Harnessing clusters of hybrid nodes with a sequential task-based programming model

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Outline

Introduction

- Specialized dense linear algebra libraries
  - Netlib BLAS & LAPACK sequential references, Intel MKL multithreaded vendor library, ScaLAPACK MPI reference, Nvidia CuBLAS GPU library, HPL Top 500 benchmark, ...
- Runtime systems usually abstract a single node
  - Plasma/Quark, Flame/SuperMatrix, Morse/StarPU, Dplasma/PaRSEC ...
- How should nodes communicate?
  - Using explicit MPI user calls
  - Using a specific paradigm: Dplasma
- Can we keep the same paradigm and let the runtime handle data transfers?
  - Master-slave model (e.g.: ClusterSs)
  - Replicated unroll model (e.g. Quarkd)
- Example: Cholesky factorization (DPOTRF)

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  for (i = j+1; i < N; i++)
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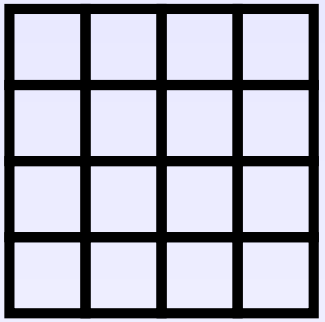

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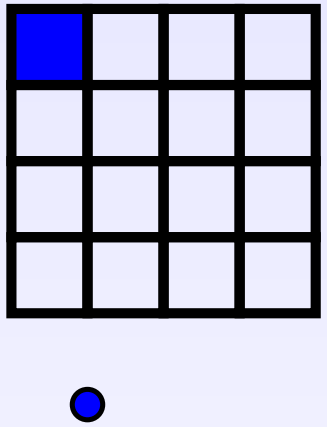

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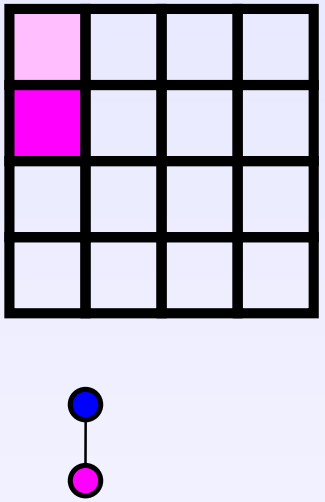

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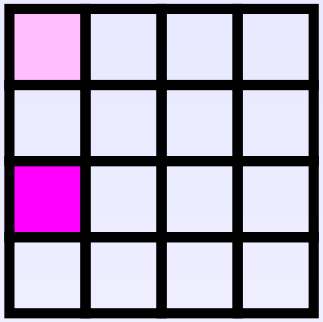

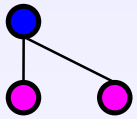

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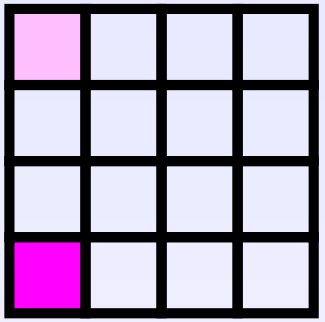

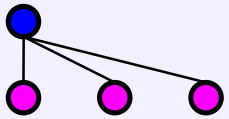

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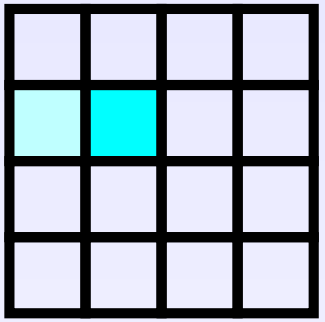

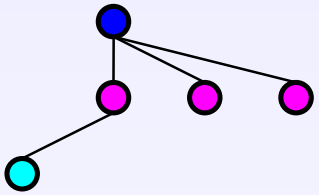

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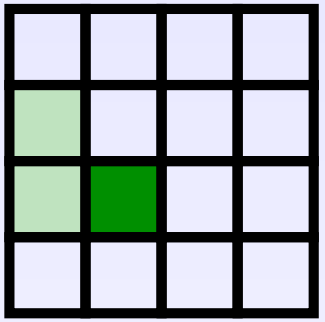

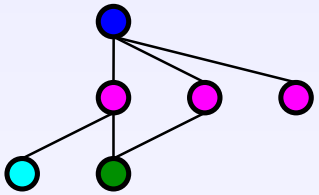

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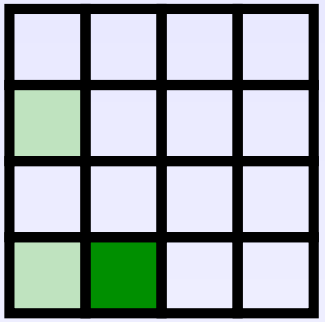

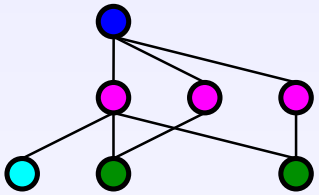

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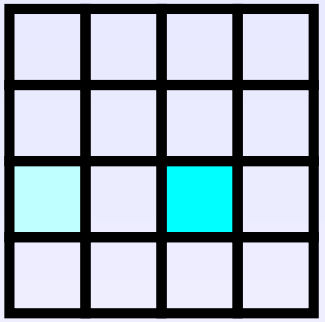

