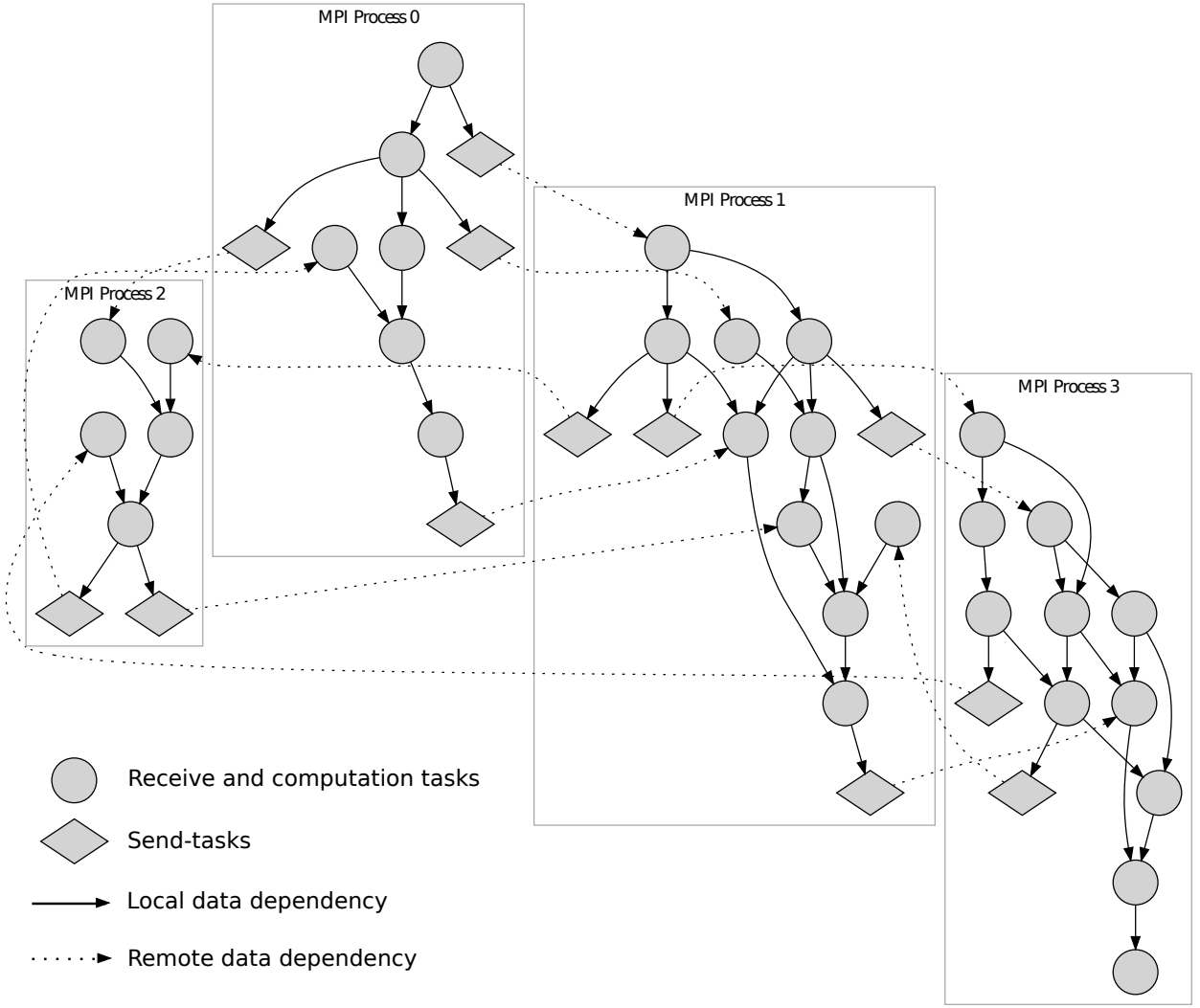
- **MPI+OpenMP(tasks)** applications
  - Distributed data-flow graph
  - Scheduler knowledge limited to local subgraphs



A data-dependency task graph distributed across 4 processes

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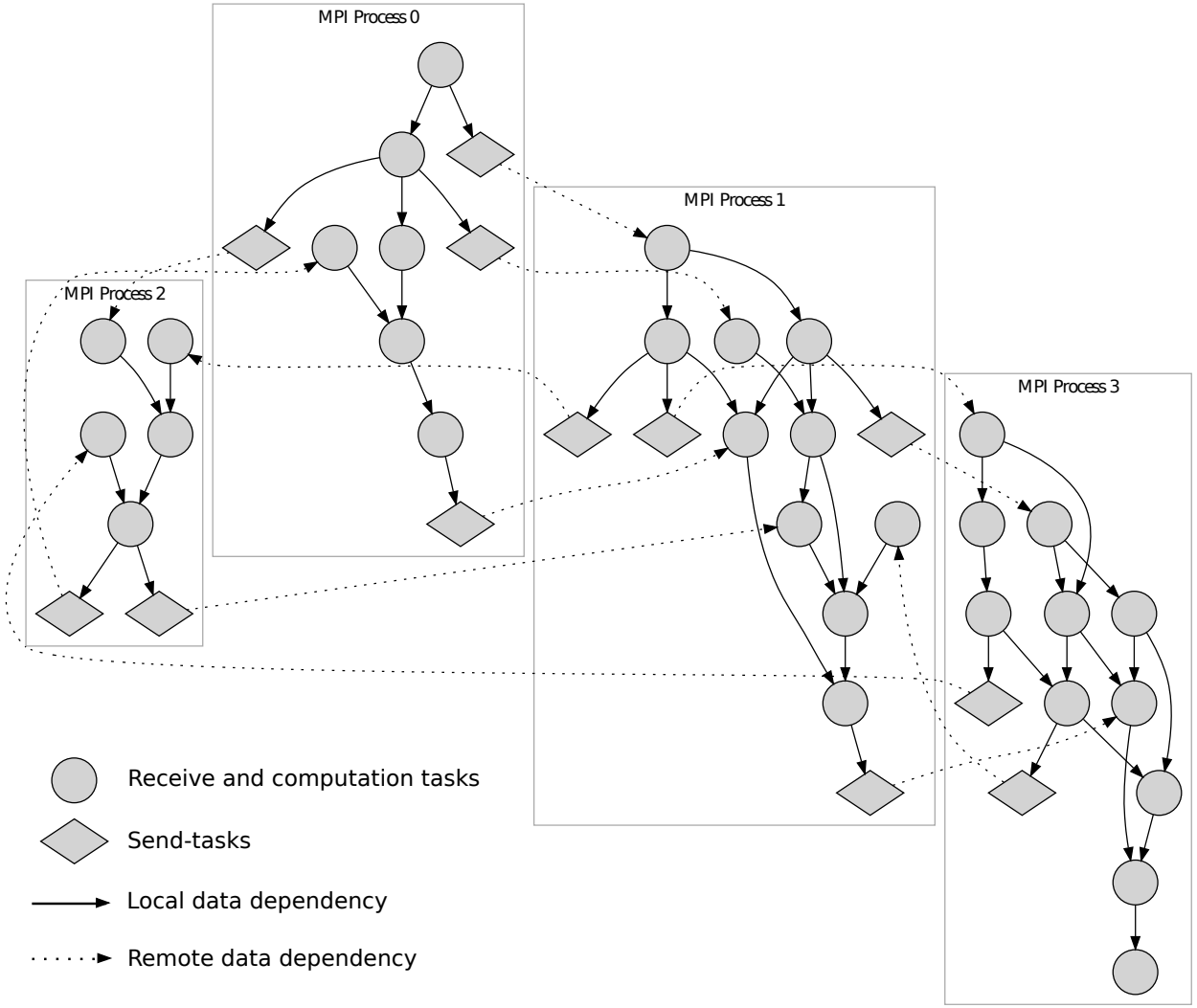
➡ **Scheduling** issues

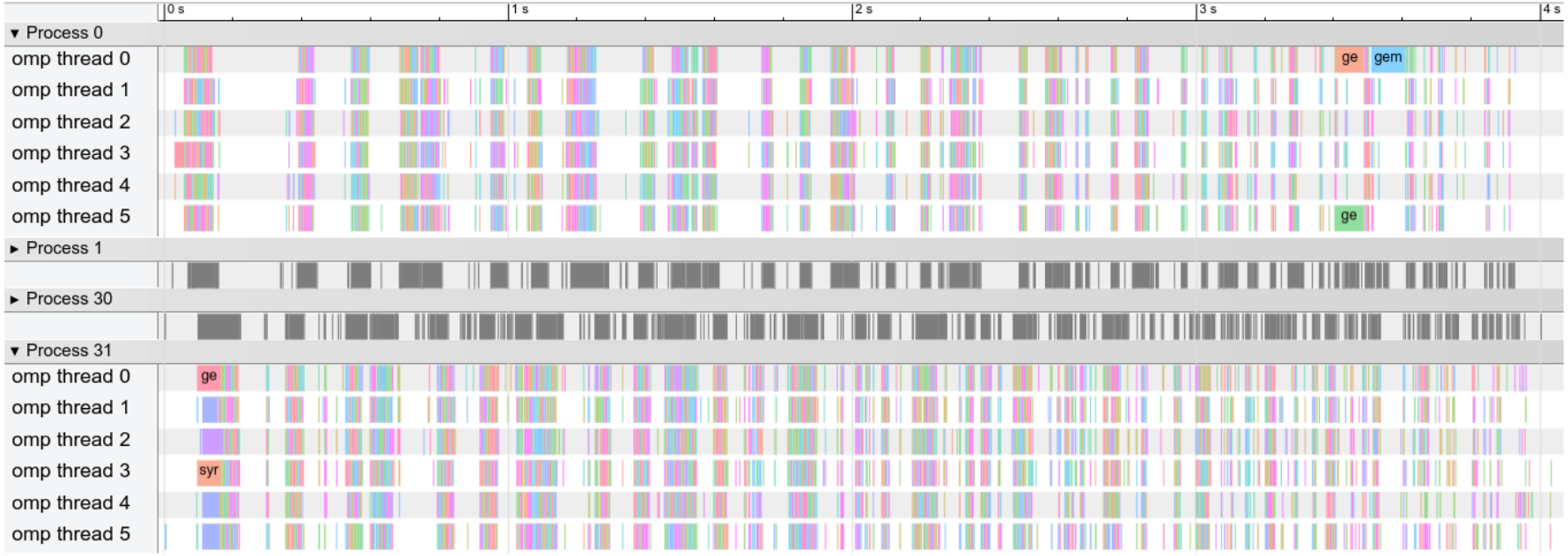


A data-dependency task graph distributed across 4 processes

Motivation – scheduling issues

- FIFO task scheduling
- Task-based Cholesky matrix factorization (MKL) **[TASKYIELD, CHOLESKY]**

- Skylake nodes
  - Intel(R) Xeon(R) Platinum 8168 CPU @ 2.70GHz
  - 2 sockets (NUMA) – 24 cores per socket



Task scheduling on a matrix of size 32,768 with blocks of size 512 on 4 Skykake nodes with 8 processes per nodes, of 6 threads each

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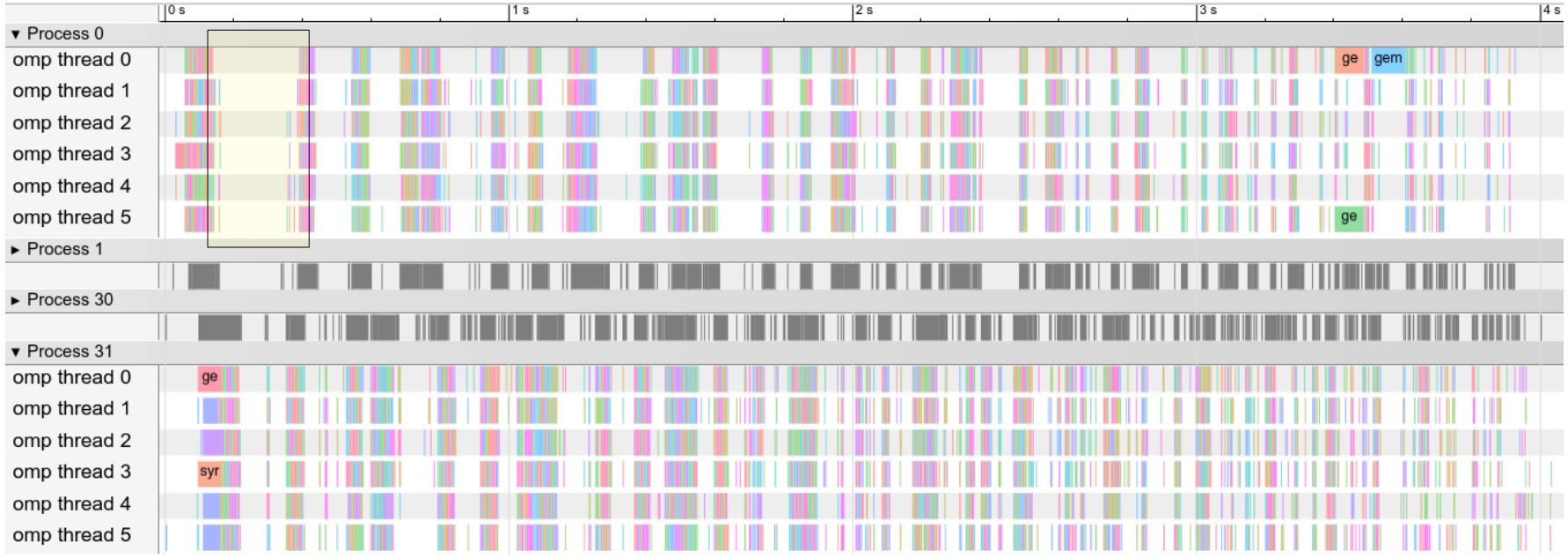

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➡ Can we reduce **idle** periods with a better scheduling policy?

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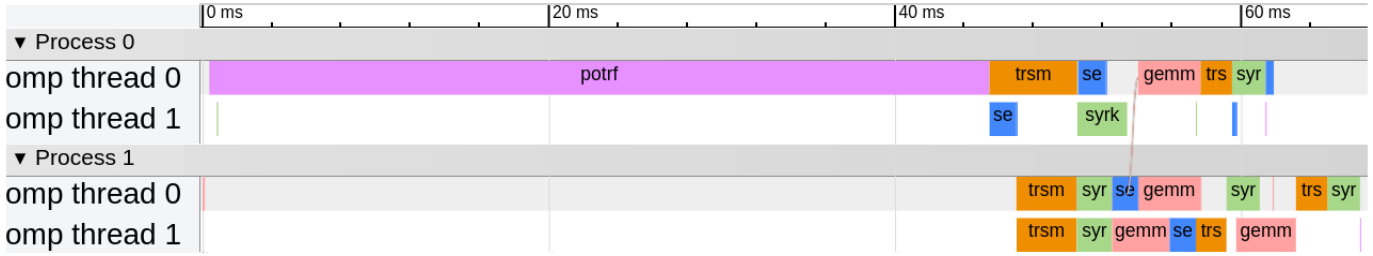
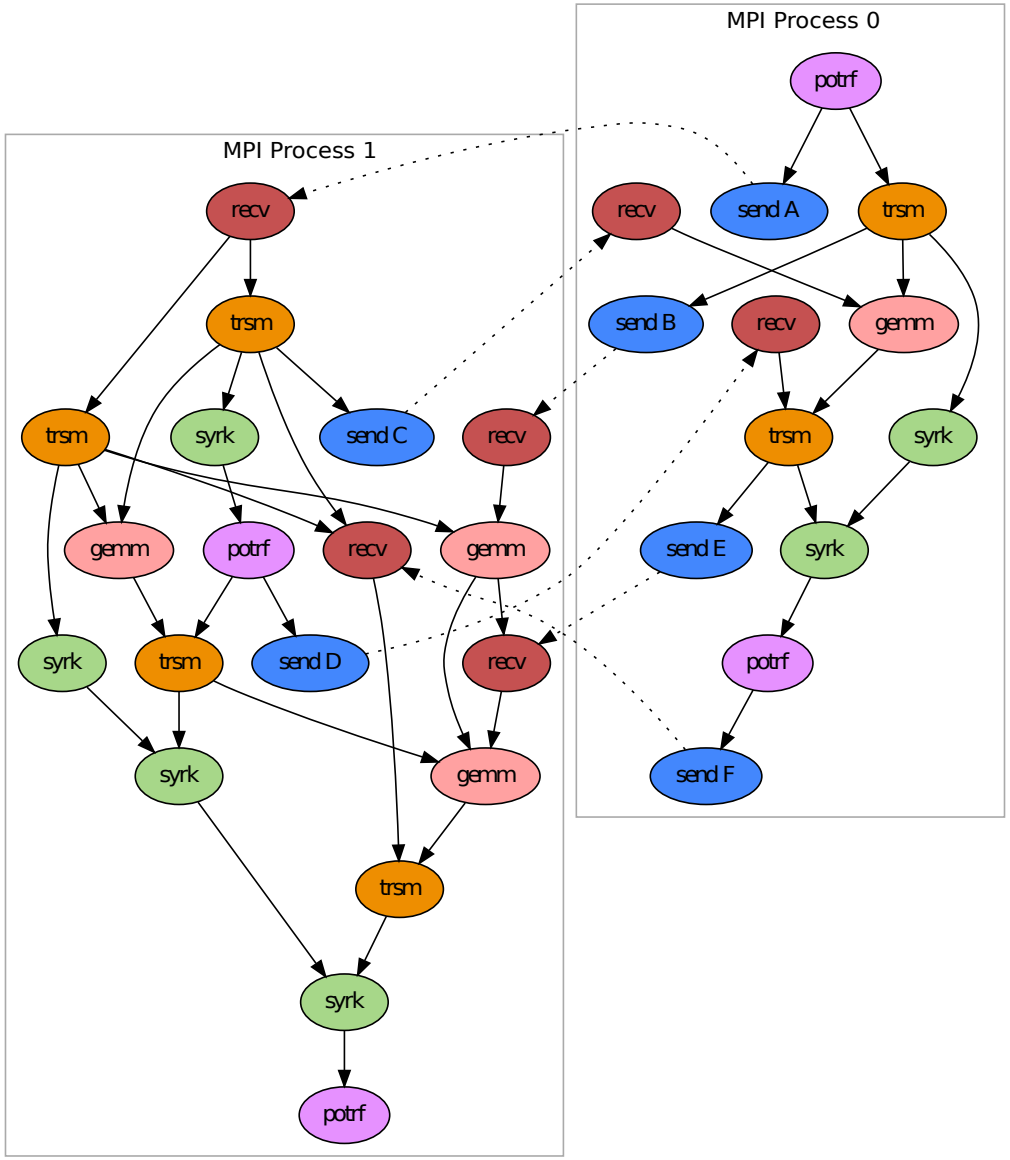
Motivation - a minimal case

- Cholesky Factorization
  - Matrix of size 2,048 with blocks of size 512
  - 2 processes with 2 threads





Data-dependency graph of the minimal case

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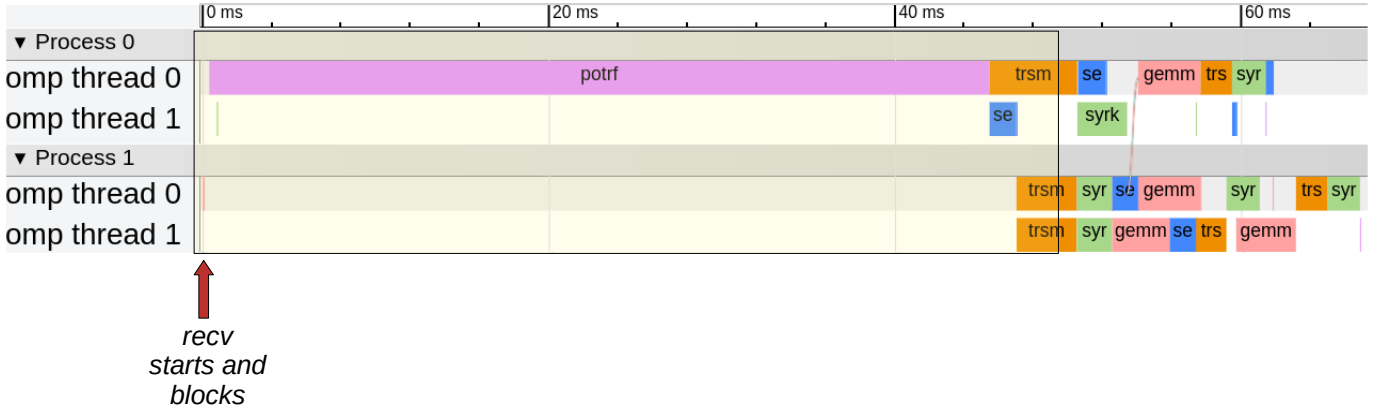
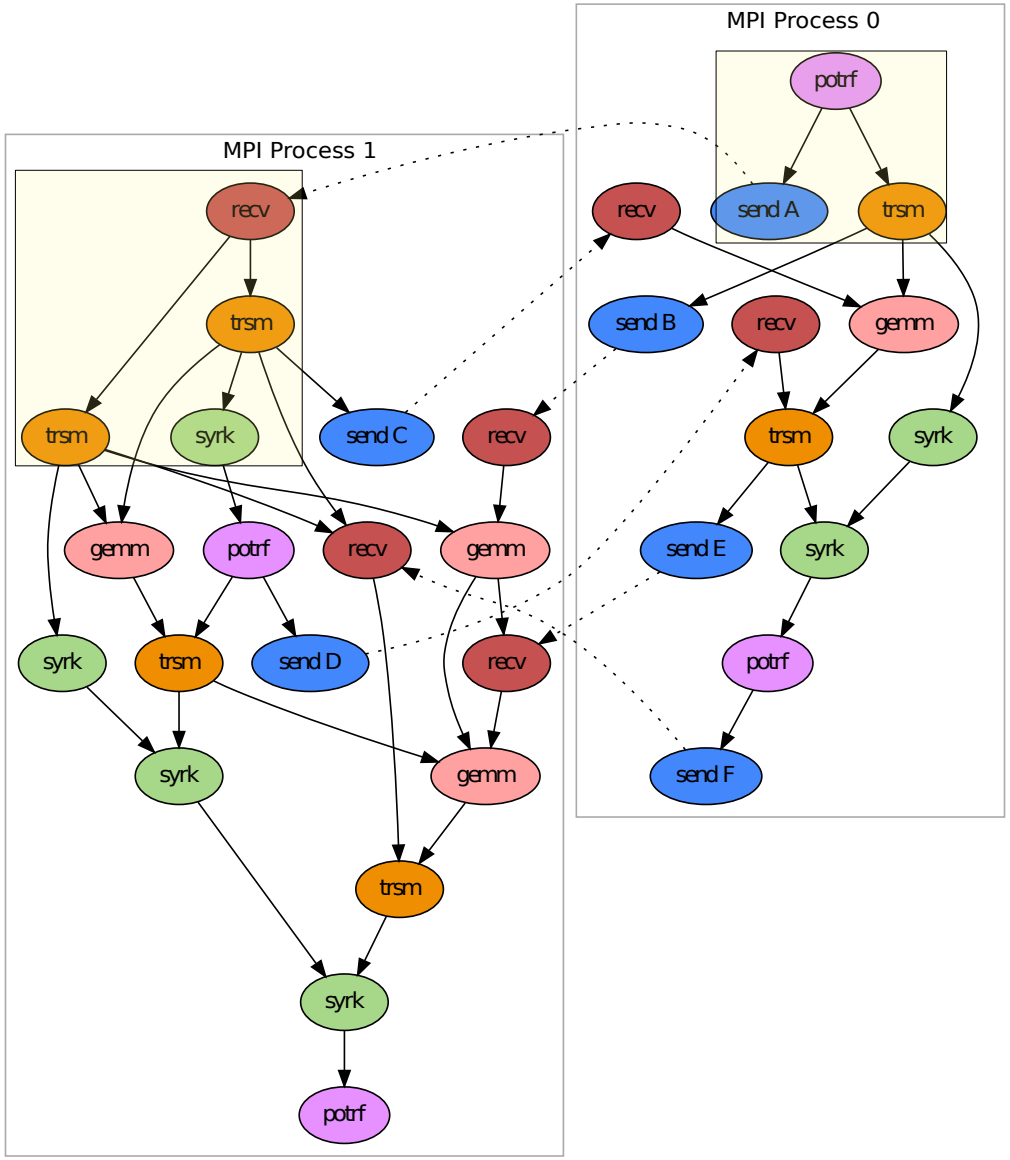


Initially, **low parallelism** is expressed → no possible gain



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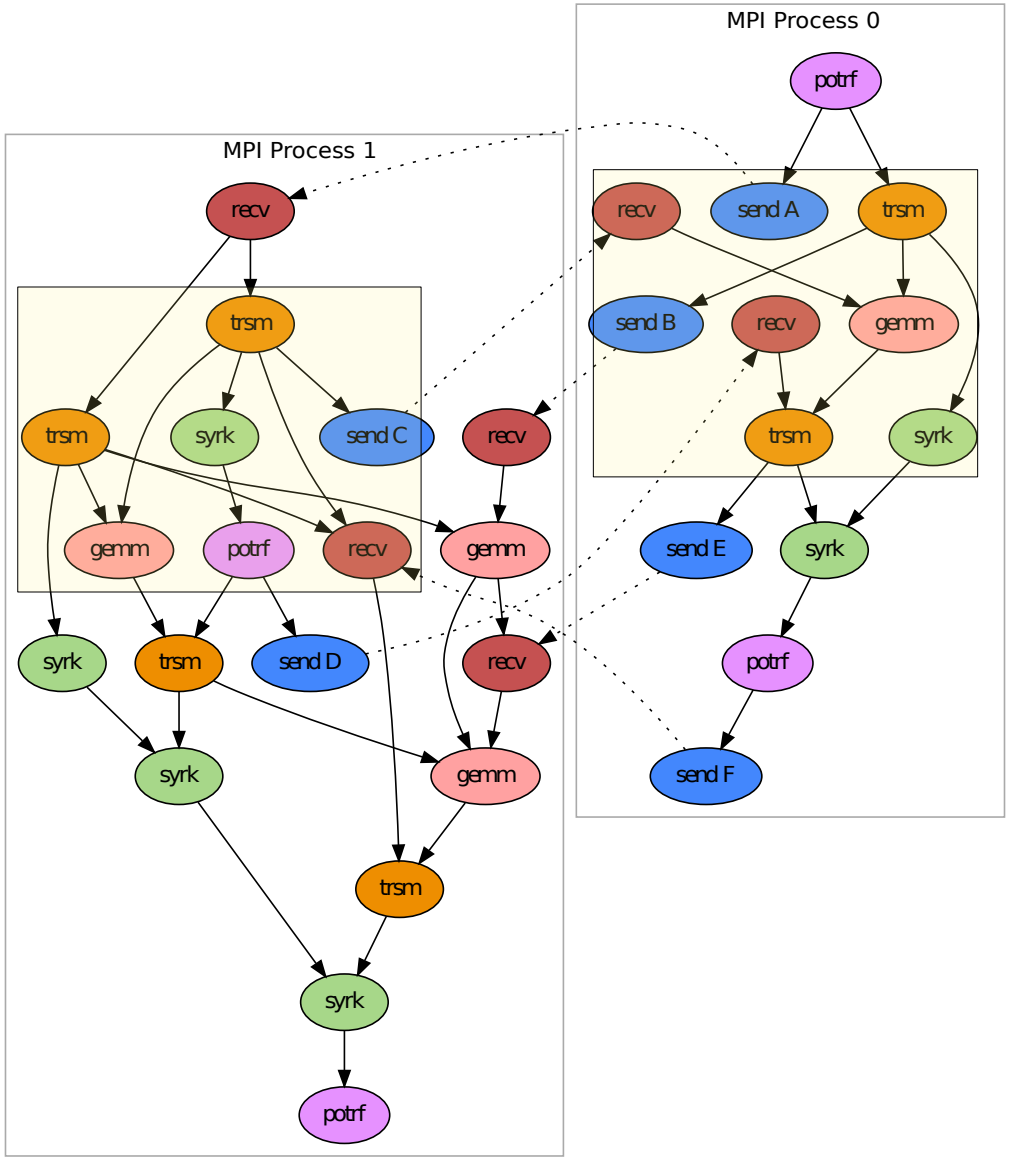
Idle time due to **scheduling decisions**



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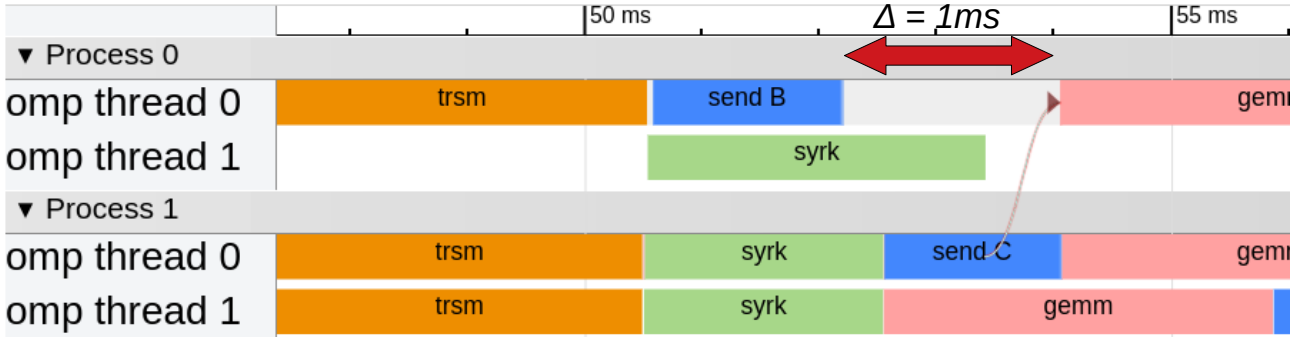
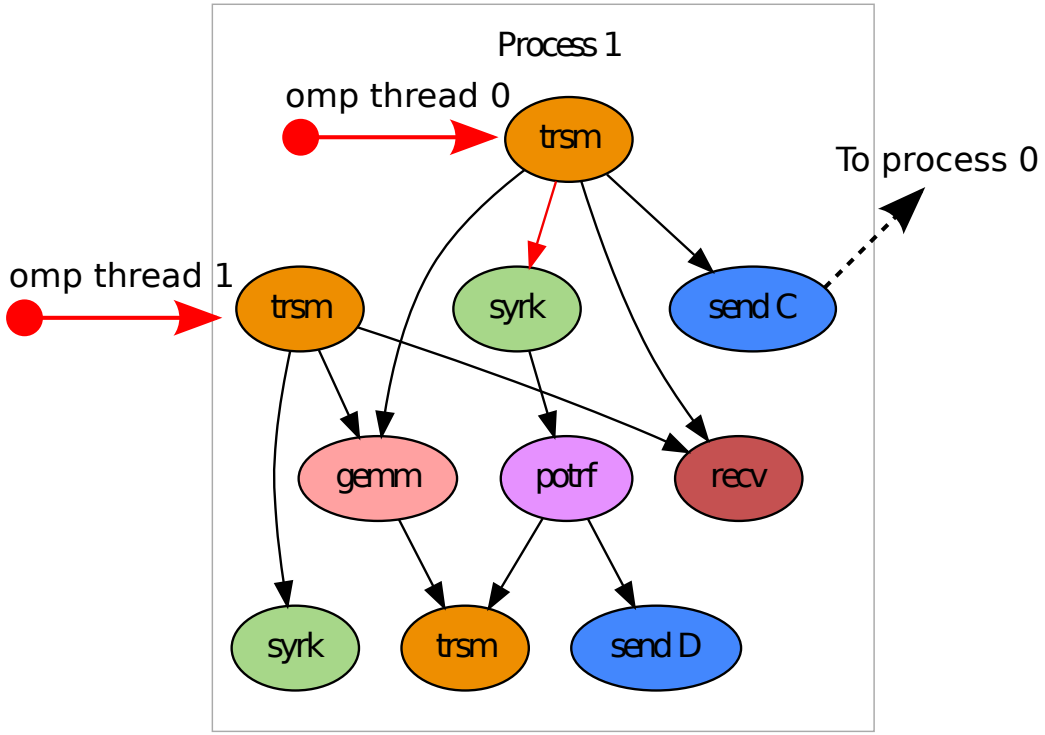


FIFO task scheduling on the minimal case

We **zoomed** in the idle period



Subgraph of process 1 on the minimal case

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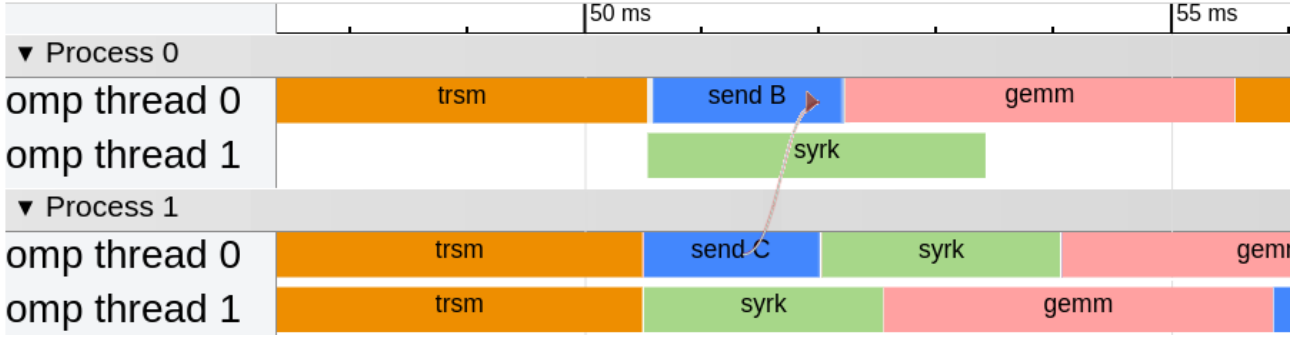

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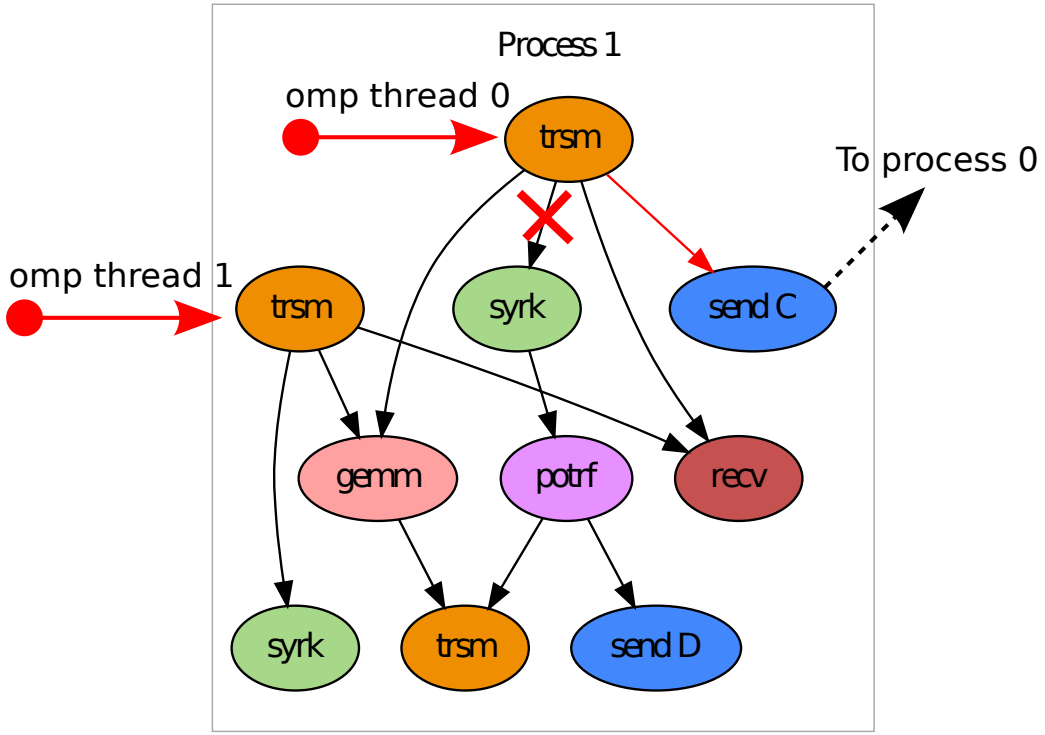

Subgraph of process 1 on the minimal case

Problem

➡ Wrong scheduling decisions taken locally make remote threads **idle**

Related work

- MPI+OpenMP interoperability issues
  - Loss of threads (or even deadlocks) when nesting MPI blocking operations within OpenMP tasks – **[QCD benchmark]**

```
1    # pragma omp task depends(in: data)
2    {
3        […]
4        MPI_Send(data, …) ;
5        […]
6     }
```

Hybrid MPI+OpenMP(tasks) minimal code example

[QCD benchmark] - Meadows, Larry & Ishikawa, Ken-ichi. (2017). OpenMP Tasking and MPI in a Lattice QCD Benchmark.

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- MPI+OpenMP interoperability issues
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- Several solutions - **[TASKYIELD] – [TAMPI] – [MPI-DETACH]**
  - Task switch to overlap waiting time
  - Enables working MPI+OpenMP(tasks) applications

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Introduction (4/4)

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  - Task switch to overlap waiting time
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➡ Scheduling issues remains

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Hybrid MPI+OpenMP(tasks) minimal code example

Contribution

- **Task scheduling strategy for hybrid MPI+OpenMP(tasks) applications**
  - Task re-ordering
  - Favoring local send operations to reduce remote idle times

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Contents

Communication-Aware Task Re-ordering Strategy

- **Priority Policies**
- Implementation

Communication-Aware Task Re-ordering Strategy (1/5)

Task Ordering

- Ready tasks with the highest priority first
- OpenMP **priority hint** clause

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Manual Approach (MA1)

- Hint to **1** on **send-tasks**
- No hint on other tasks (0 by default)

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2   {
3       […]
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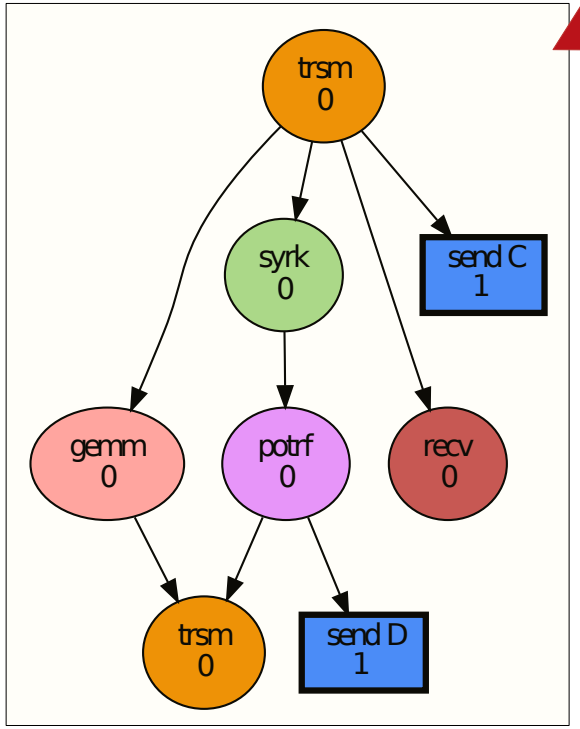

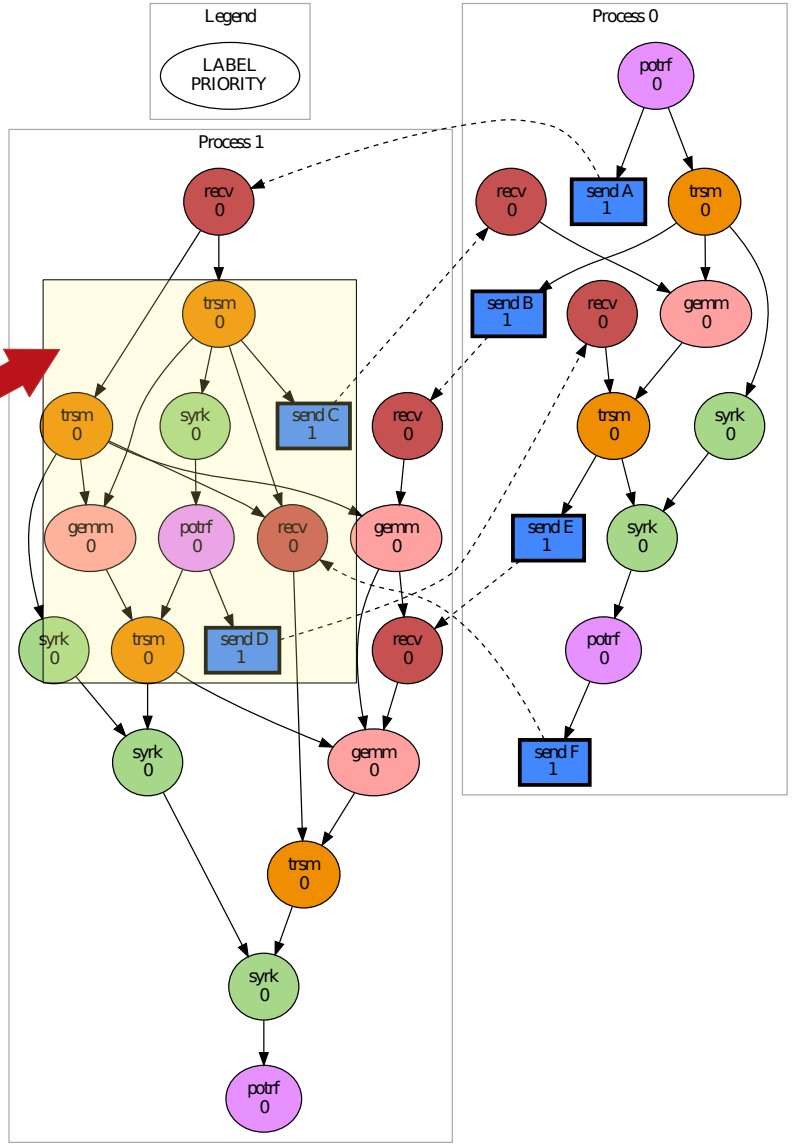

Data-dependency graph and MA1 priorities

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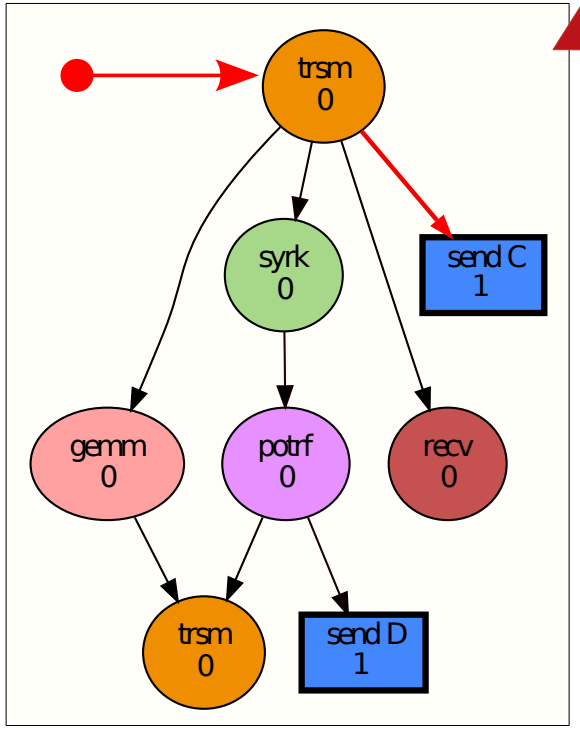
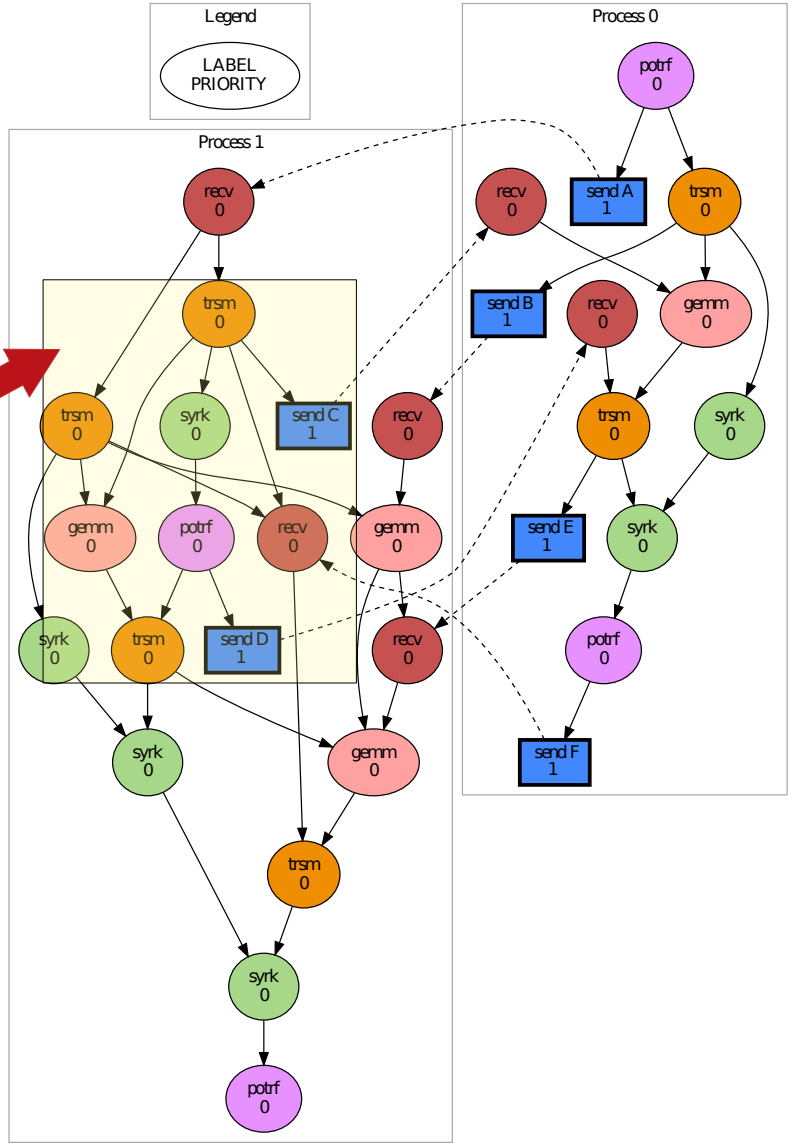
→ Once **trsm** is completed, **send C** is elected