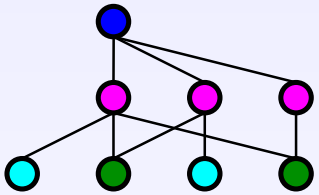

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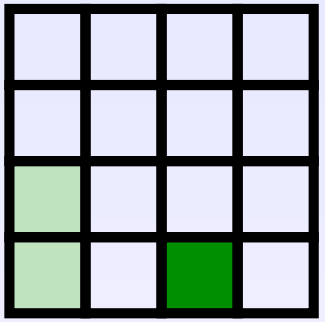

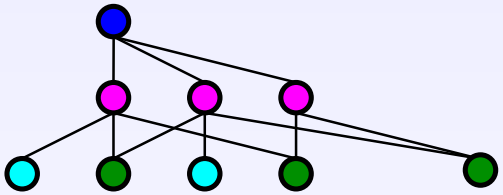

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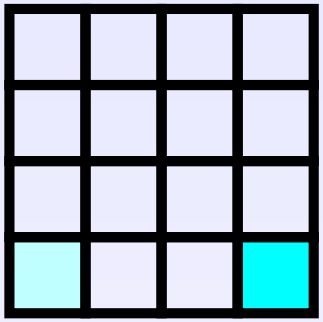

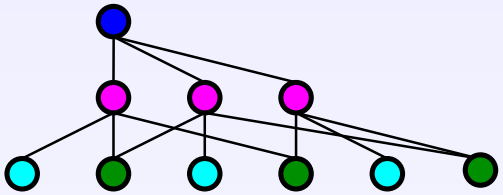

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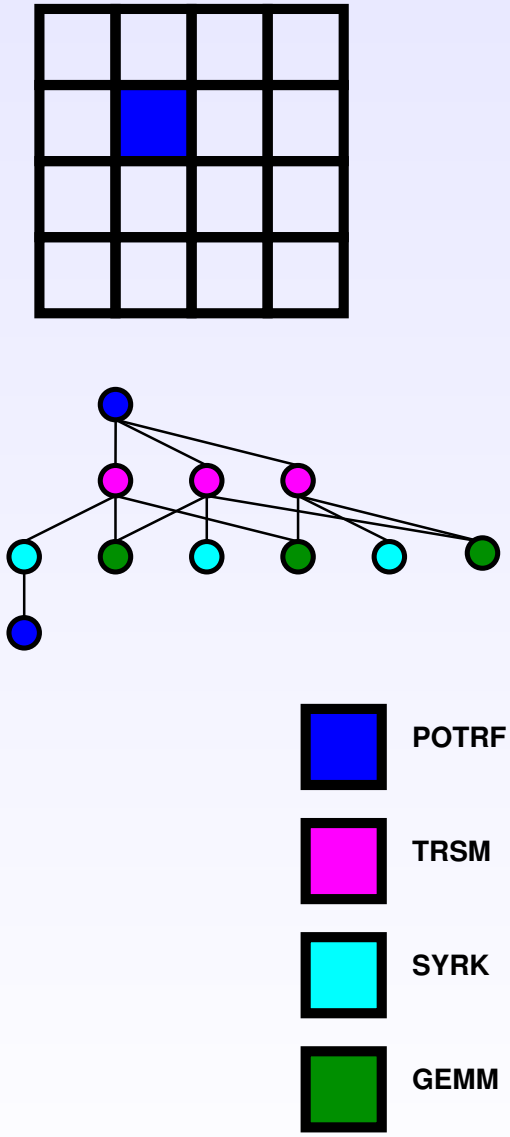

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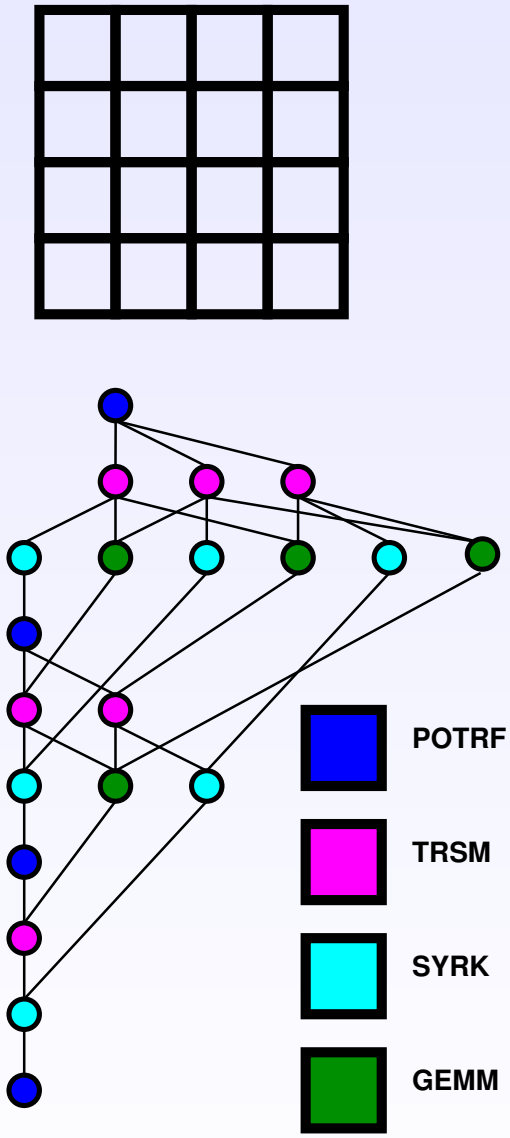