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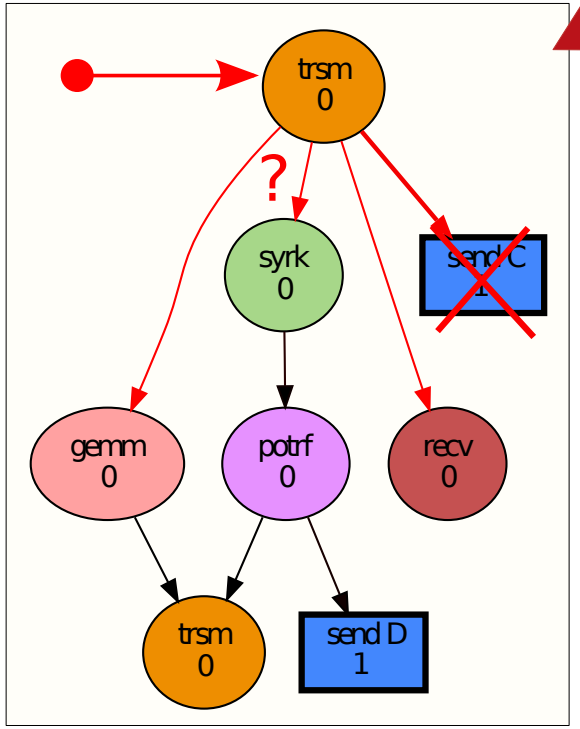
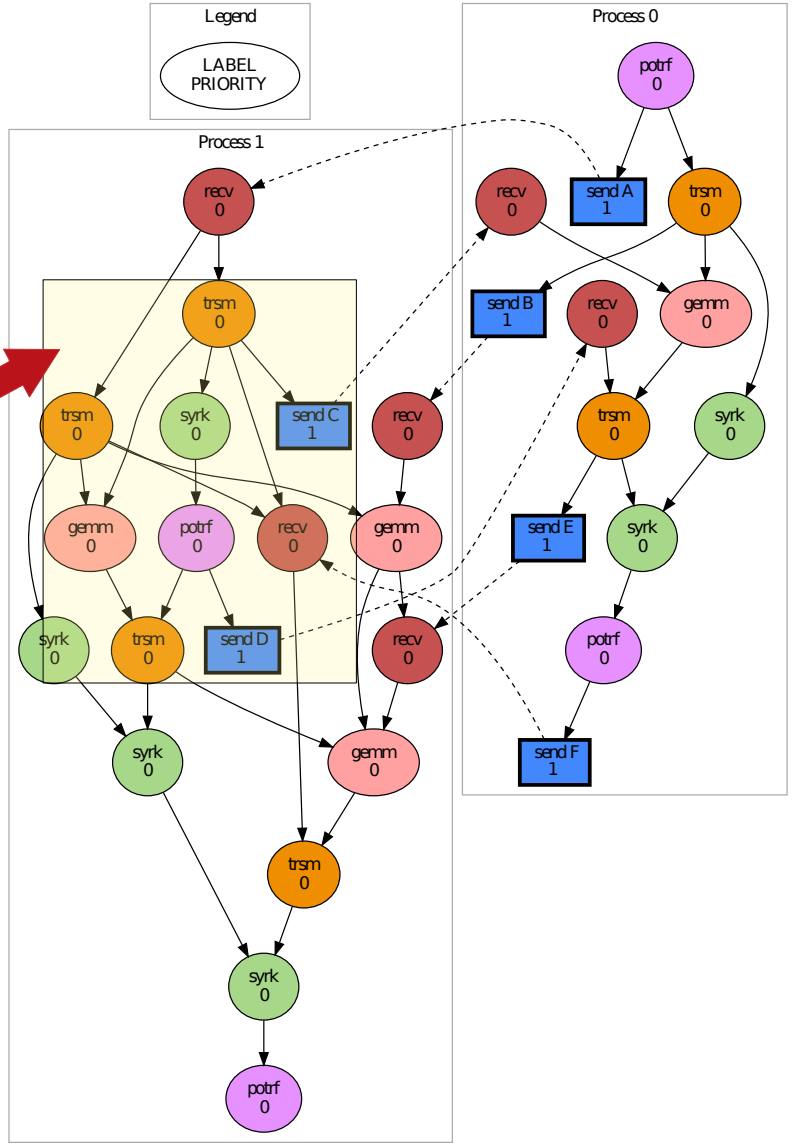
After **send C**: **syrk**, **gemm** or **recv**?





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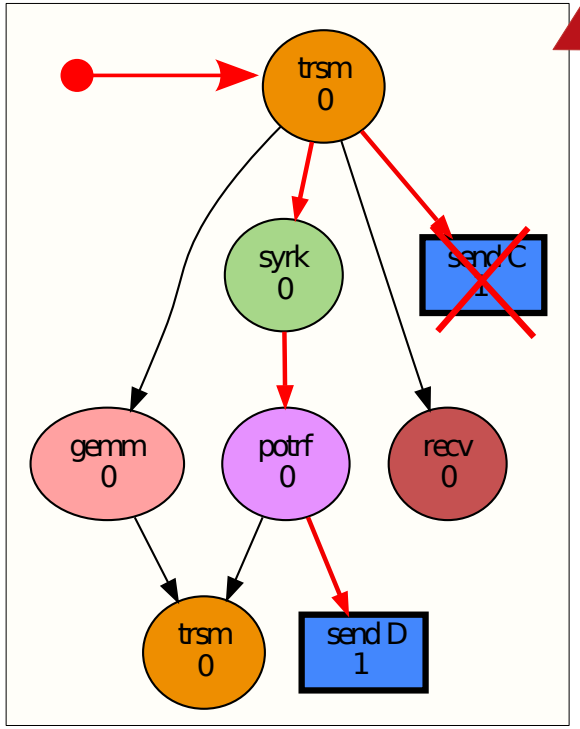

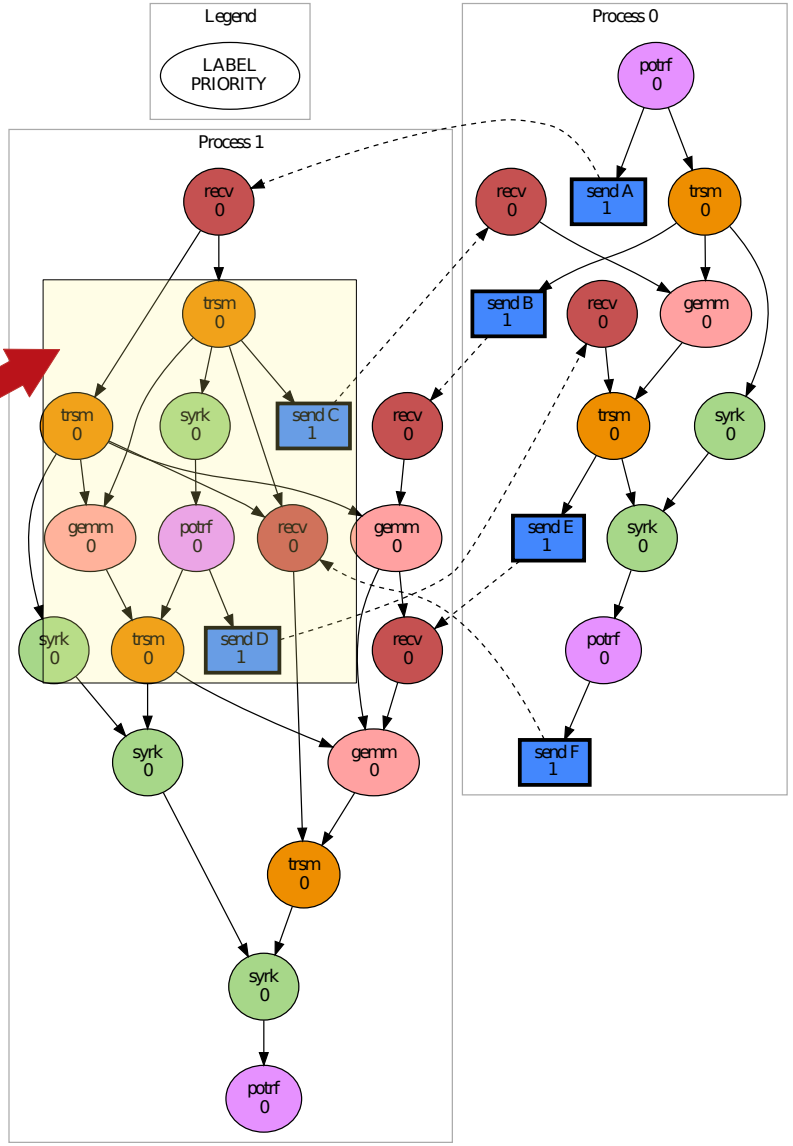

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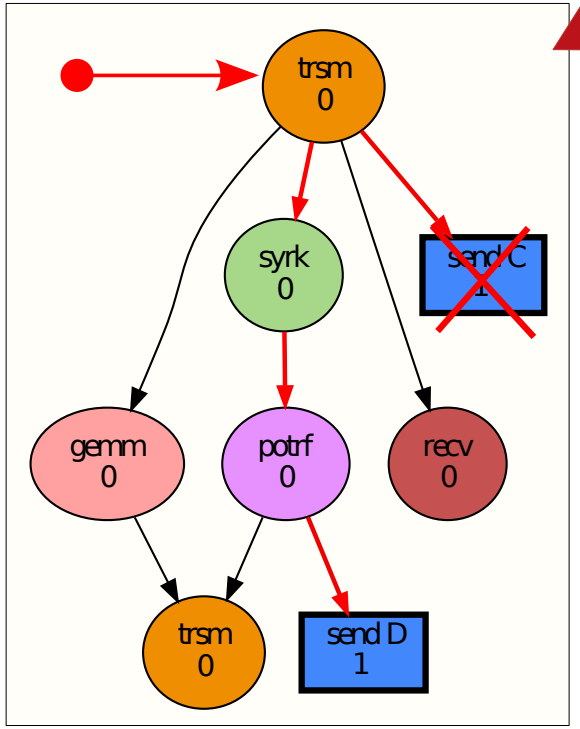
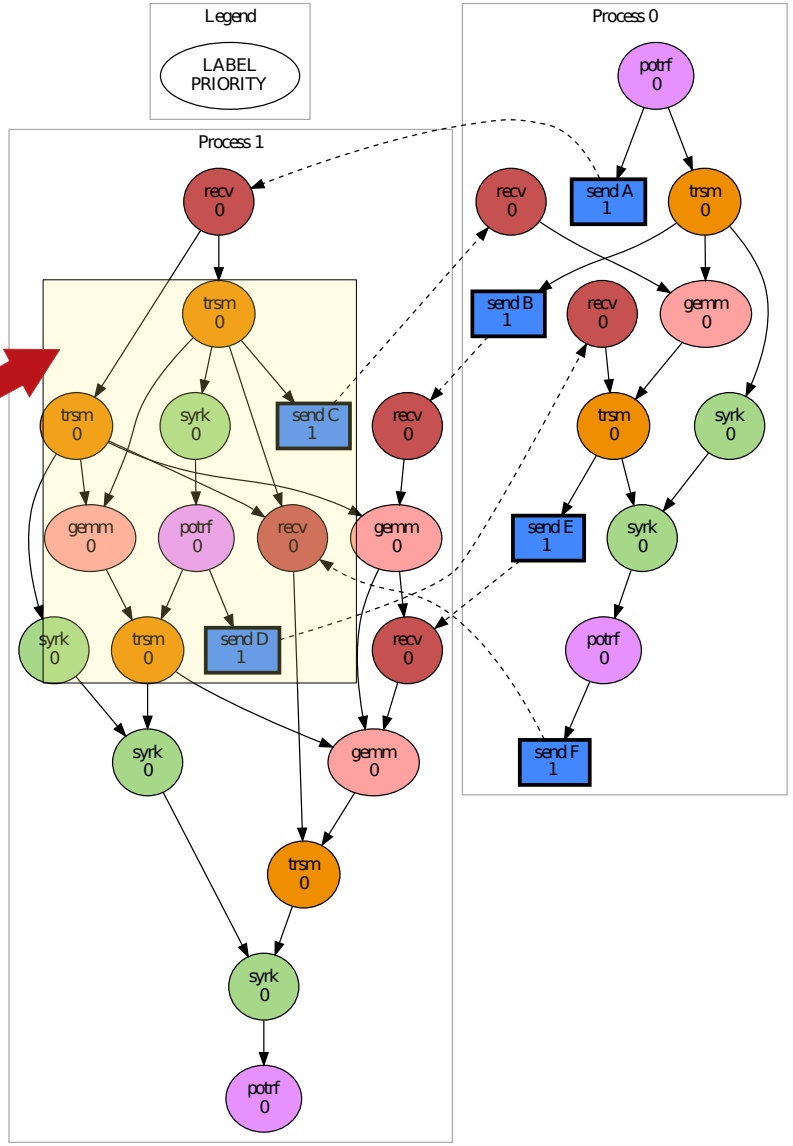
➡ Schedule send-task **predecessors**





Data-dependency graph and MA1 priorities

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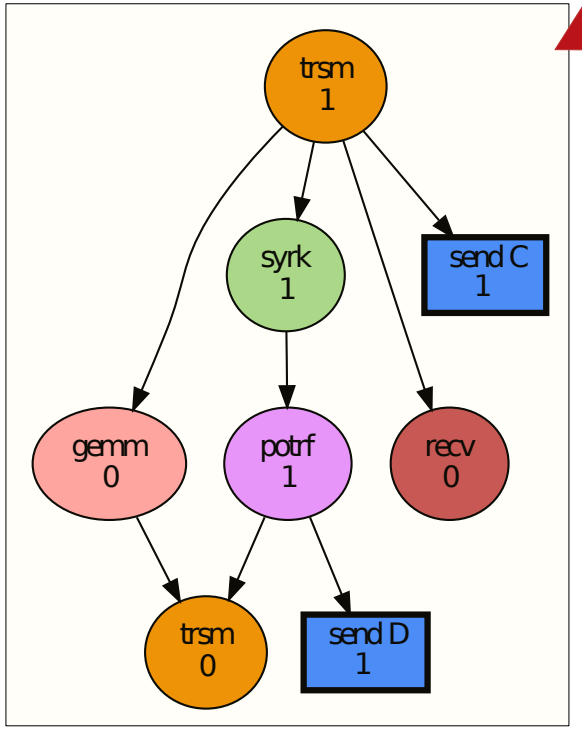

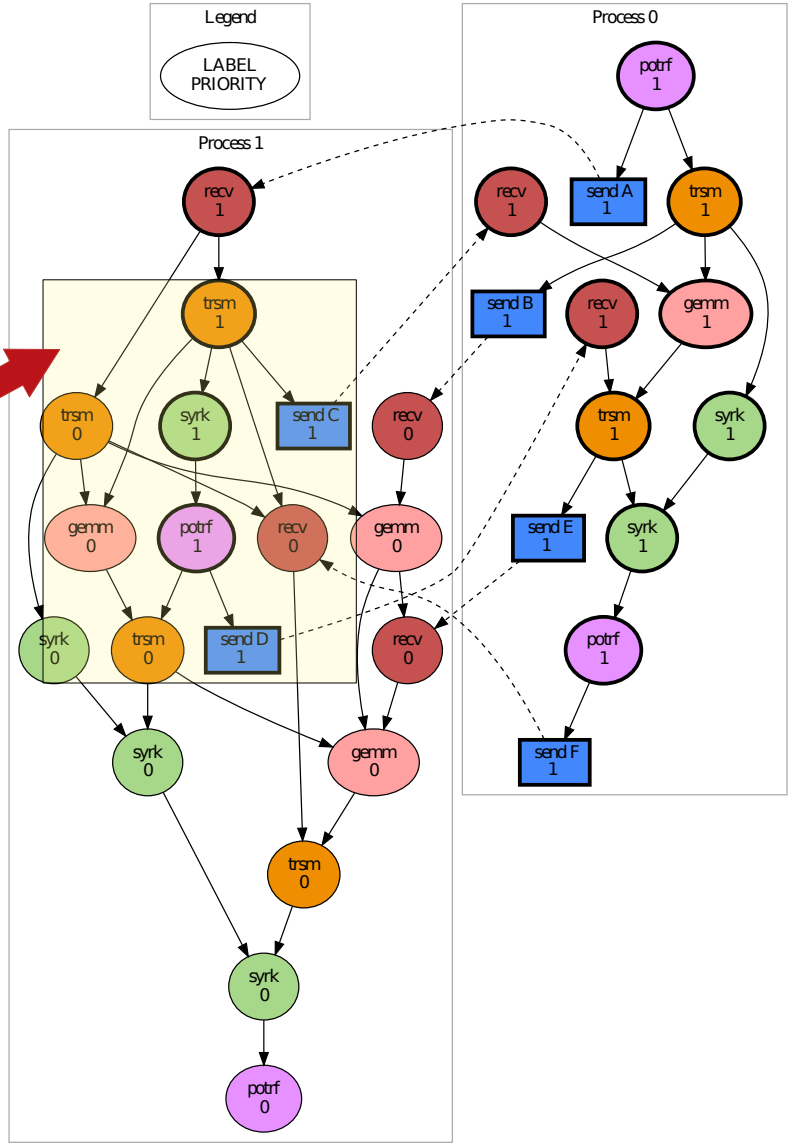

Data-dependency graph and MA2 priorities

Communication-Aware Task Re-ordering Strategy (2/5)

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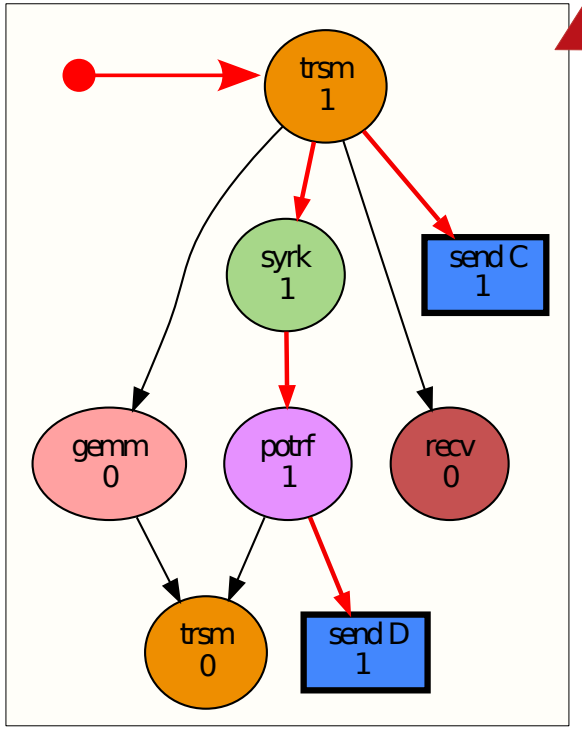
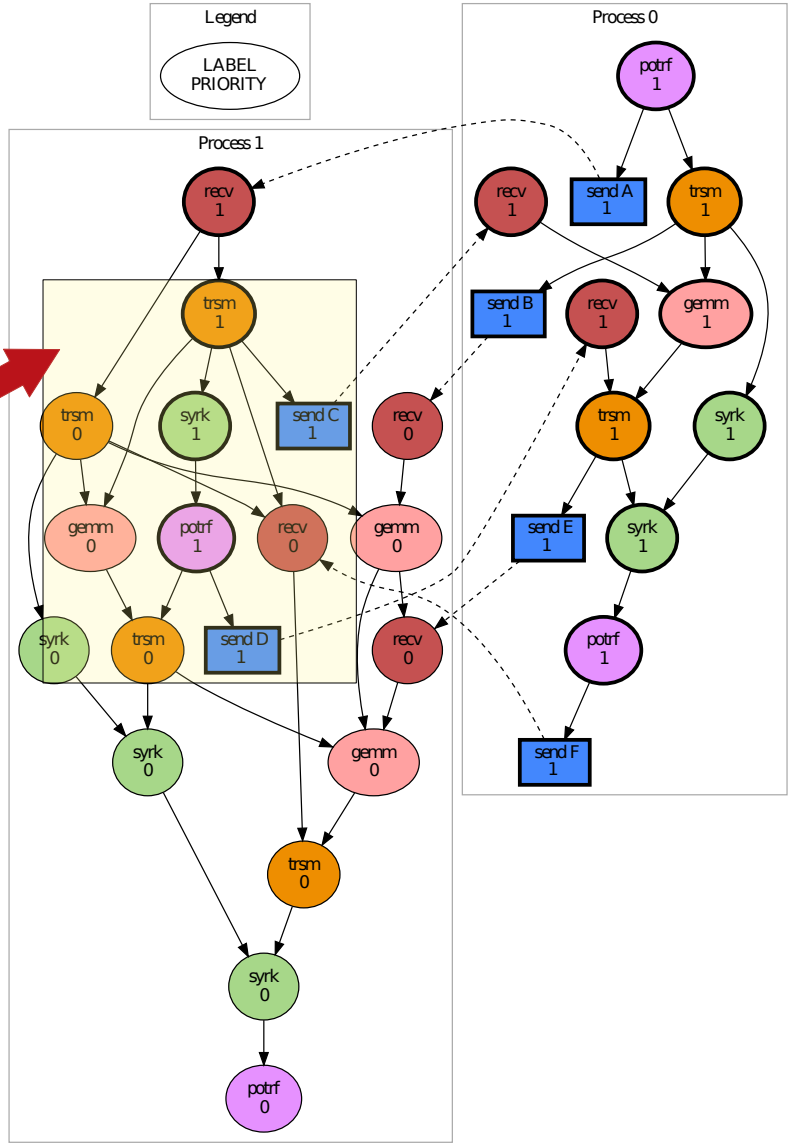
Advantages