Runtime parallel execution on a heterogeneous node

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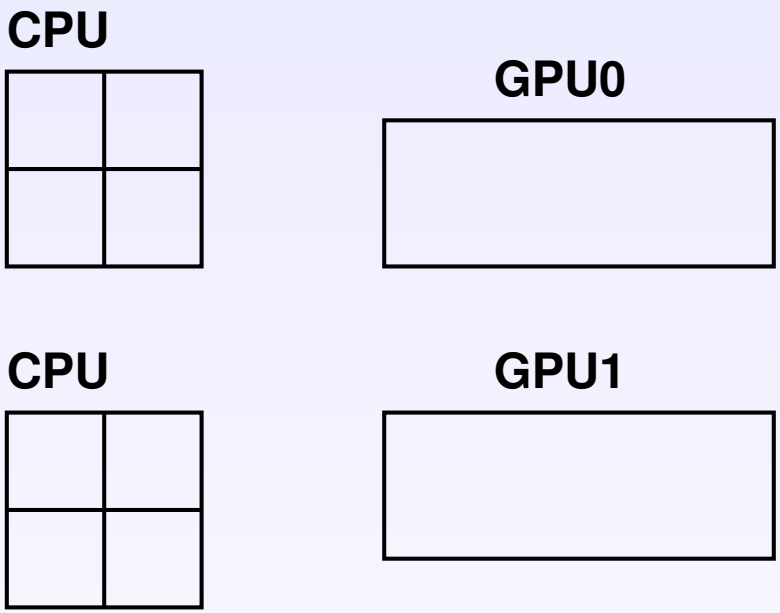

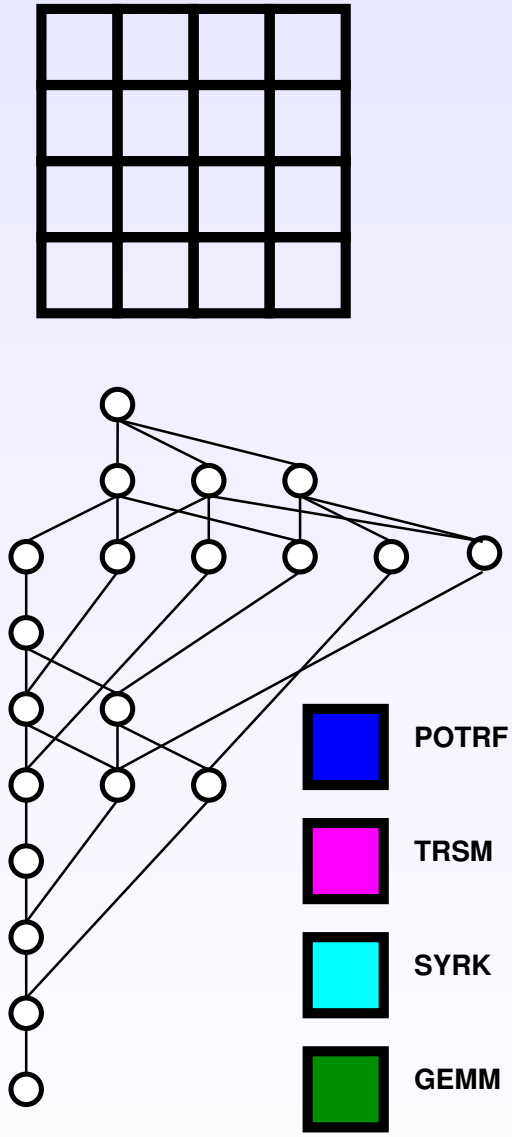

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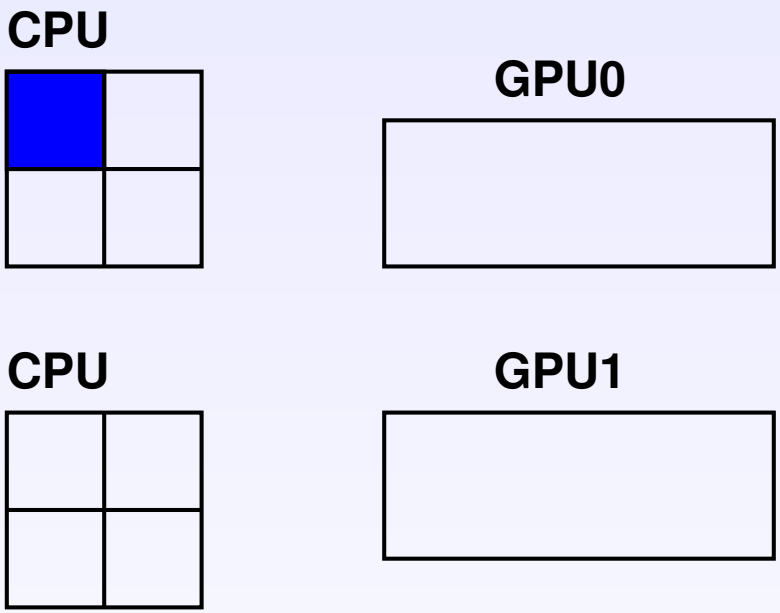

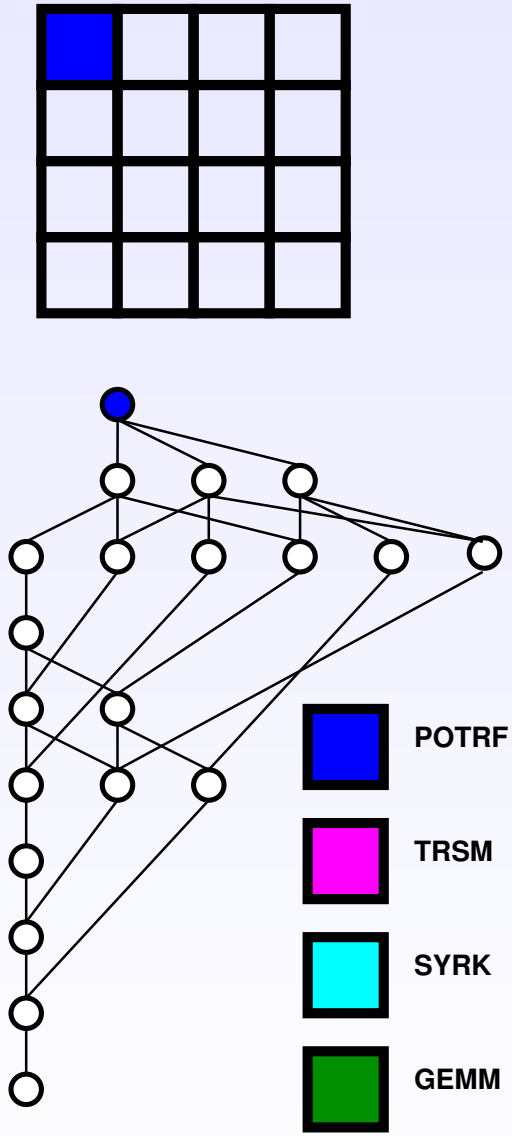

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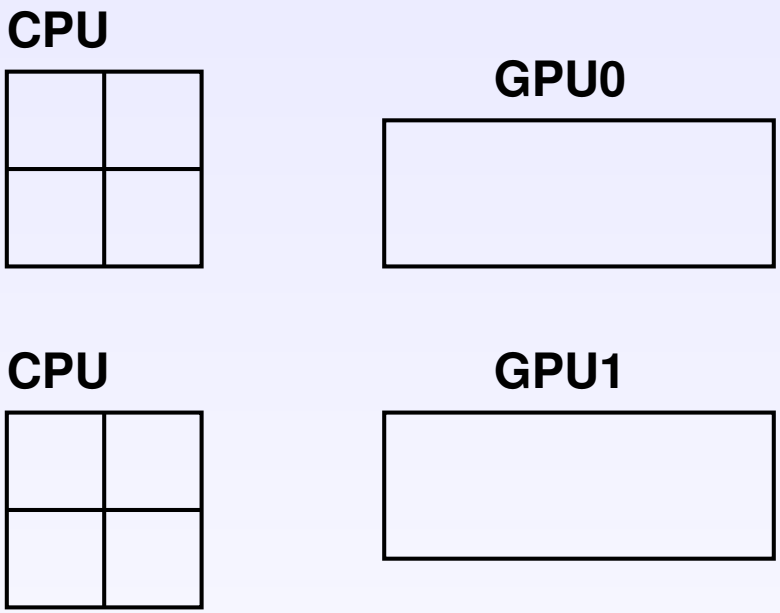

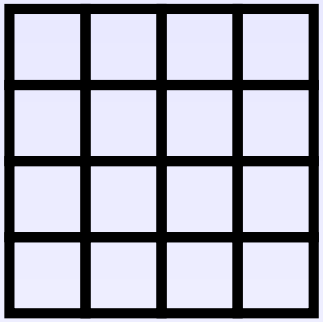

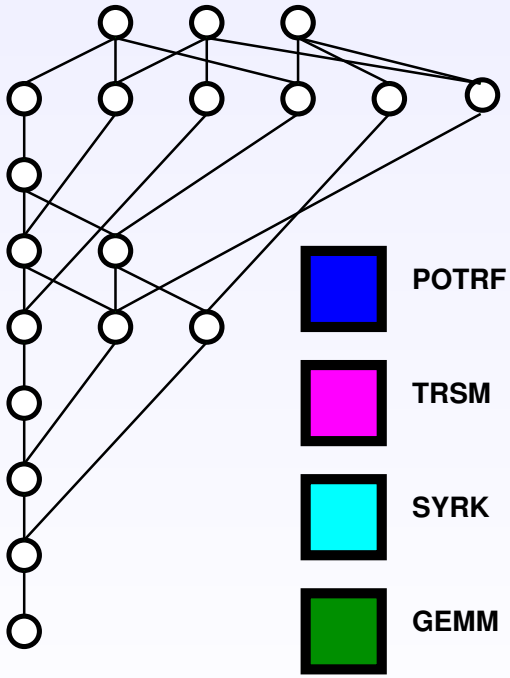

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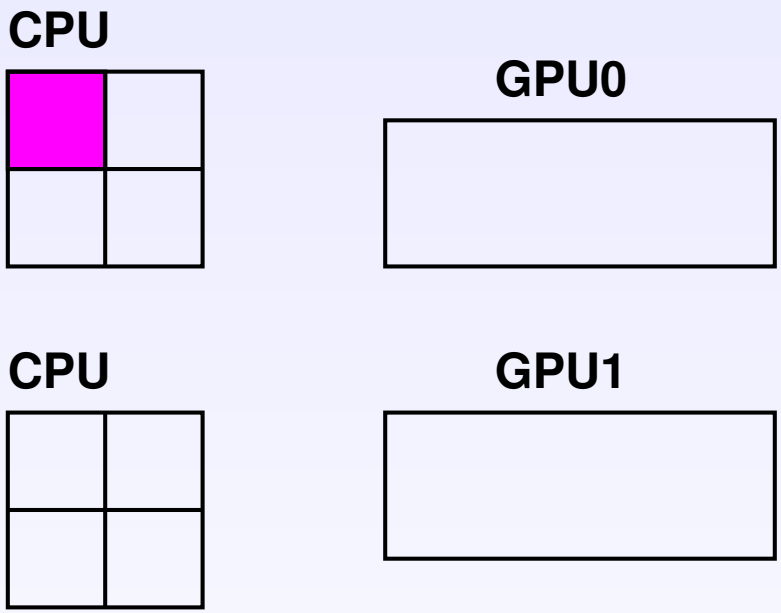