- Predecessors are marked

→ **syrk** - **potrf** over **gemm** and **recv**





Data-dependency graph and MA2 priorities

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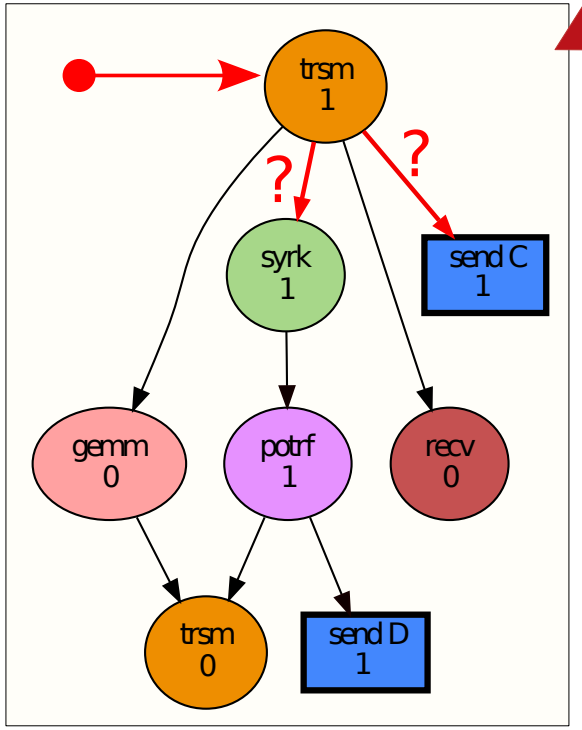
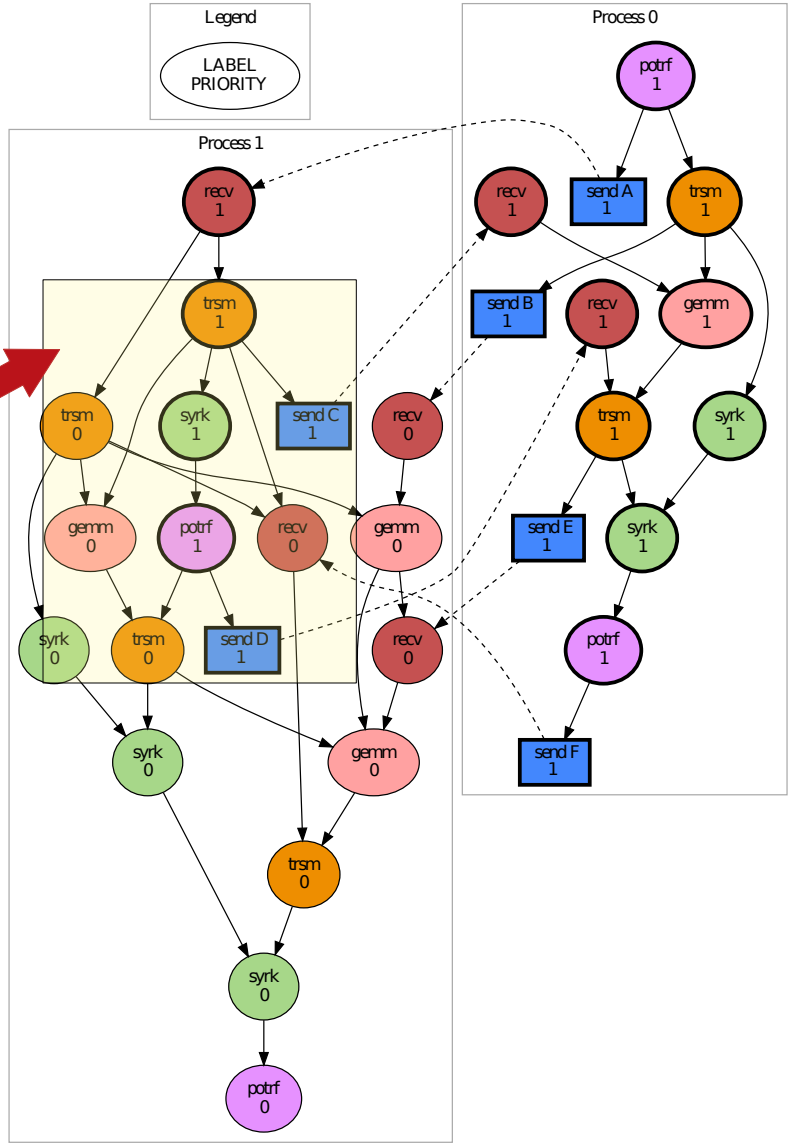
→ **syrk** or **send C**?





Data-dependency graph and MA2 priorities

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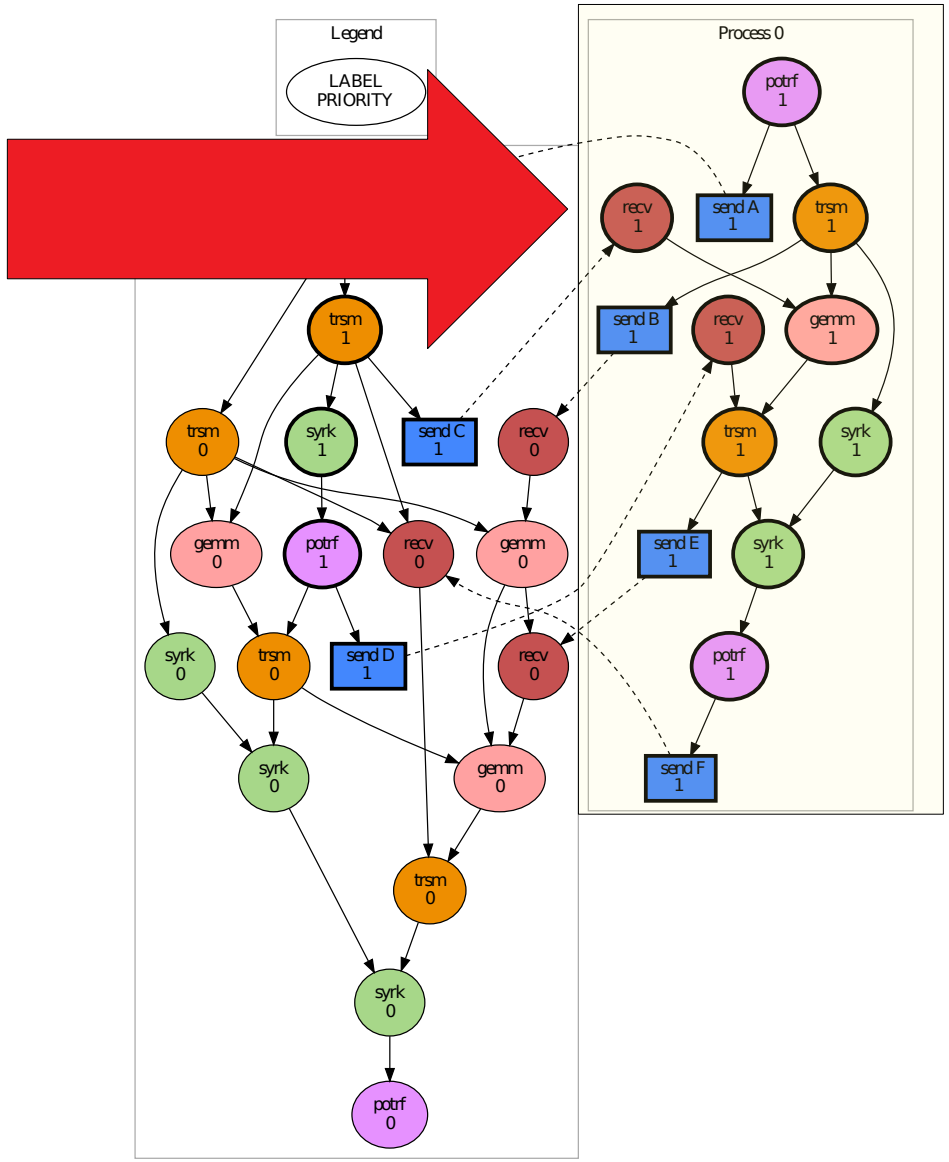

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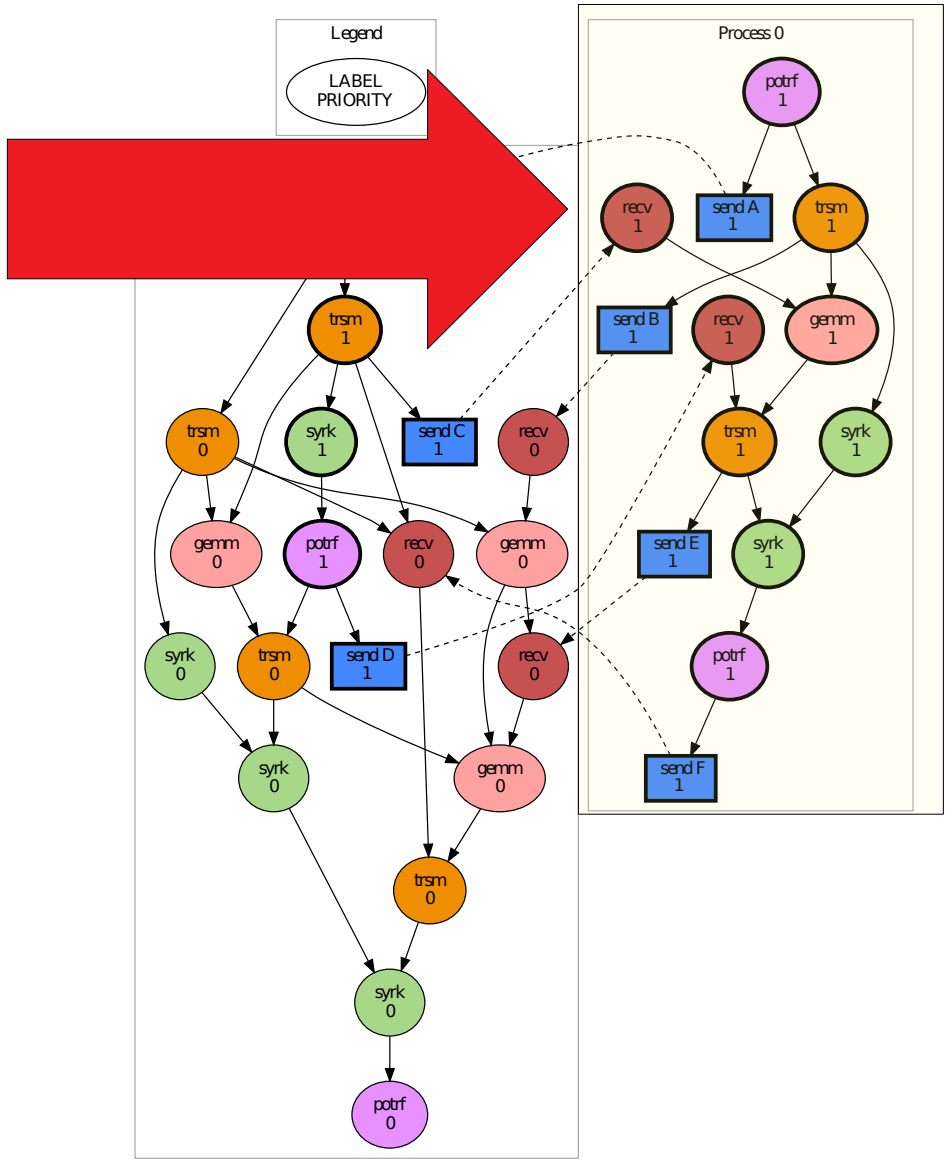
➡ Distinguish **send-tasks**, their **predecessors**, and other tasks



Data-dependency graph and MA2 priorities

Manual Approach (MA3)

- Hint to **omp_get_max_priority() - closest distance** to a **send-task**
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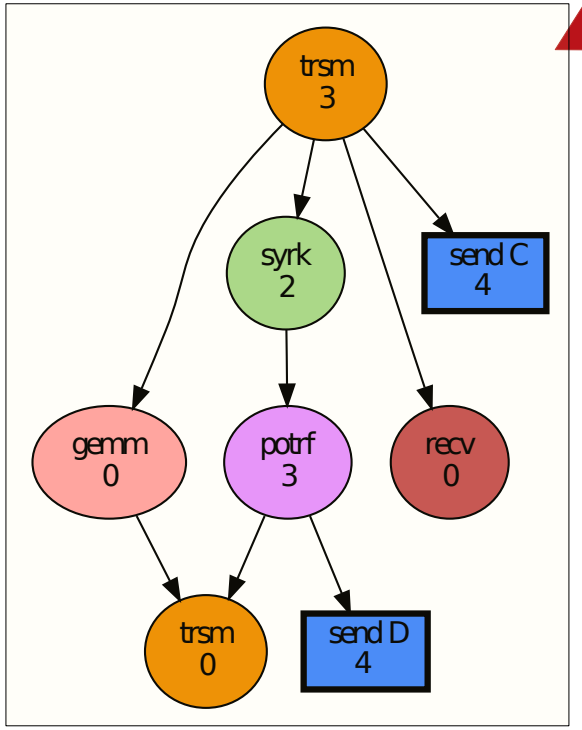

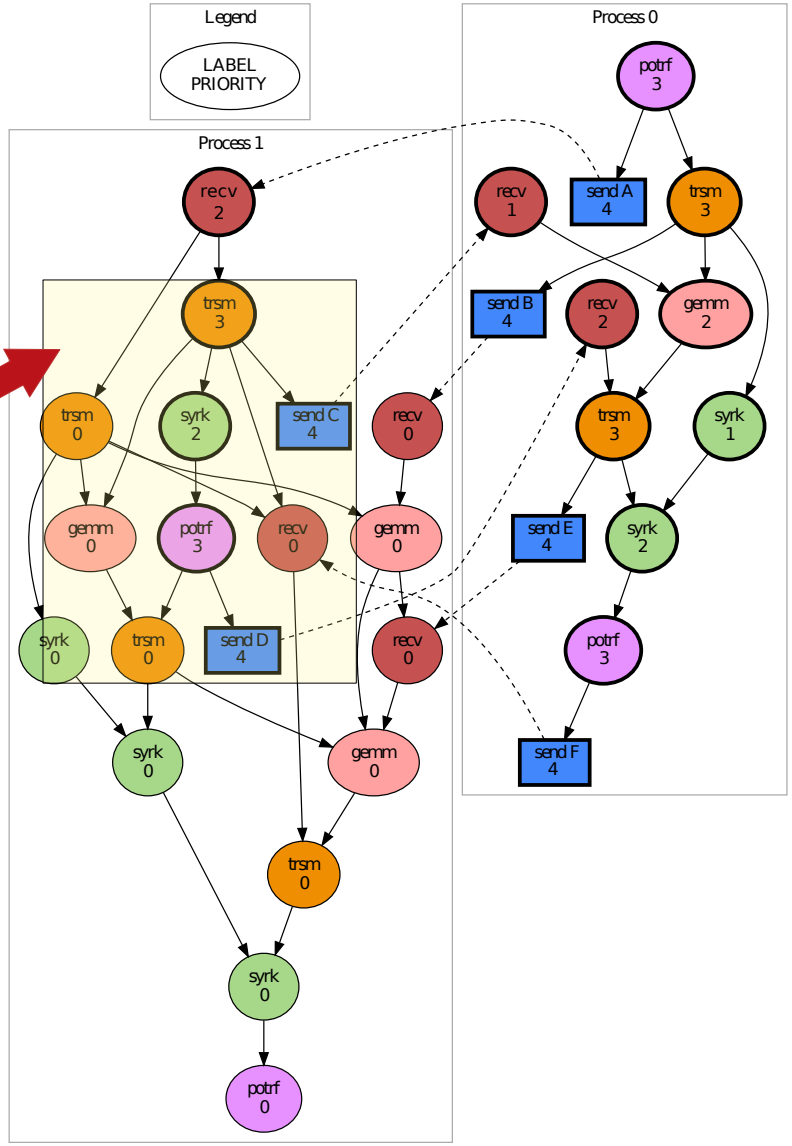

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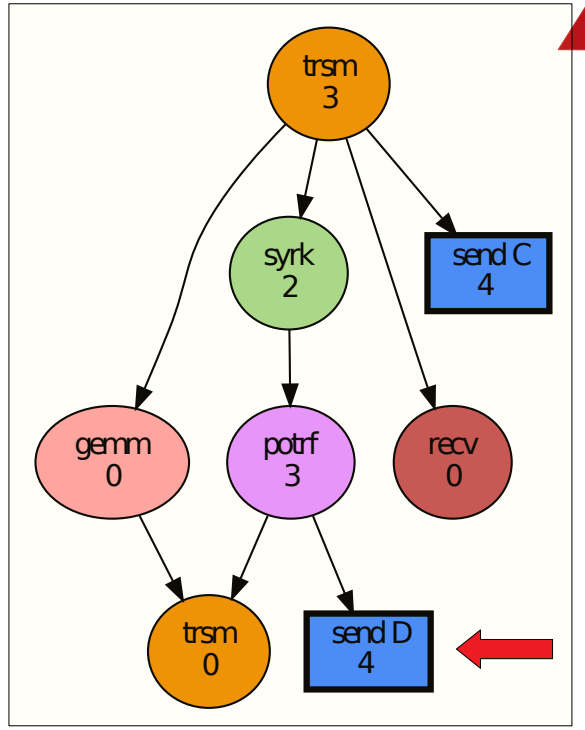

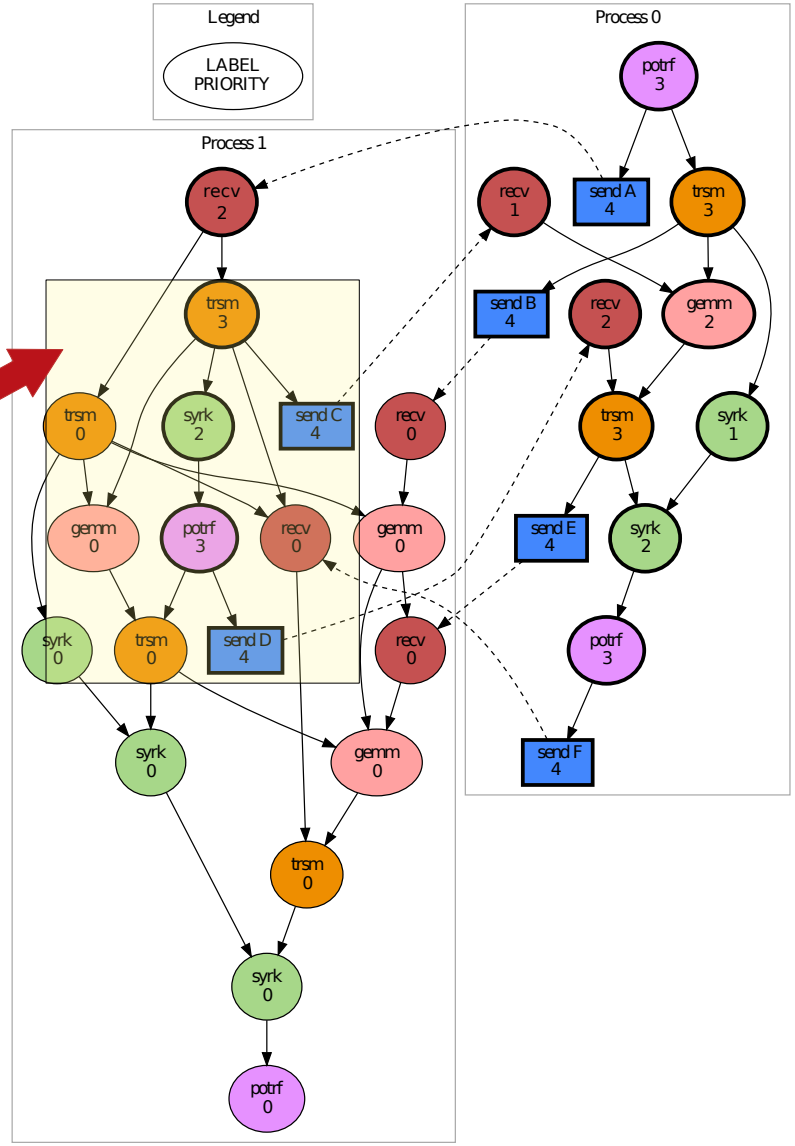

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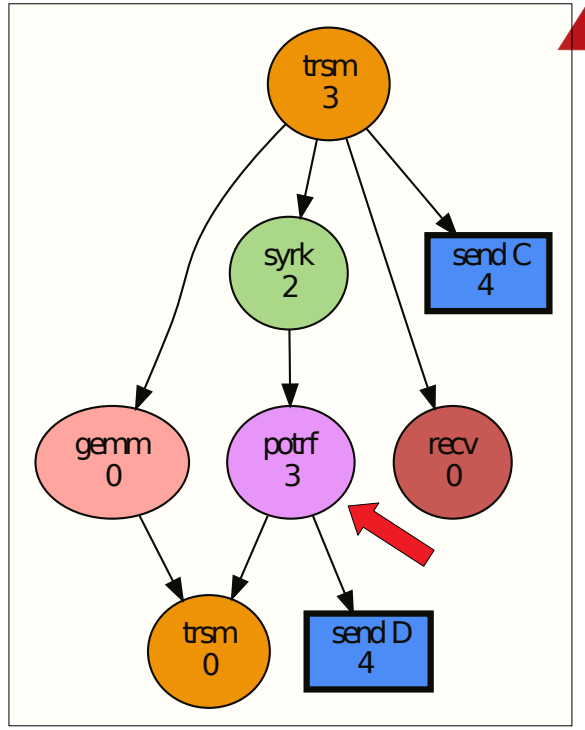