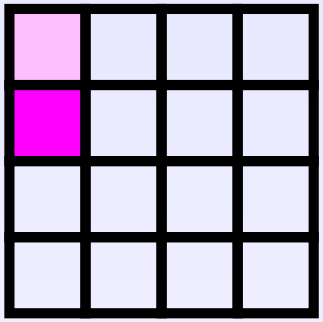

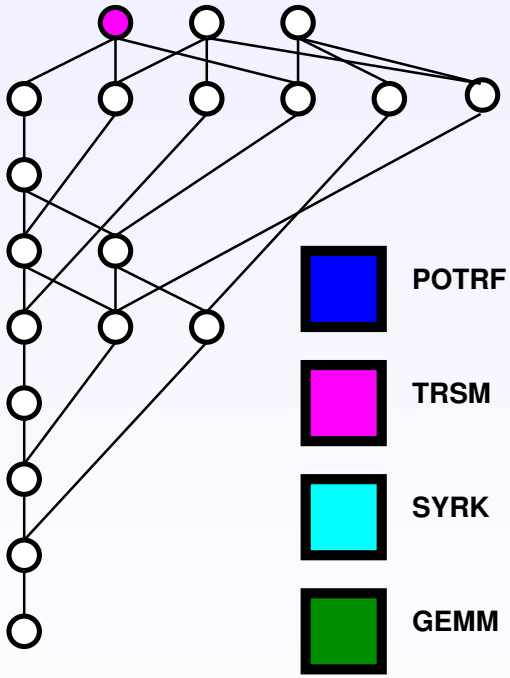

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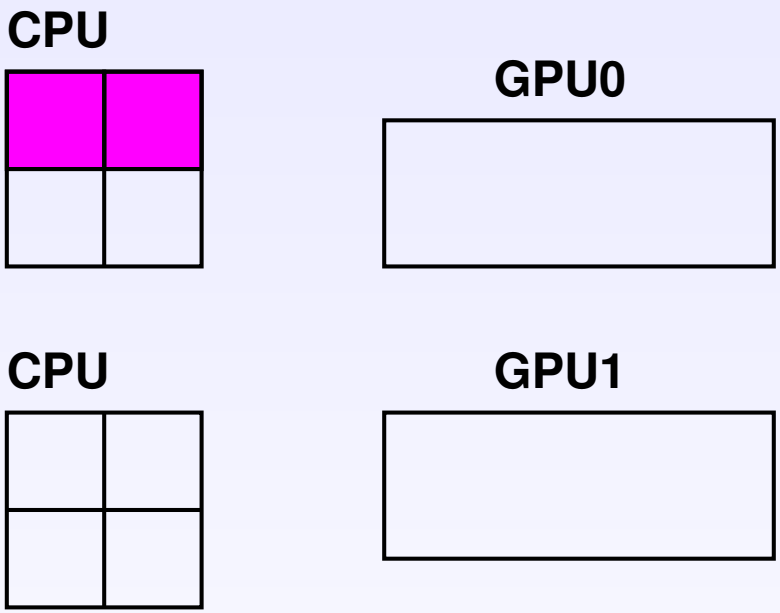
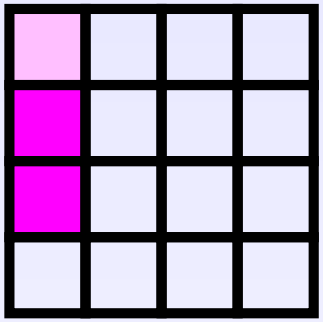
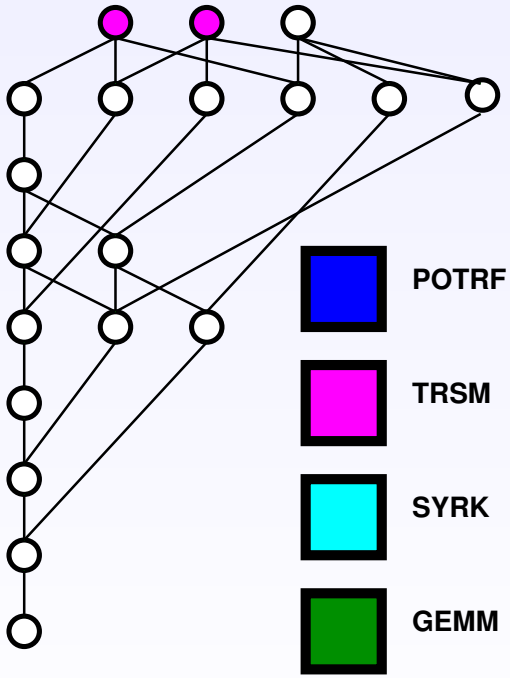
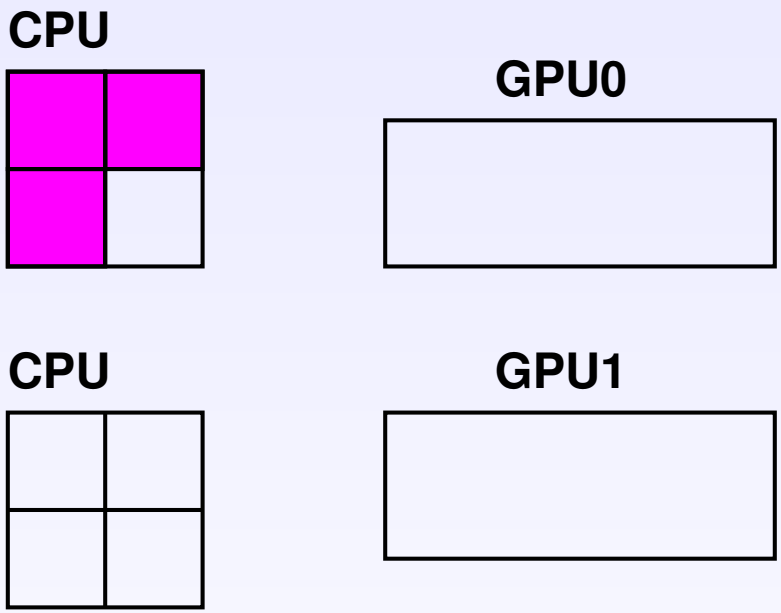