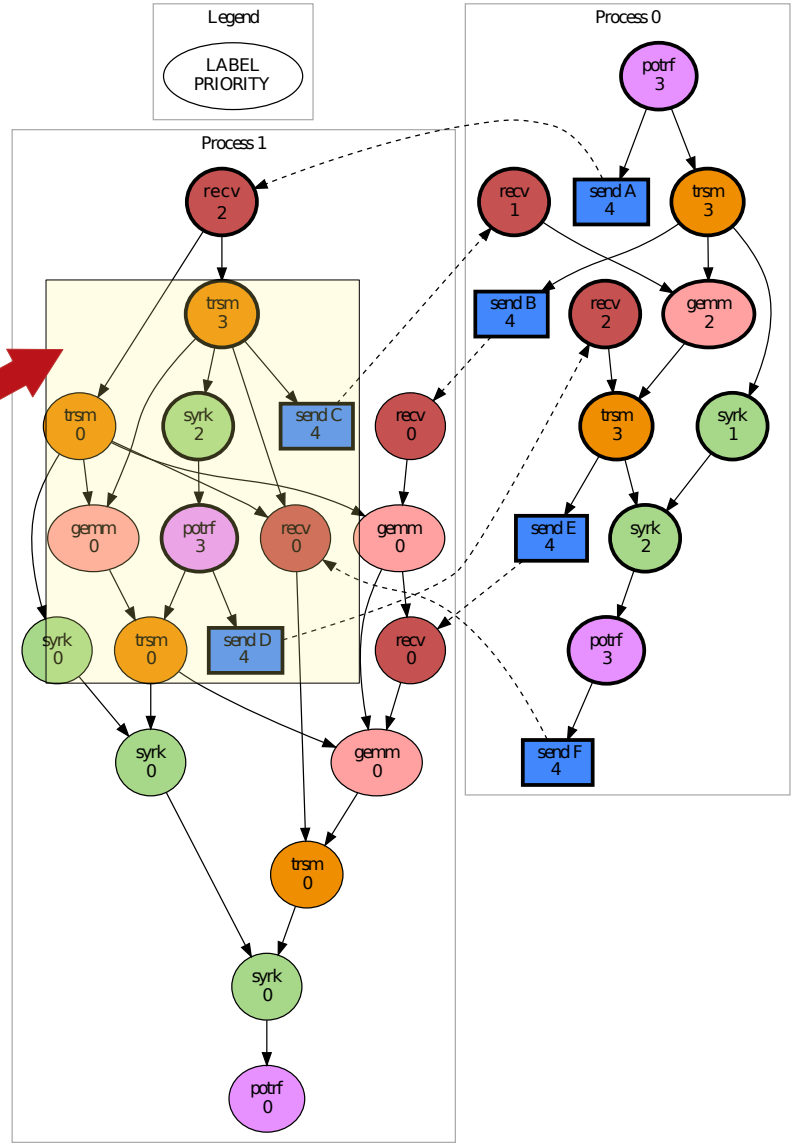

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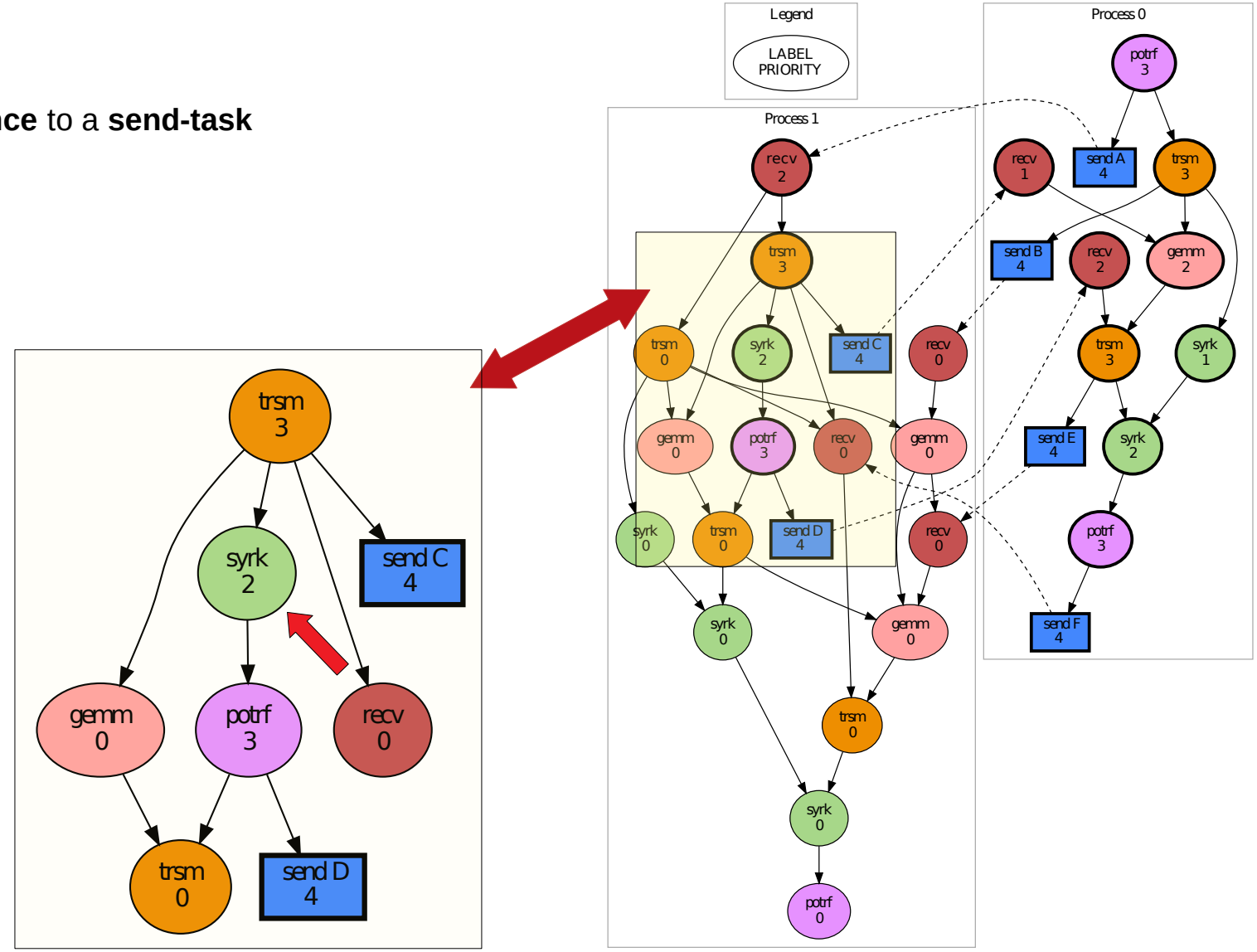

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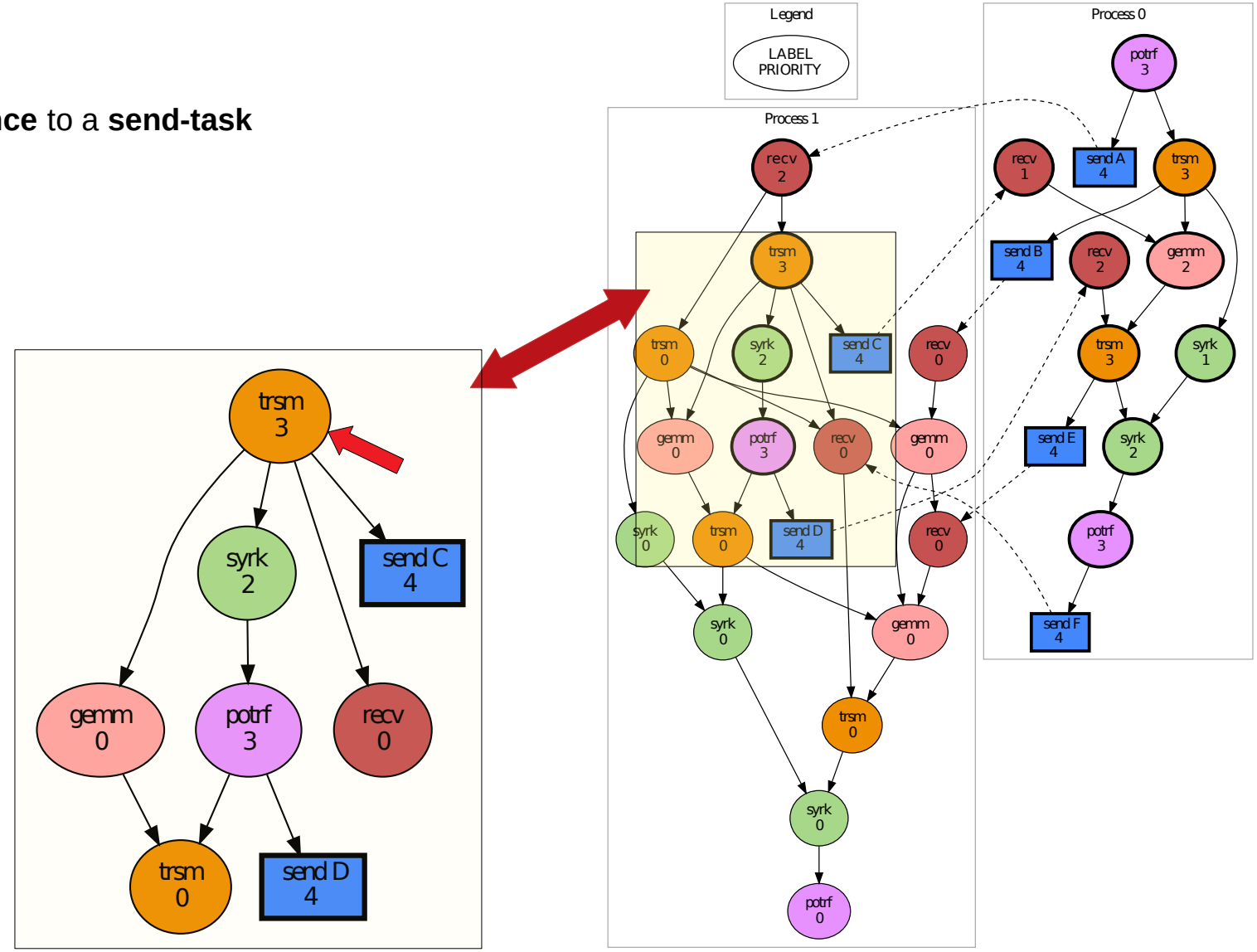

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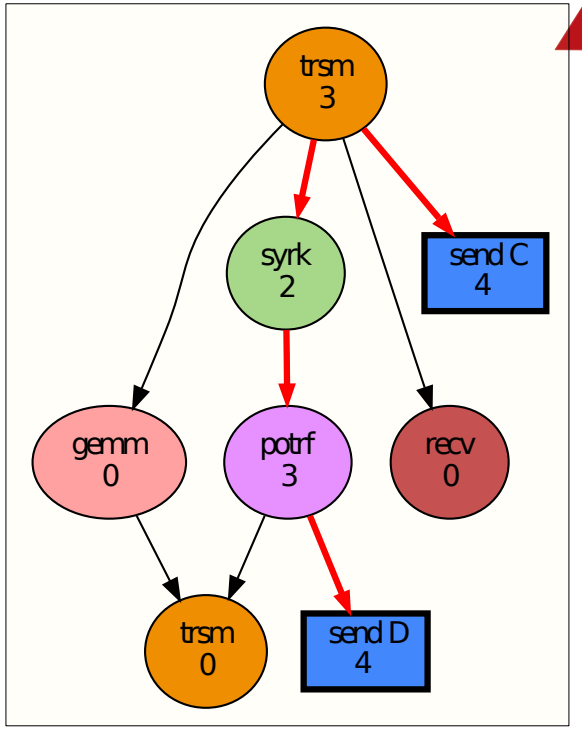

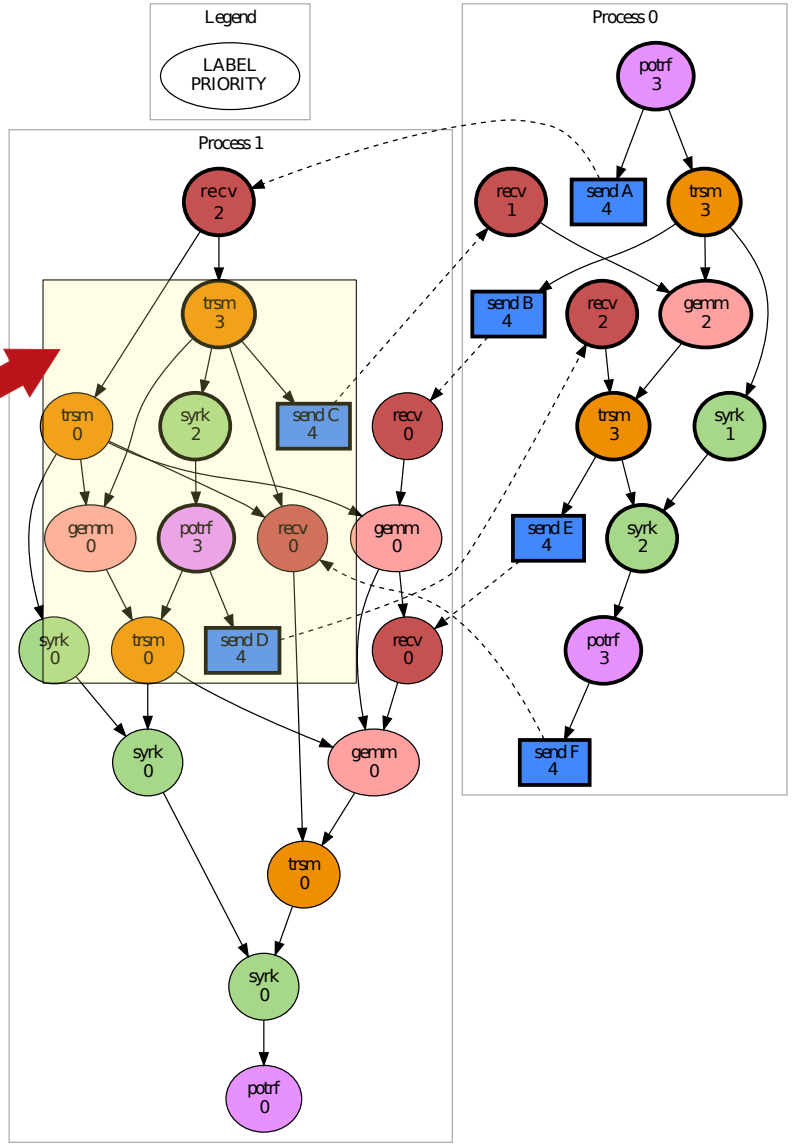

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Communication-Aware Task Re-ordering Strategy (3/5)

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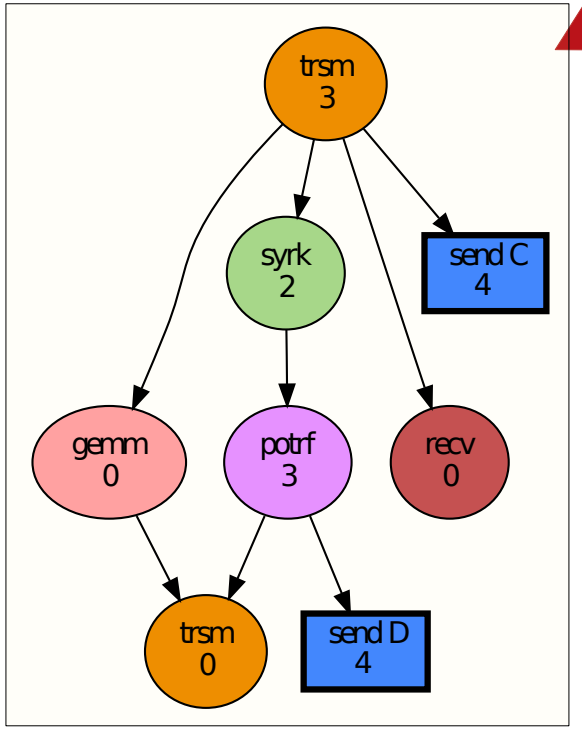

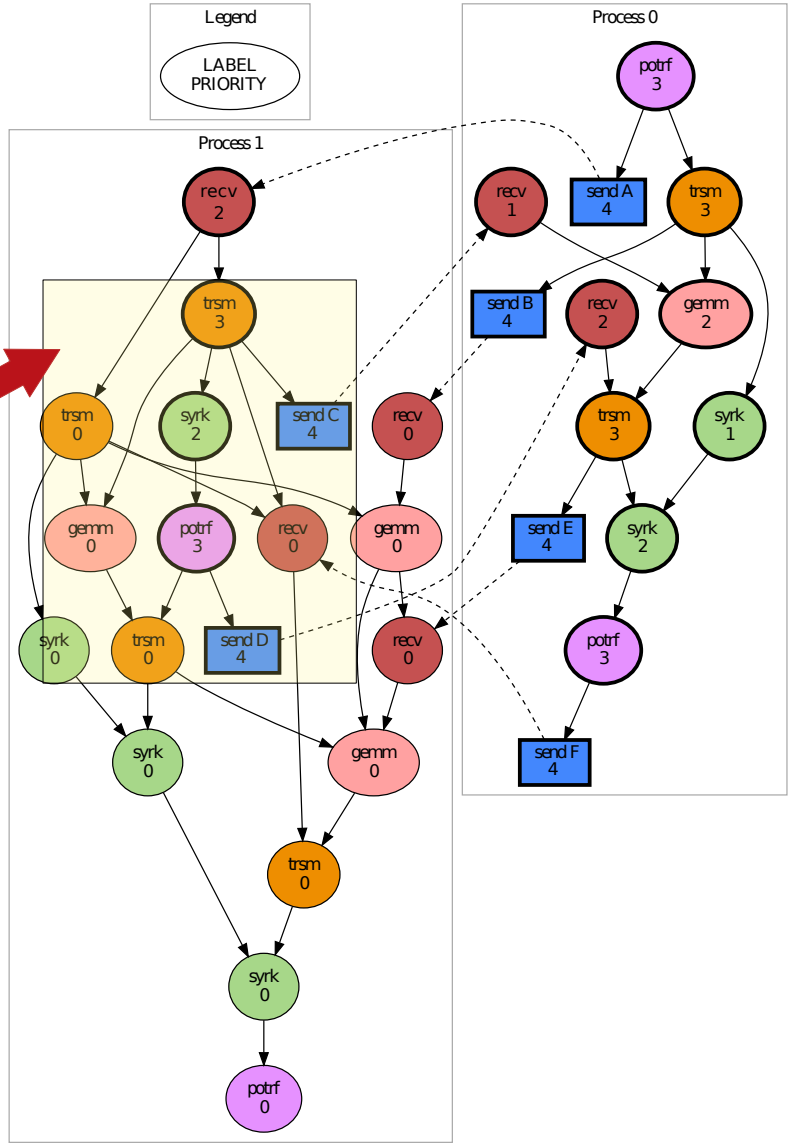

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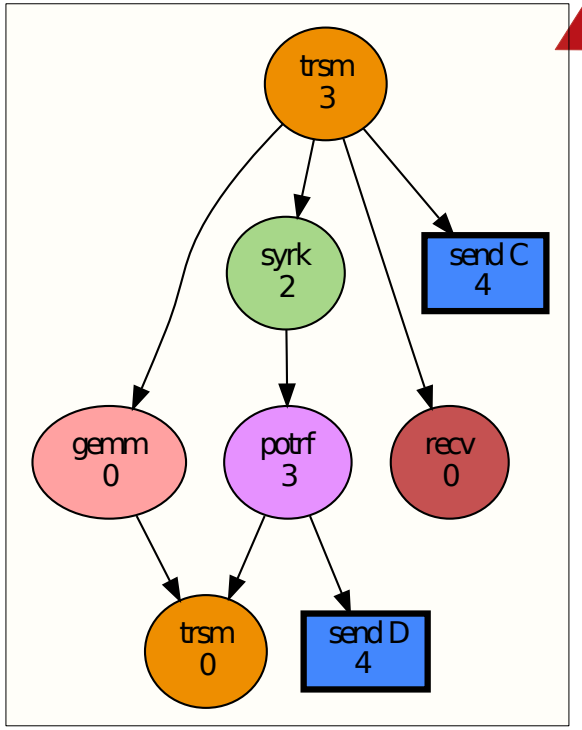

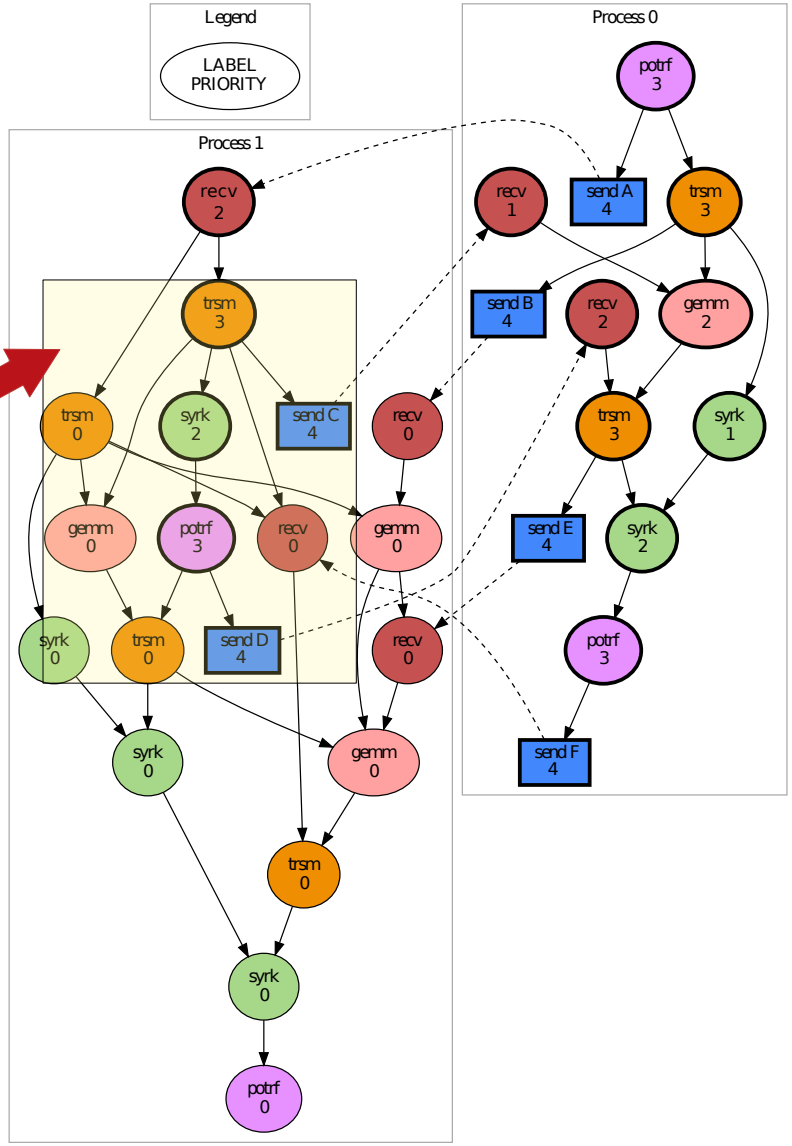

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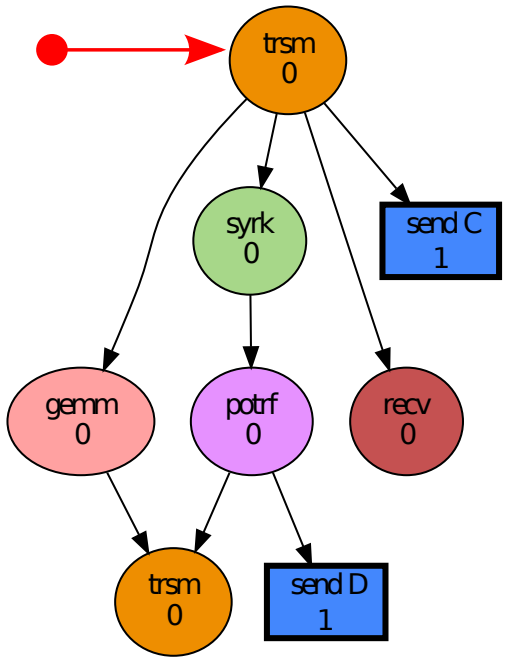
Hybrid MPI+OpenMP(tasks) minimal code example