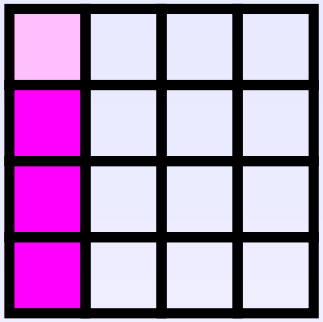


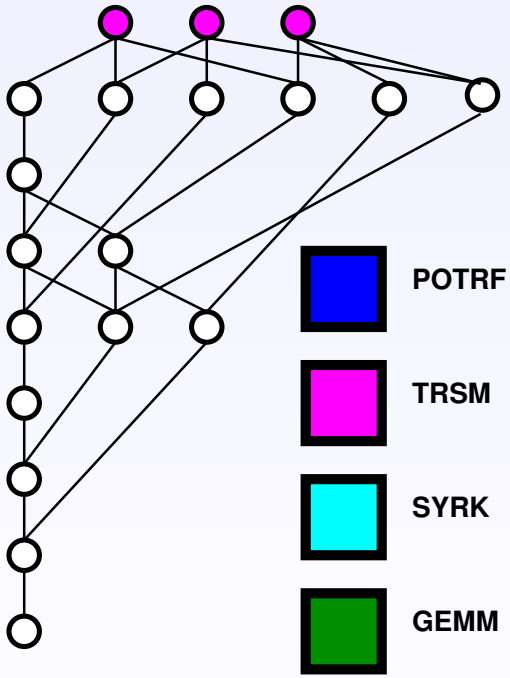


Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

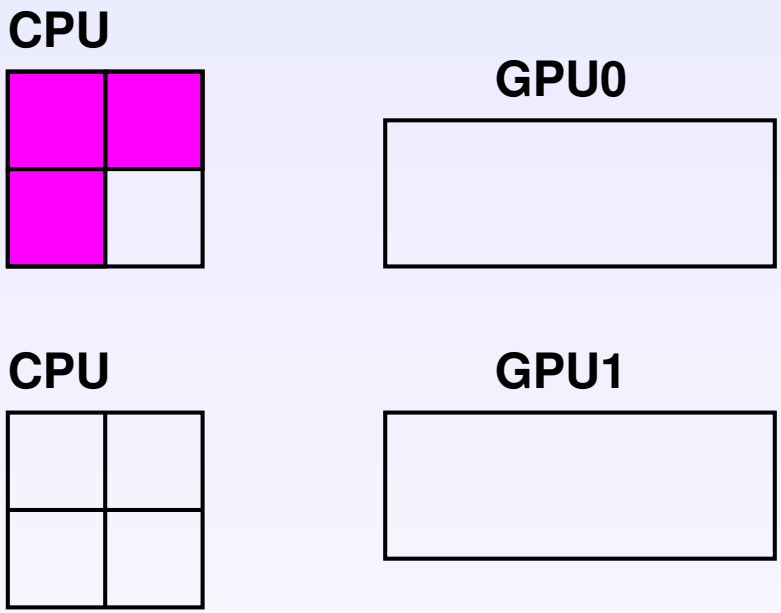


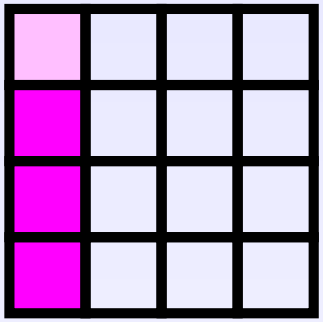


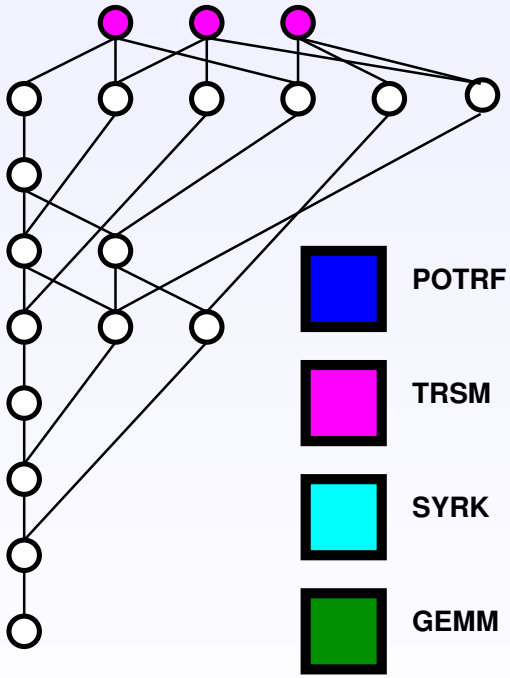


Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



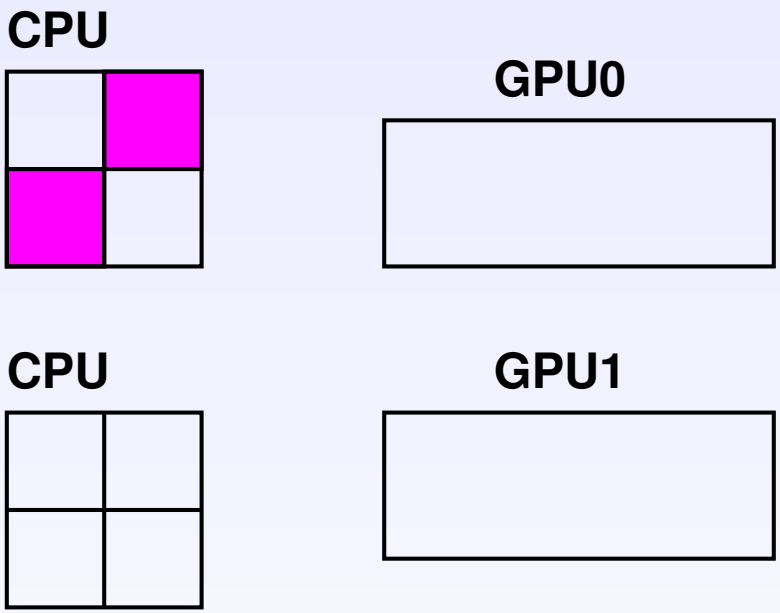


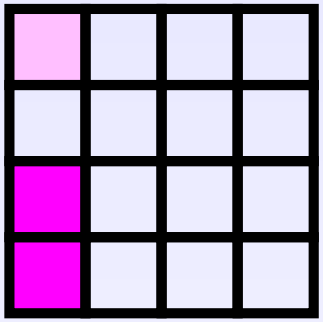


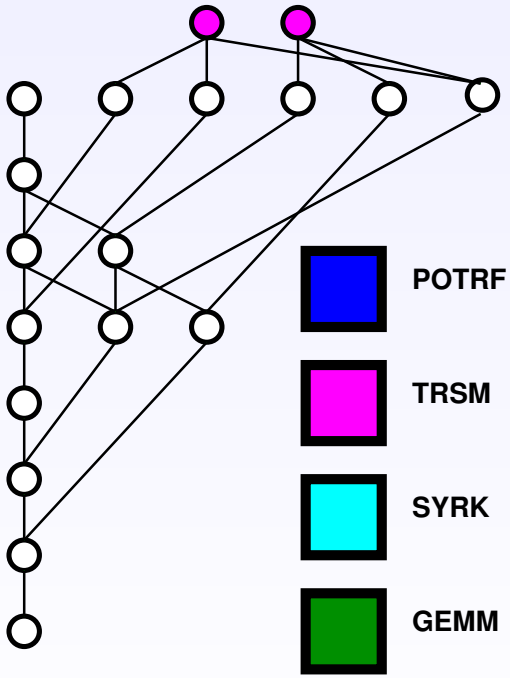
- Handles dependencies

Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



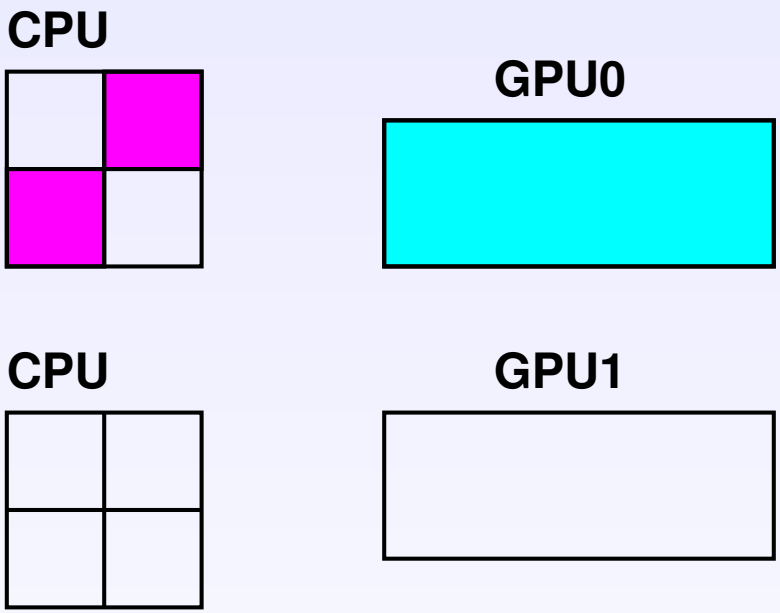


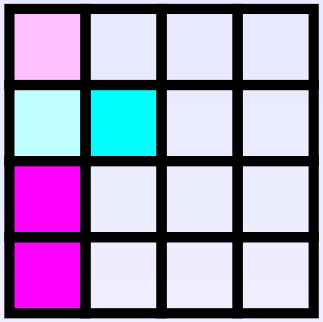


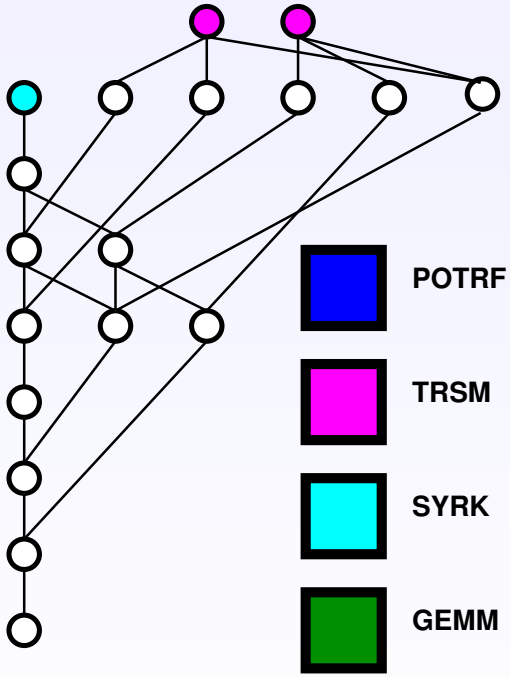