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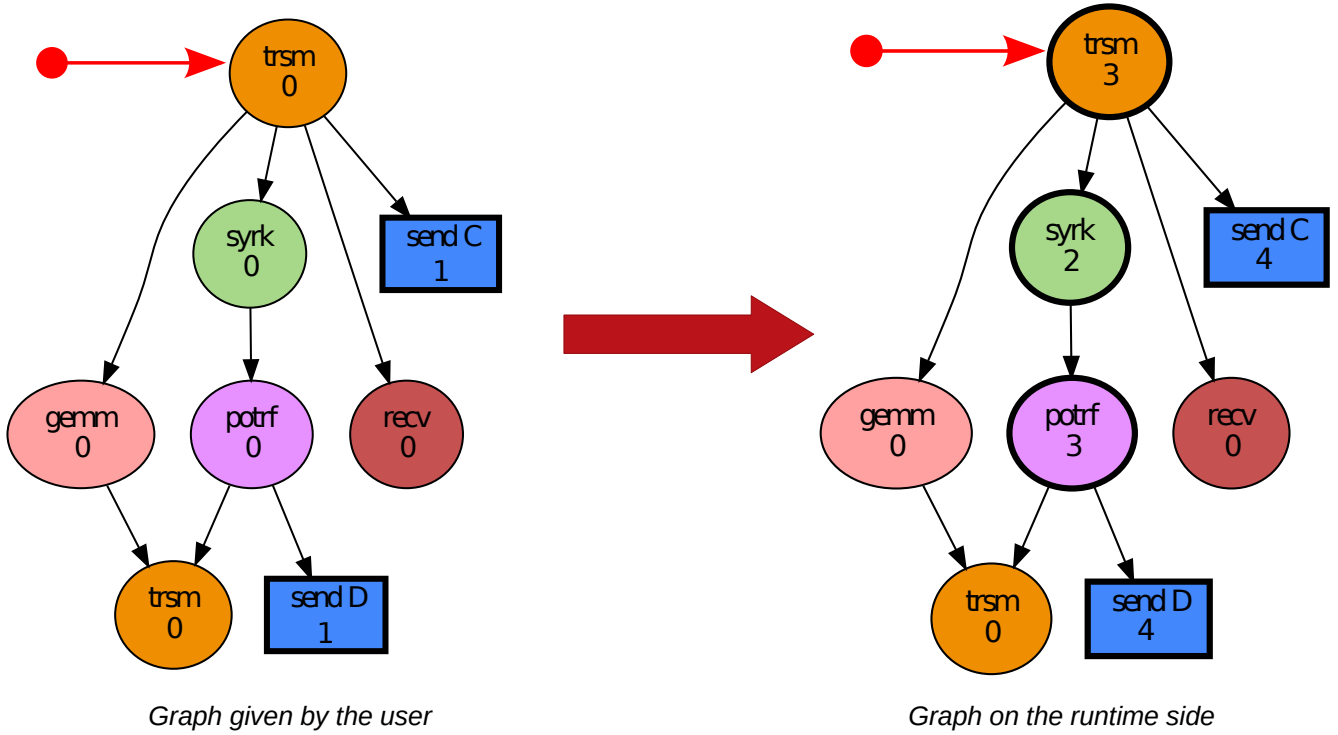

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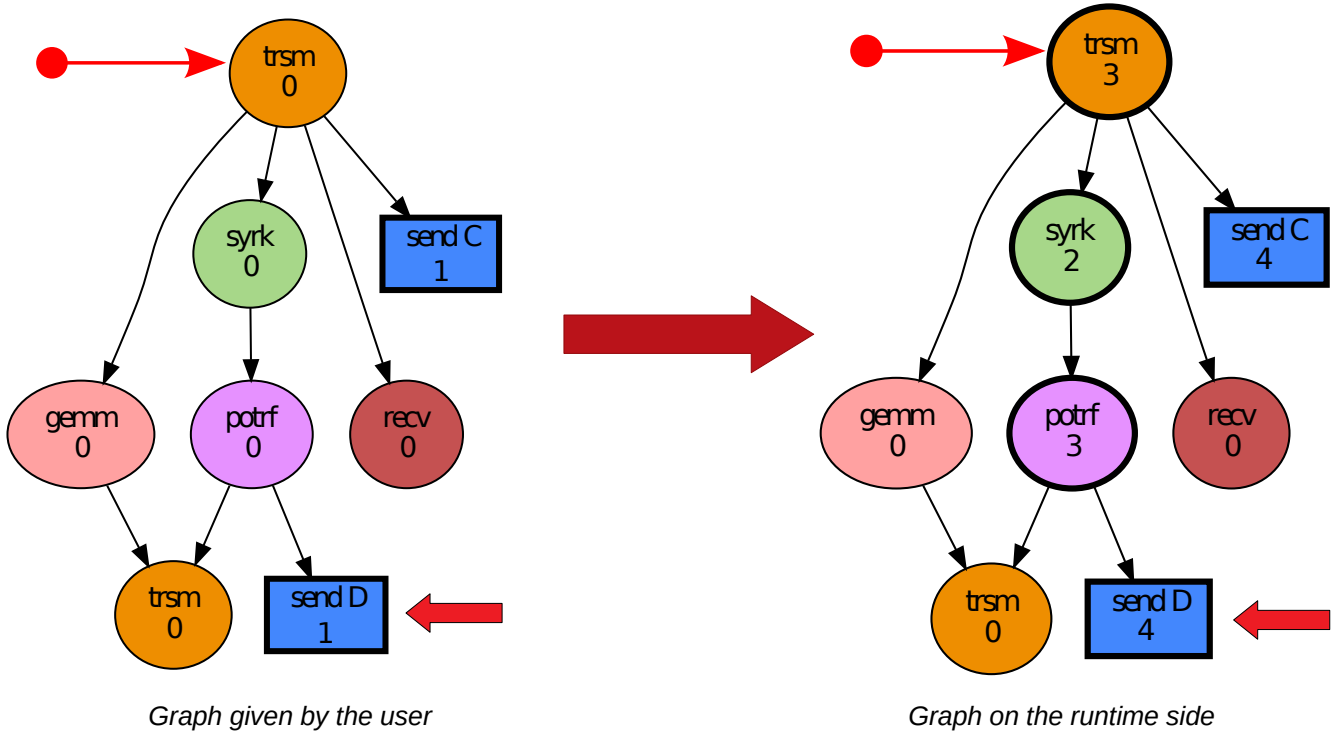

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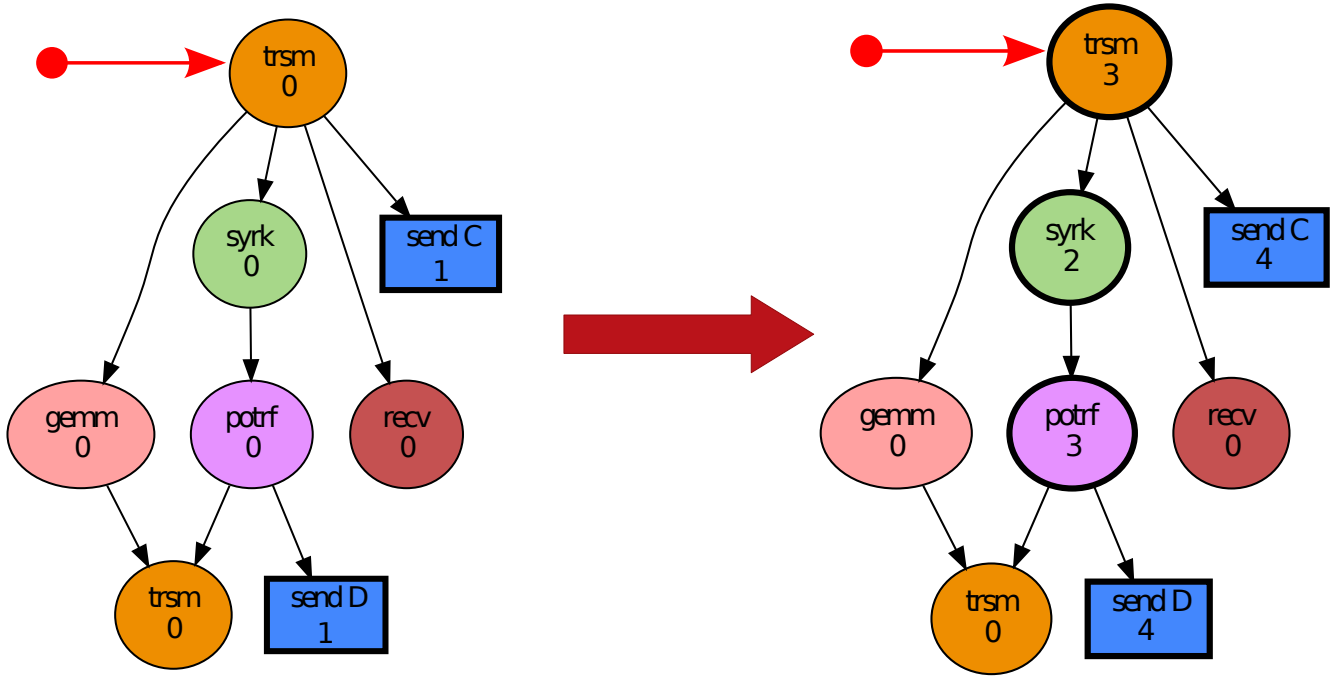

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Communication-Aware Task Re-ordering Strategy (5/5)

Fully-automatic (FA)

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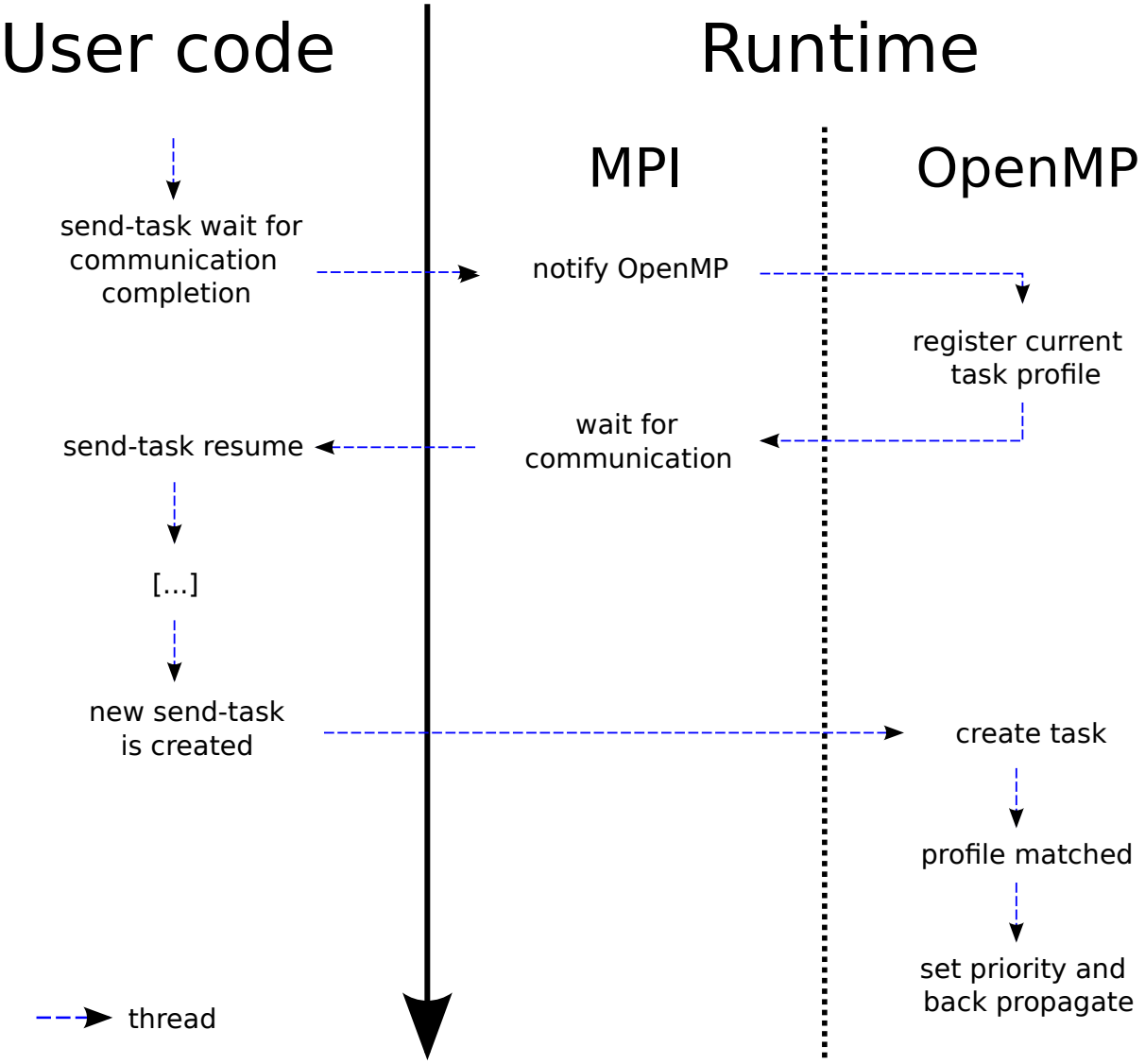
On **send-tasks execution**

- MPI runtime notifies OpenMP runtime

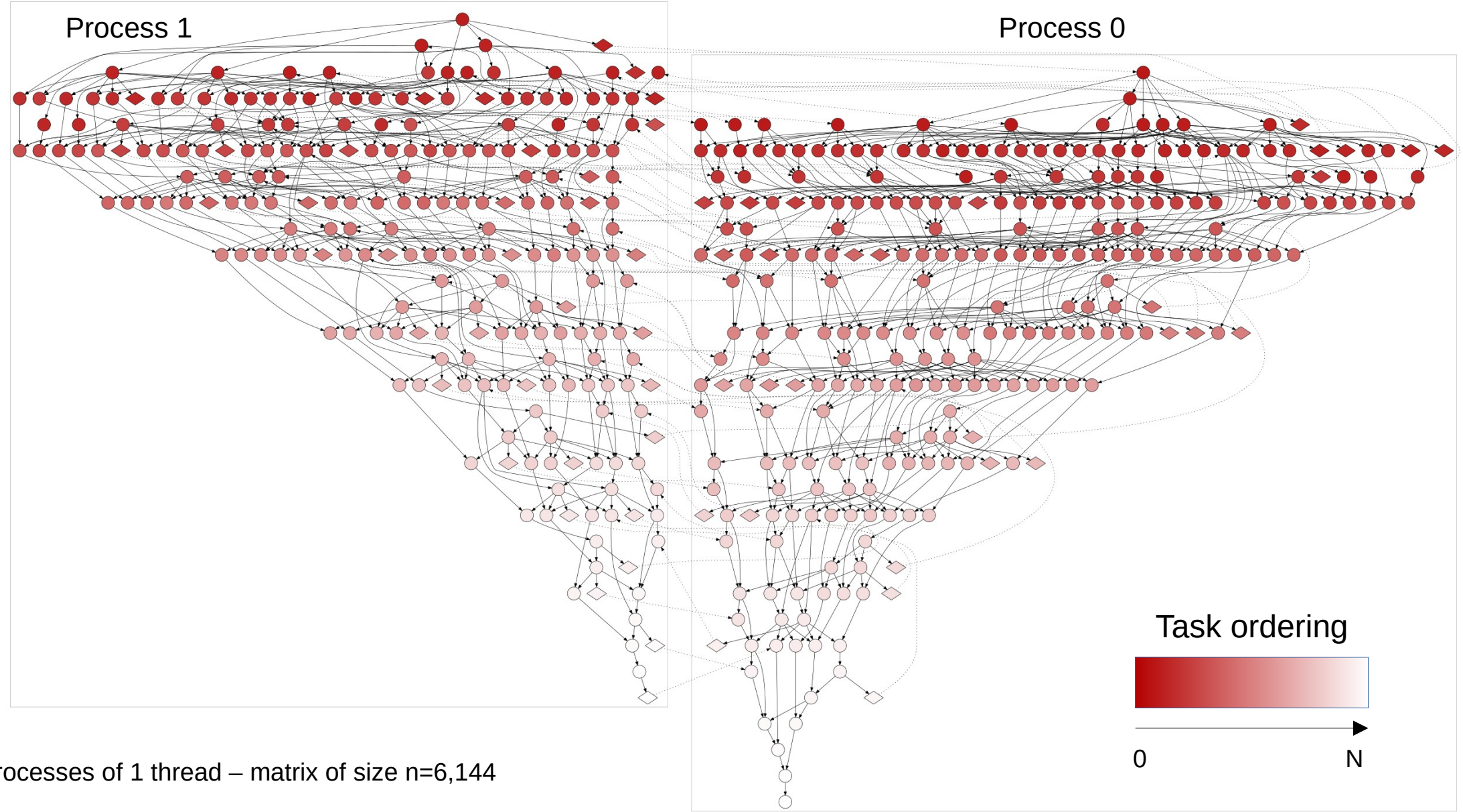
- OpenMP runtime stores current task profile
  - Size (shared variables)
  - Properties (tiedness, final…)
  - Parent task identifier
  - Number of predecessors (fully-known at run-time)
  - Number of successors (may be incomplete)

- On future tasks creations, and on idle periods
  - Match profiles to detect send-tasks
  - Propagate priorities

Target **iterative-based** applications



Communication-Aware Task Re-ordering Strategy - Summary



2 processes of 1 thread – matrix of size n=6,144

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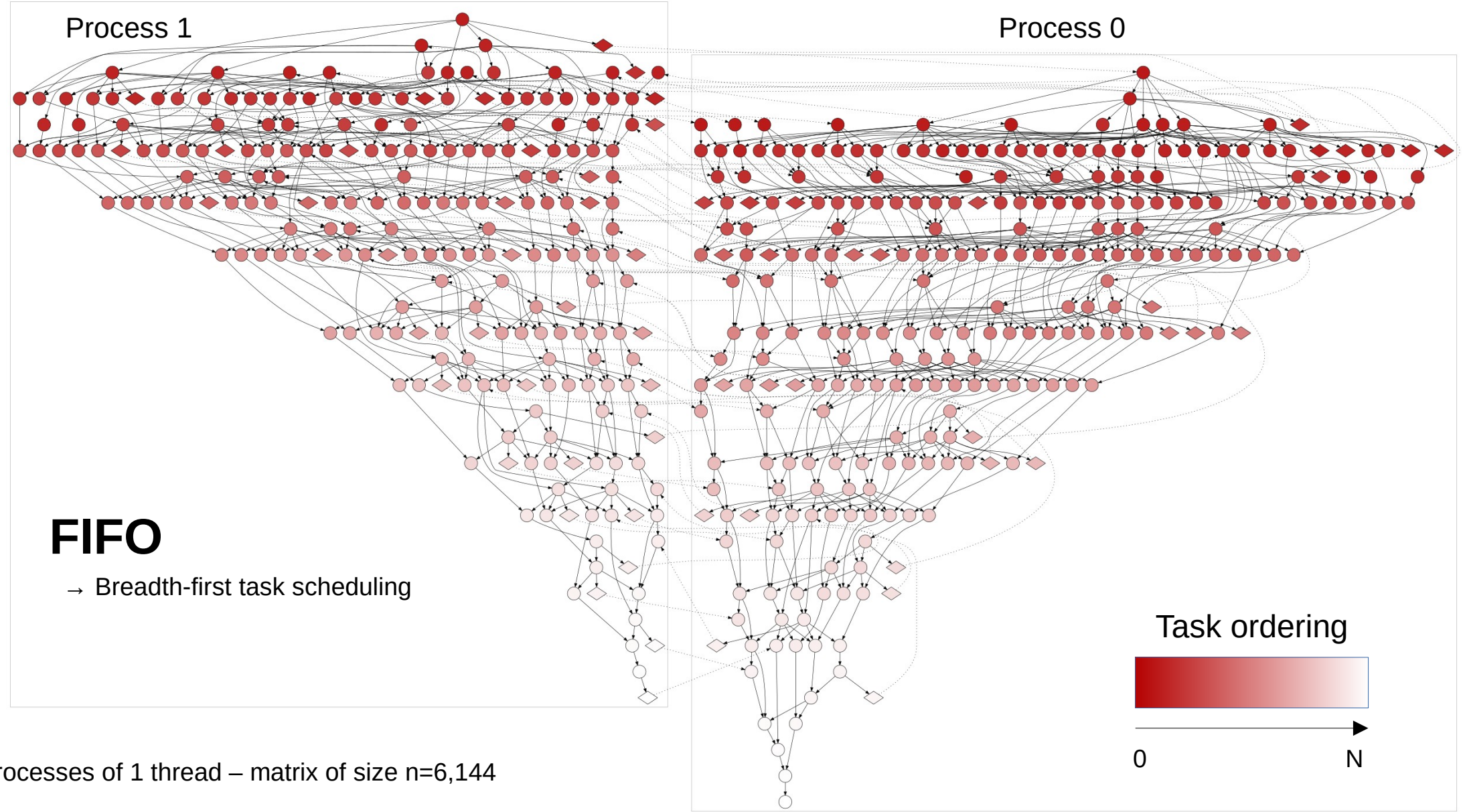

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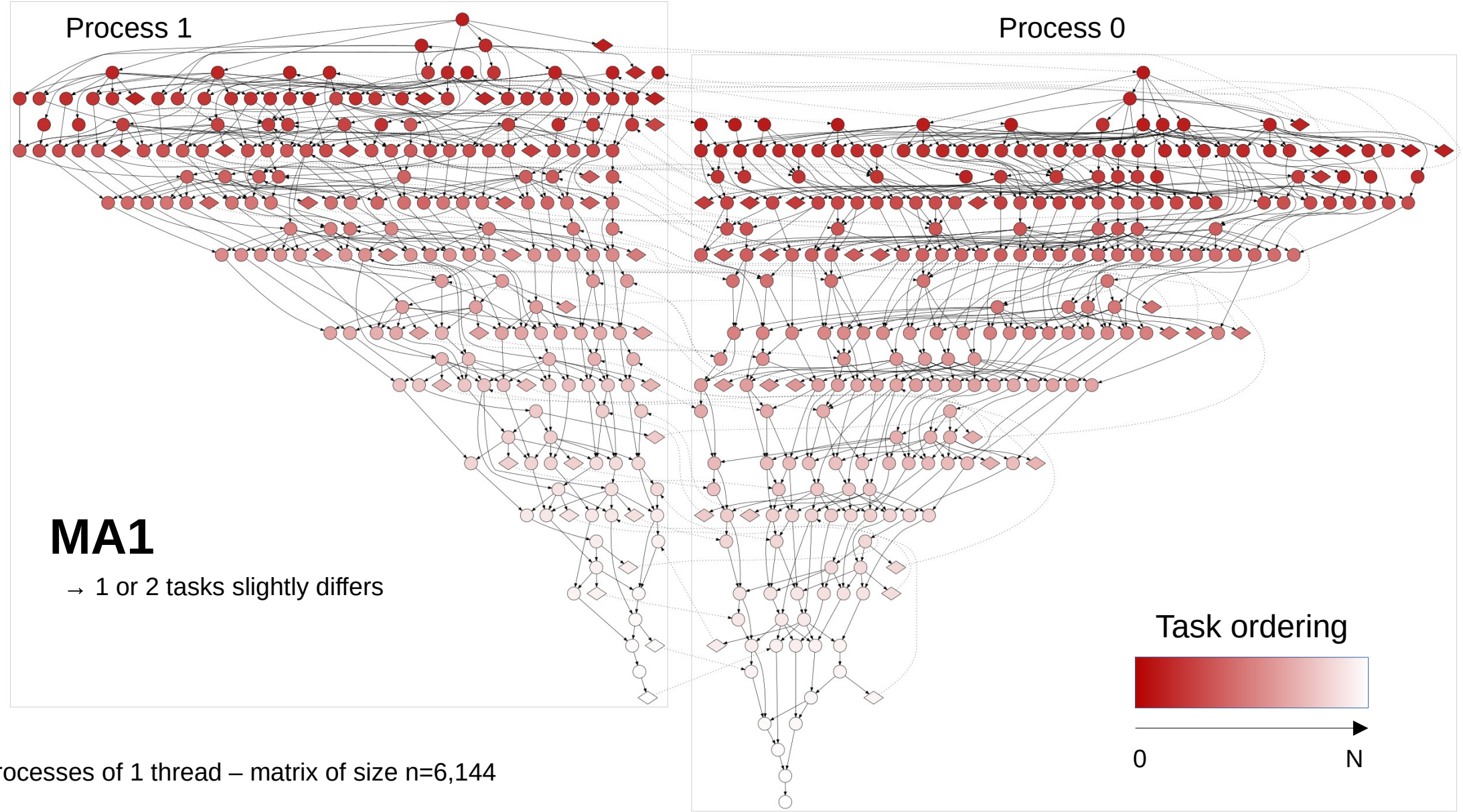

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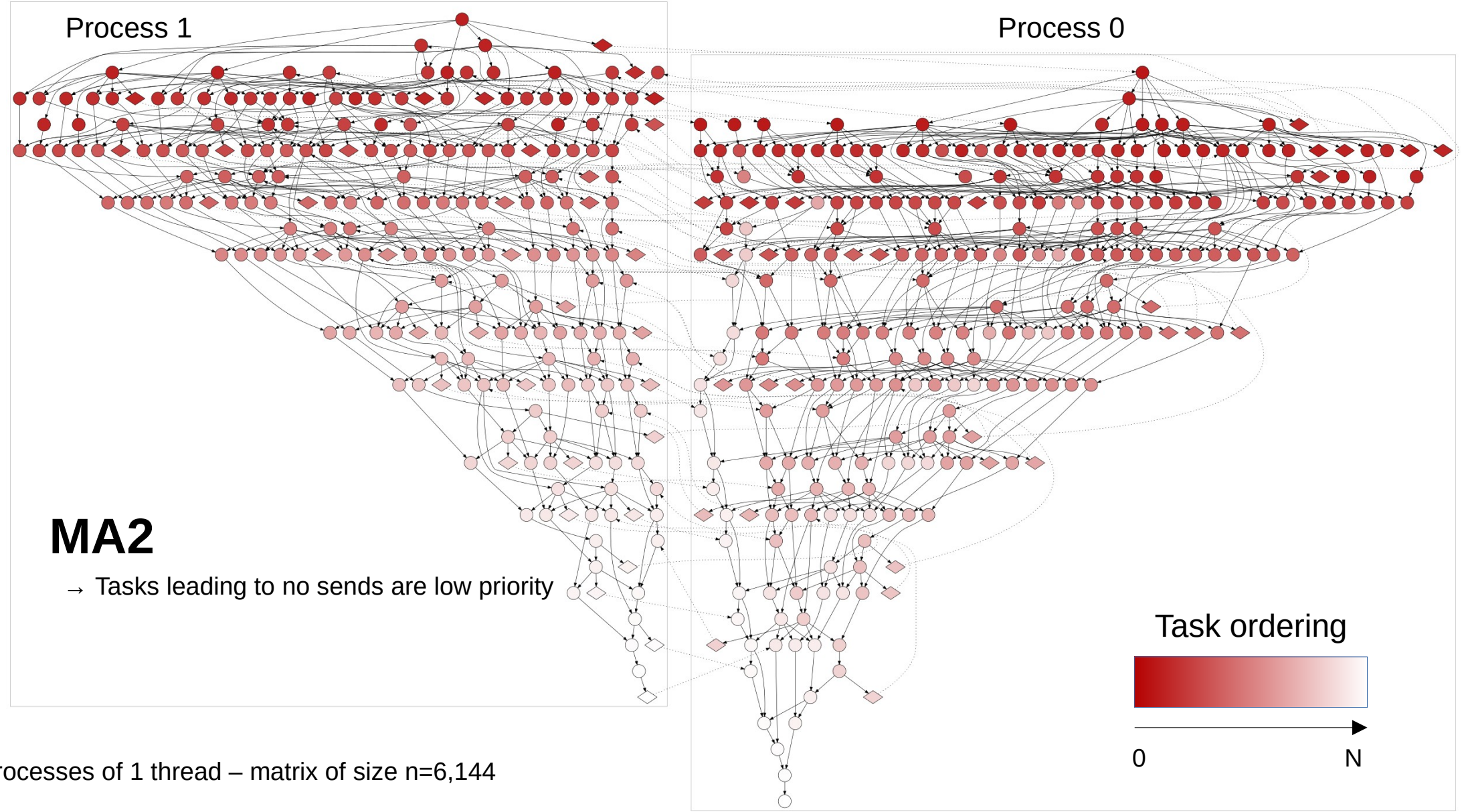

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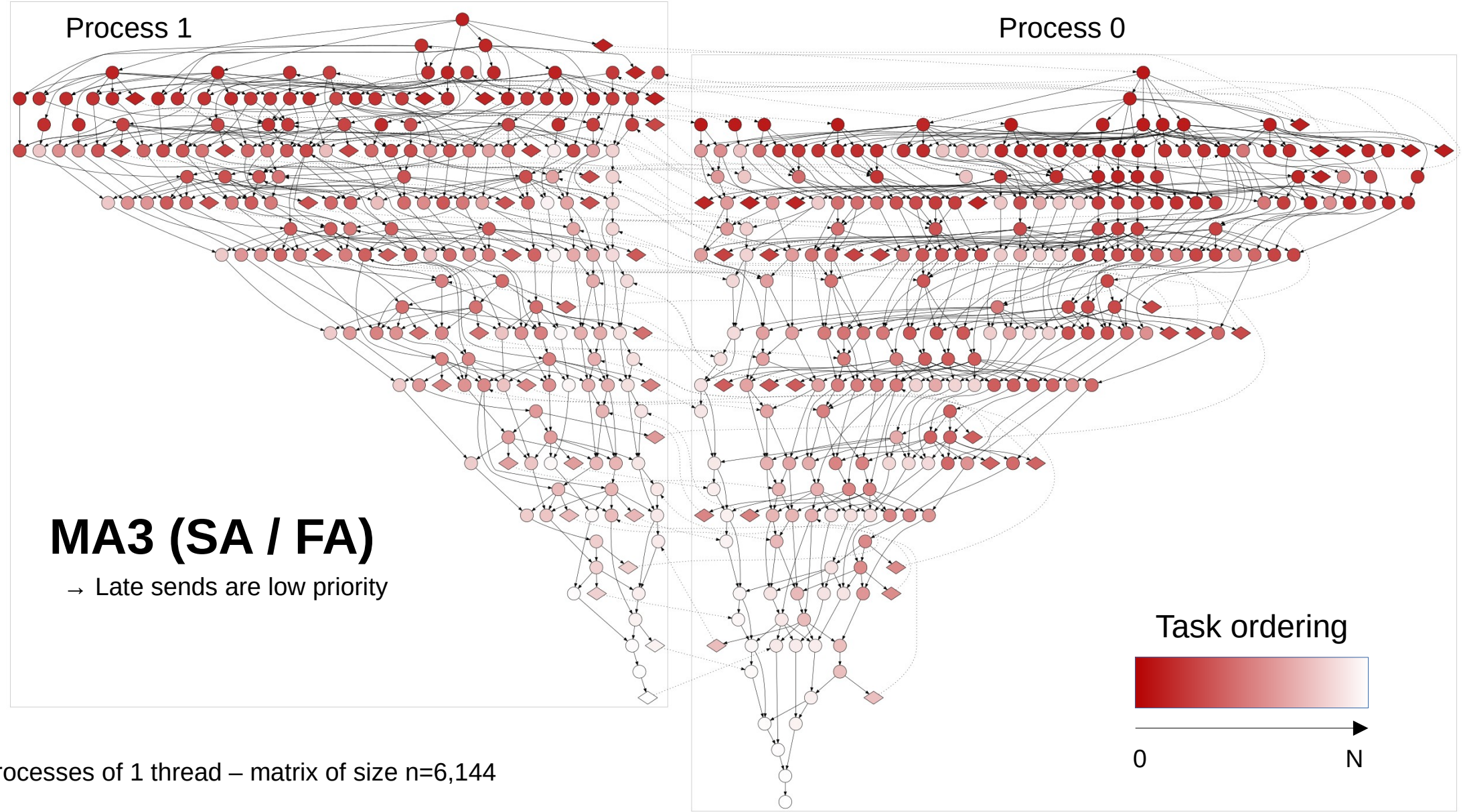

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Communication-aware task re-ordering strategy

- Priority policies
- **Implementation**

Implementation (1/2)

Multi-Processor Computing (MPC) framework

- Unified implementation of OpenMP and MPI relying on user threads **[MPC-08, MPC-10]**
- Open source implementation at https://mpc.hpcframework.com/

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Priorities computation

- MA & SA → synchronously on task creation by the producer thread
- FA → asynchronously by any threads on **idle** periods

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MPI+OpenMP interoperability

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User-side hybrid MPI+OpenMP(tasks) code

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MPC MPI+OpenMP runtimes interoperation

Implementation (2/2)

MPI+OpenMP interoperability

- The loss of thread issue → task switch
- Task blocking **is not** yielding – using `omp_event_handle_t`
- Communication progression **[Buettner et al.]**

```
50  int MPIX_Progress(MPI_Request * request)
51  {
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53      MPI_Test(request, &completed);
54      if (completed)
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1   # pragma omp task depends(in: data)
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User-side hybrid MPI+OpenMP(tasks) code

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11  /* Waits for an MPI requests to complete */
12  void MPI_Wait(MPI_Request * request, MPI_Status * status)
13  {
14      if (mpc_omp_in_explicit_task())
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20
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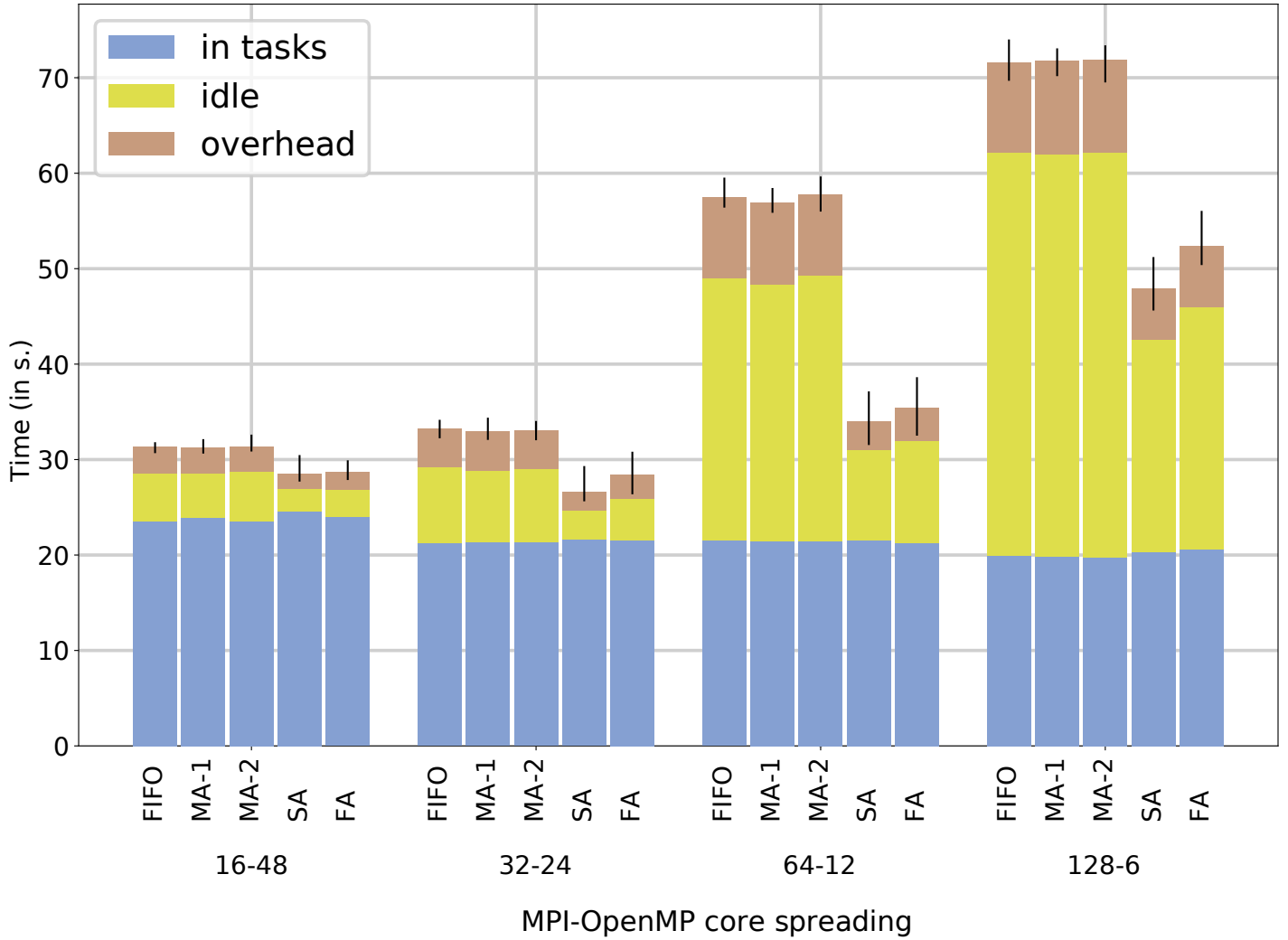
Evaluation

Core spreading over MPI+OpenMP

- Experimental Environnement
  - MPC-MPI + MPC-OpenMP
  - Skylake nodes – 16 nodes
    - Intel(R) Xeon(R) Platinum 8168 CPU @ 2.70GHz
    - 2 sockets (NUMA) – 24 cores per socket
  - Cholesky matrix factorization – matrix of size n=131,072



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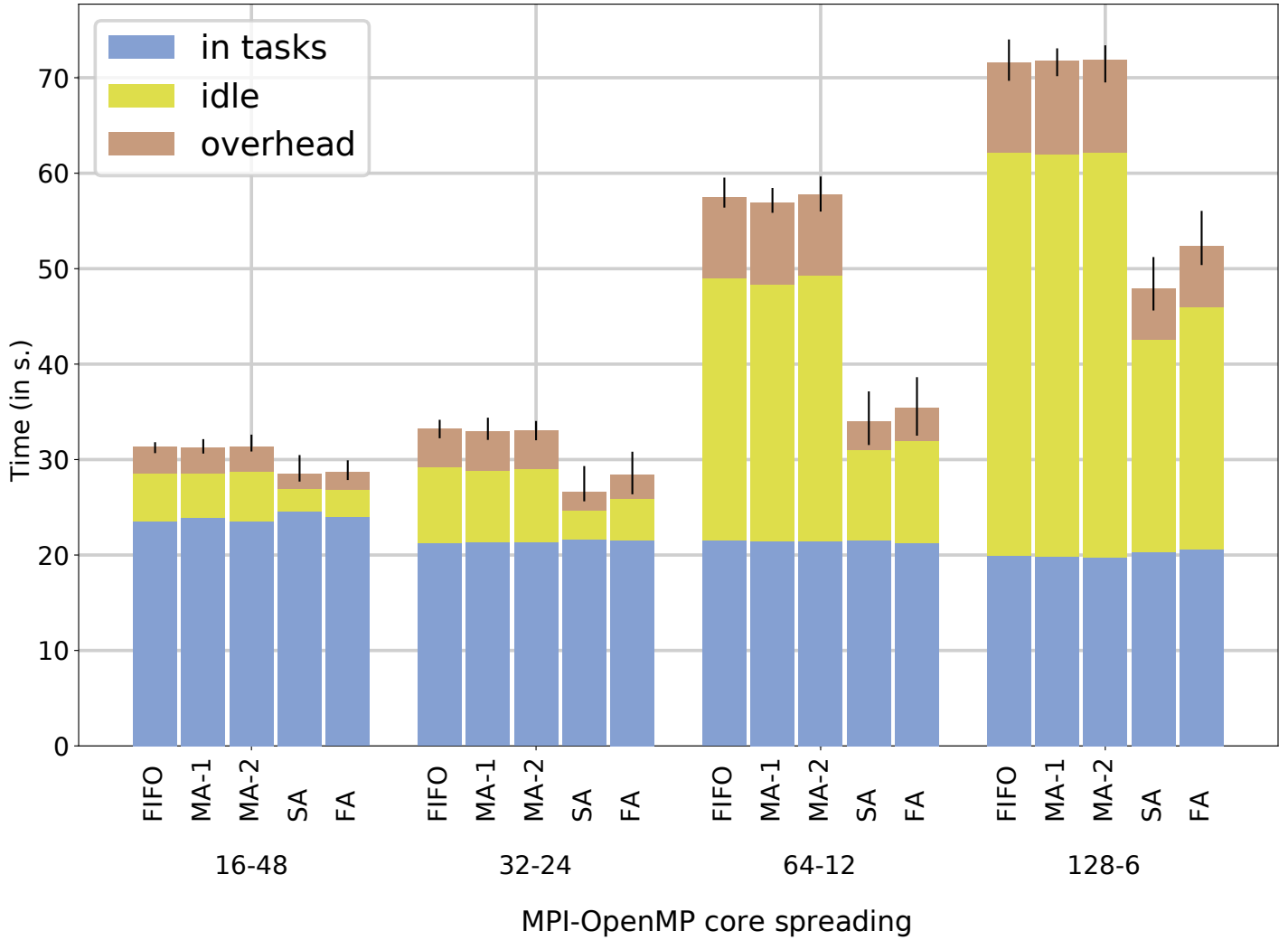

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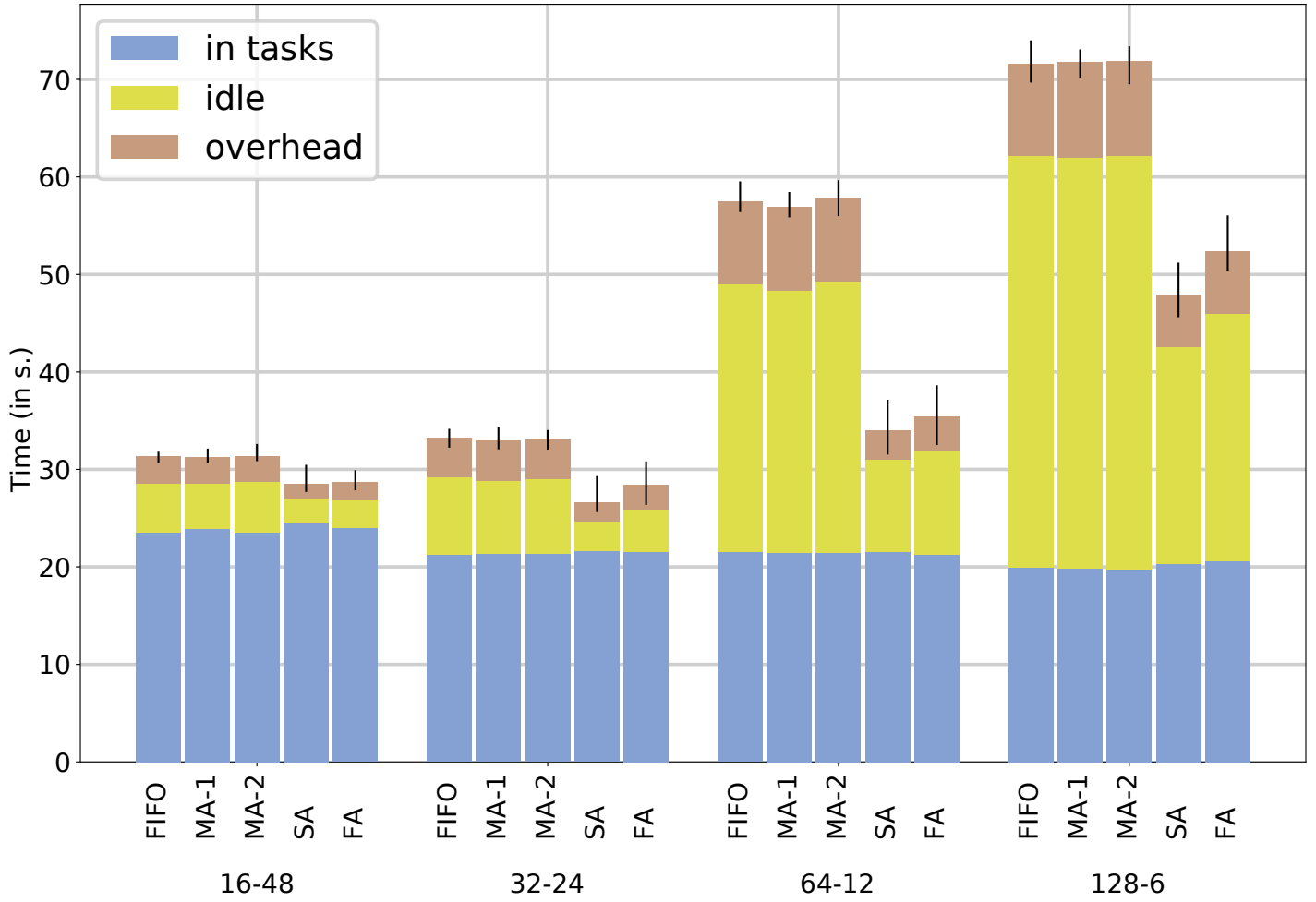

Core spreading (MPI - OpenMP)	16-48	32-24	64-12	128-6
P2P communication tasks (overall)	388,624	640,632	892,640	1,372,880

Number of point to point communication per spreading

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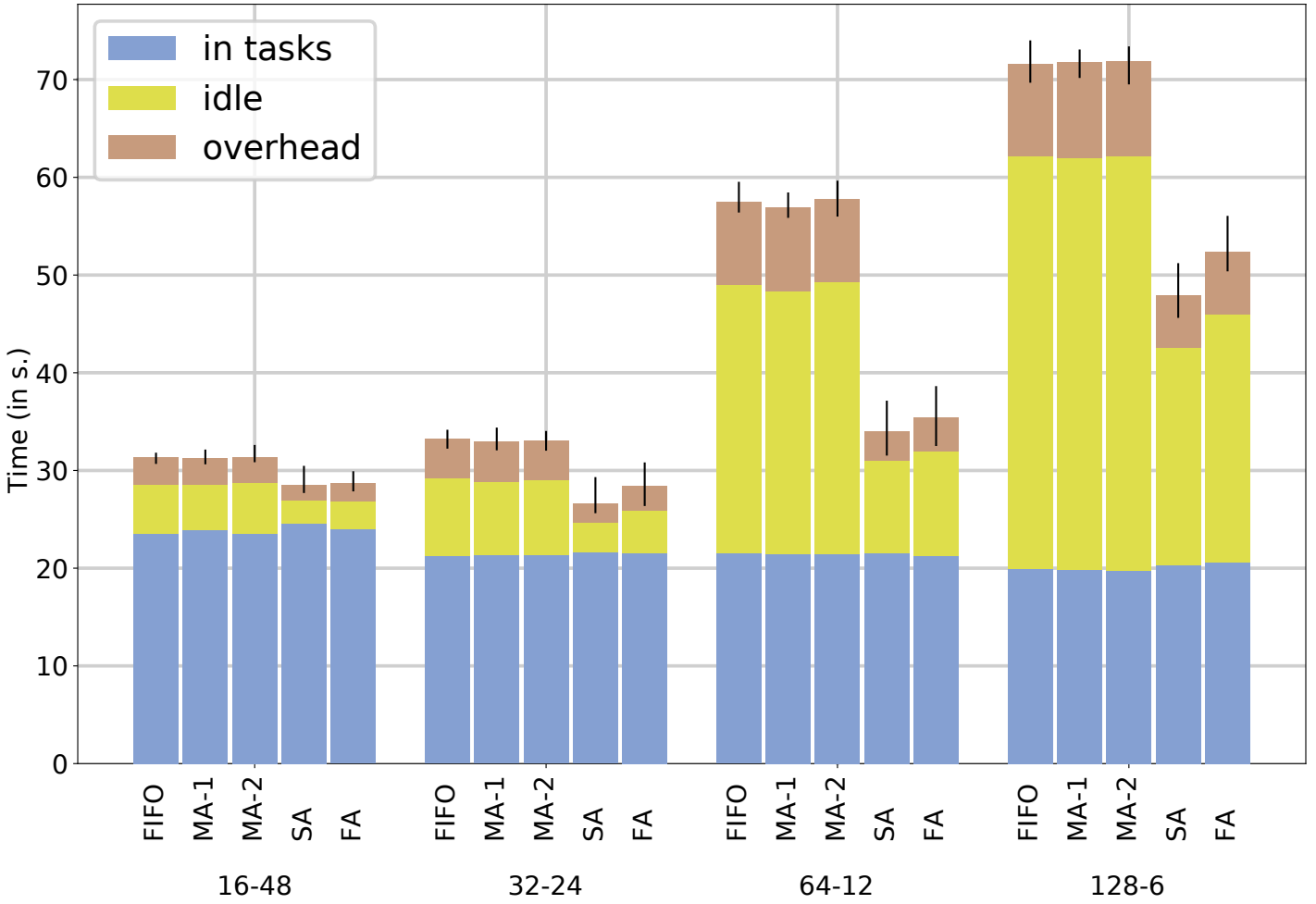
  - More communications + less threads →more idle time
  - Binary priorities are not sufficient (FIFO/MA1/MA2)
  - SA / FA re-ordering reduces idle time
  - Automation is costly: 3% to 8% performance loss



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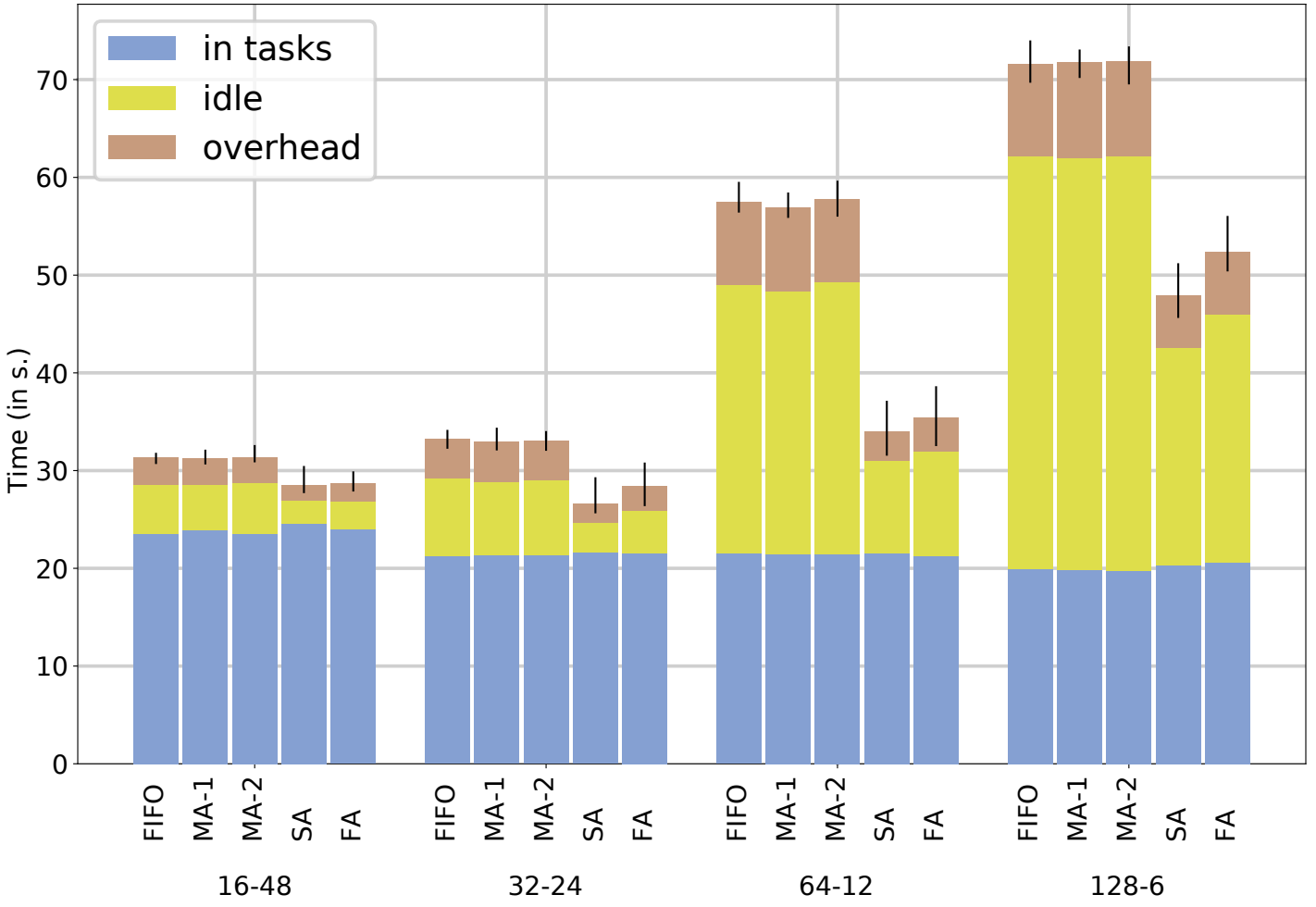
➡ Tasks re-ordering performance scaling



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Weak-Scaling

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  - Cholesky matrix factorization
    - Initial matrix of size n=41,286 for ~22.5 s.
  - 1 MPI process / processor (24 OMP threads)
  - Tasking
    - # computation task / process constant
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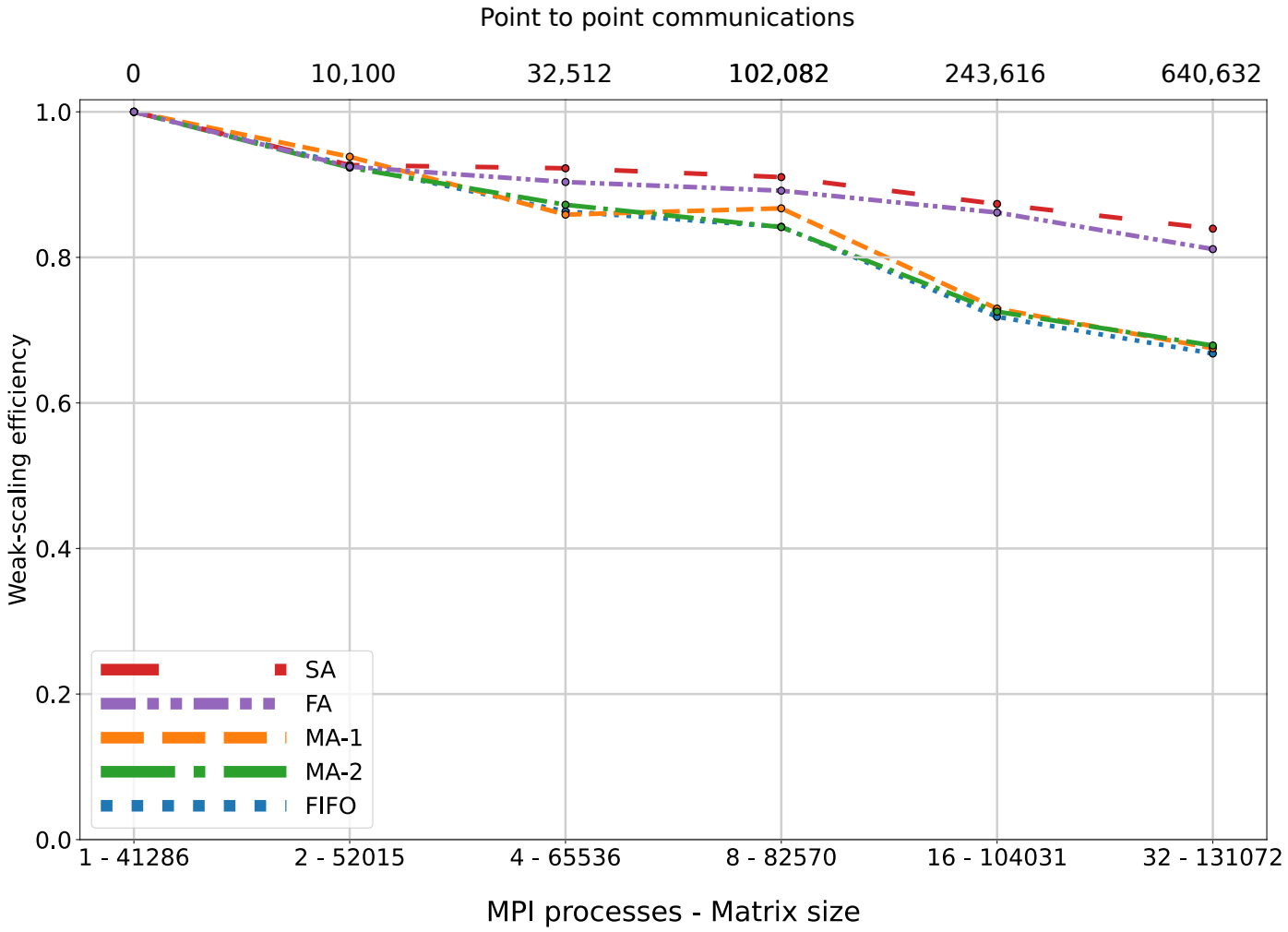

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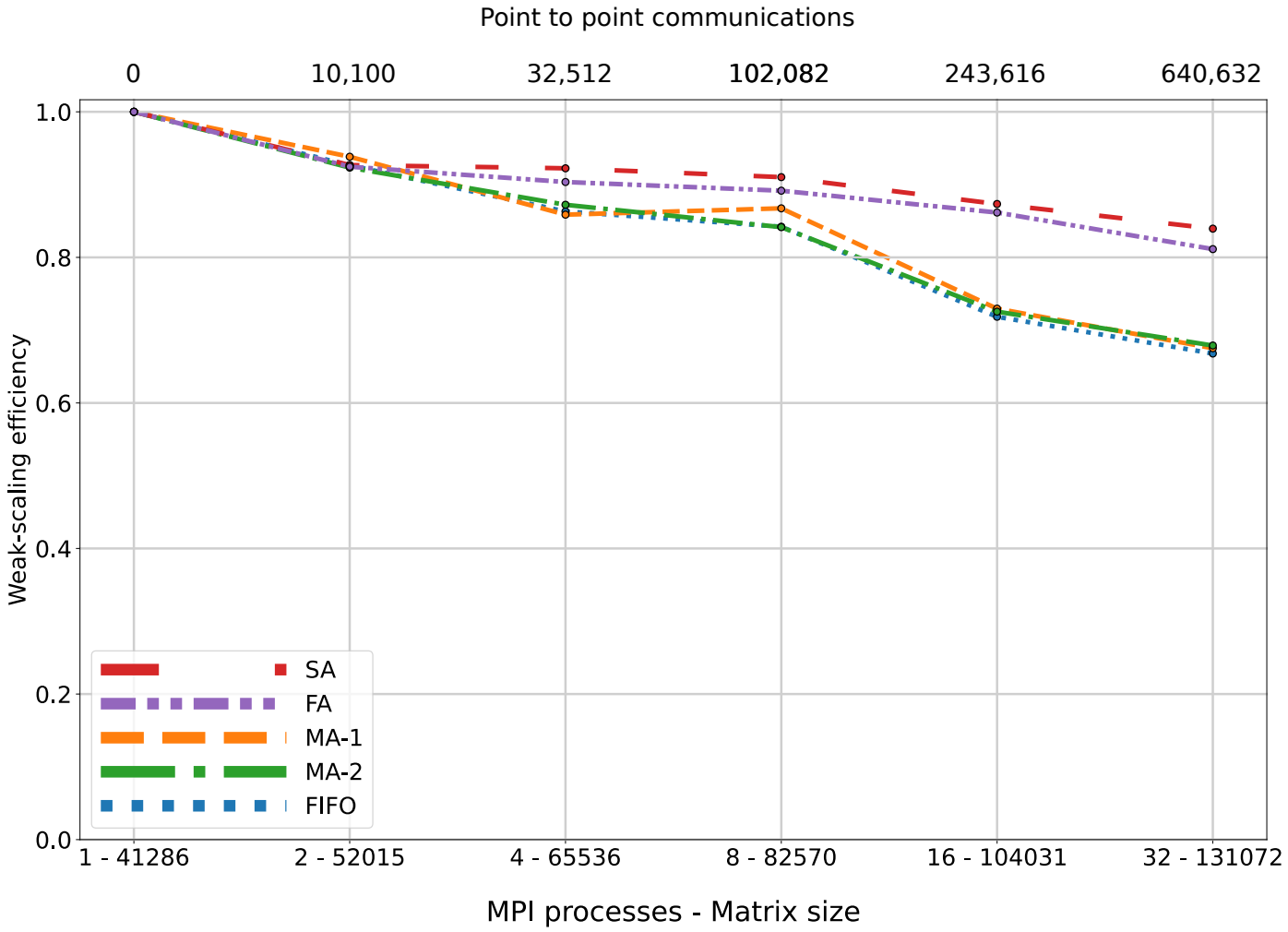

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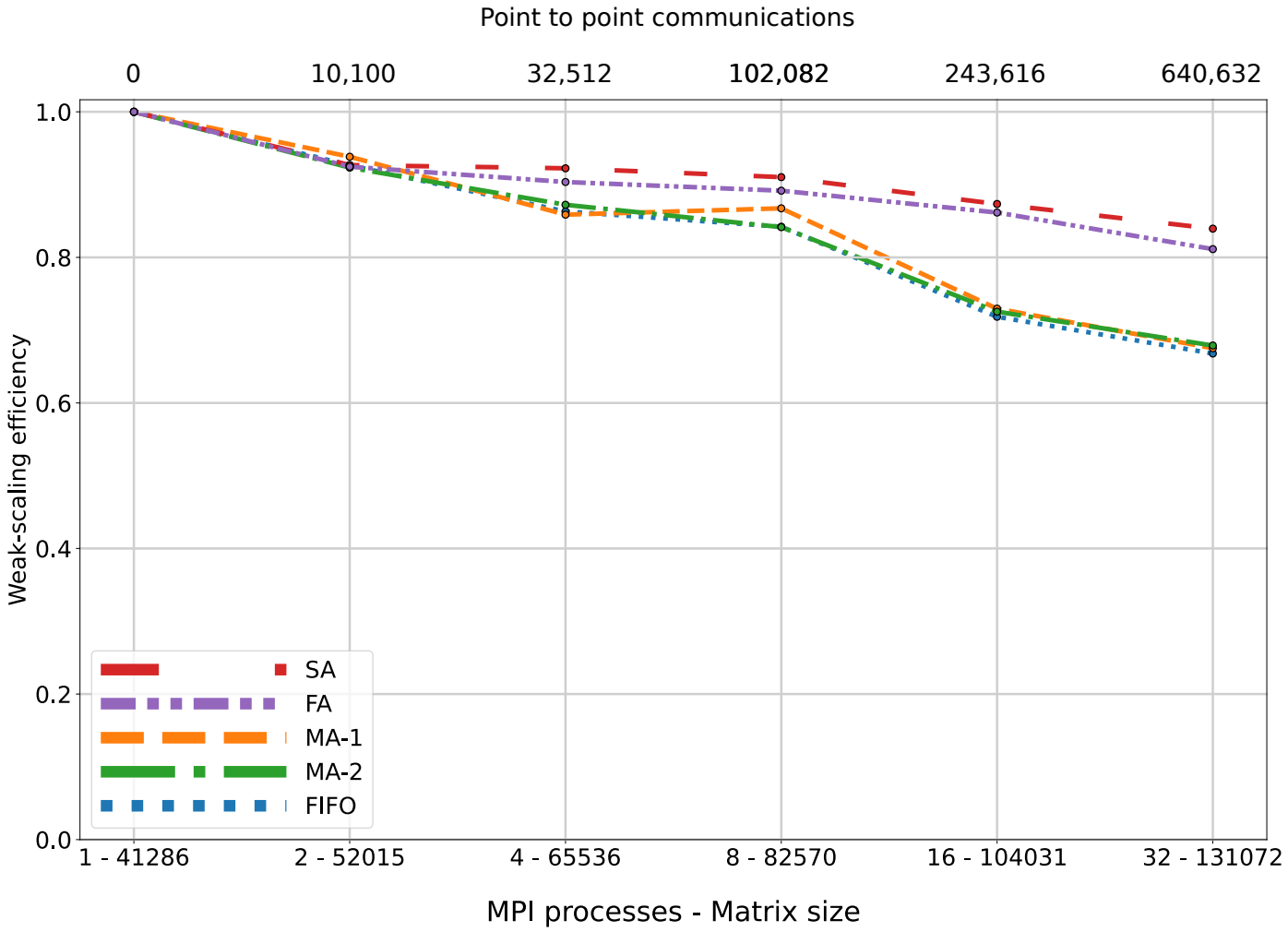
- Result
  - SA/FA dampen efficiency loss
  - 32 processors efficiency: 84% (SA) – 66% (FIFO)



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    - Loss of threads
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    - Different policies
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→ Reduces idle time, improve performance scaling

- Future works
  – More applications, larger systems
  – Adjust policy for communication intensive applications
    - Bandwidth saturation
    - Post receives to limit buffer copies
  – Vision limited to local subgraph → Take into account remote processes task dependency graph

Thank you for your attention

Multi-Processor Computing (MPC) – Patched version of this work

- Repository – https://mpc.hpcframework.com/mpc/releases/mpcframework-4.0.0-iwomp.tar.gz
- Compile and prepare environnement – see the **README** file within the archive

Cholesky Factorization Application

- Repository – https://gitlab.inria.fr/ropereir/iwomp2021
- Commit – 88793c08
- Compile and prepare environnement – see the **README** file

For any help or issues, feel free to contact us.
We will gladly help you.

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Adrien ROUSSEL – adrien.roussel@cea.fr
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