- Handles dependencies

Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



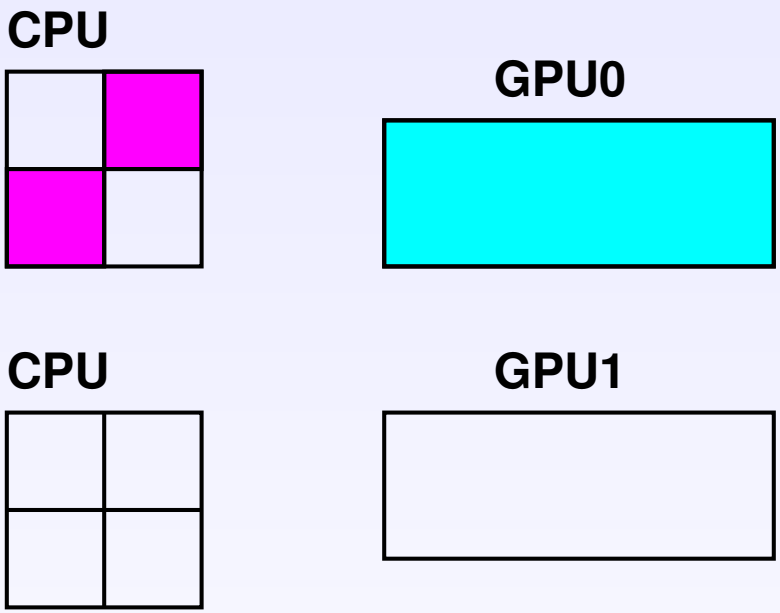


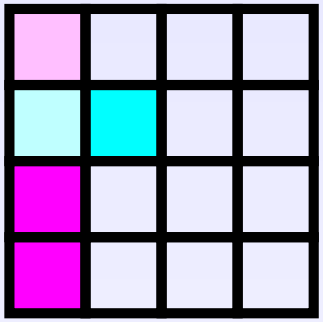


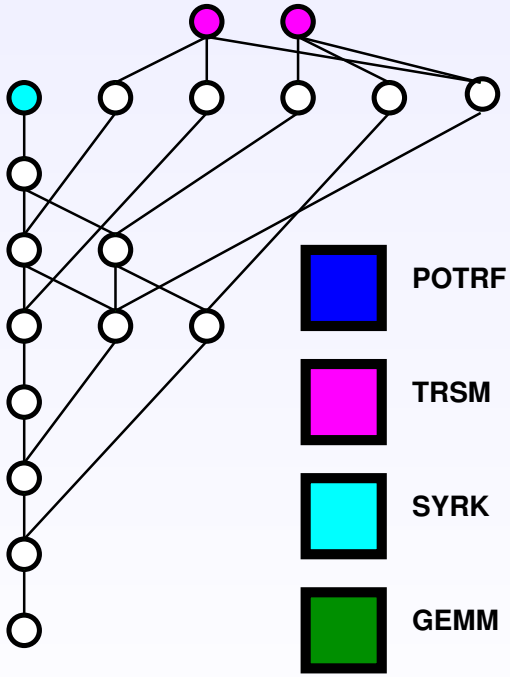
- Handles dependencies

Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



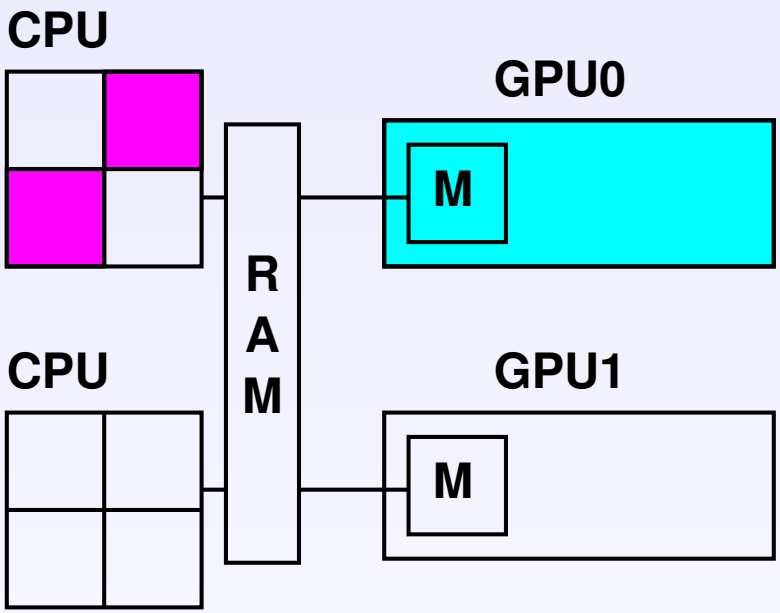


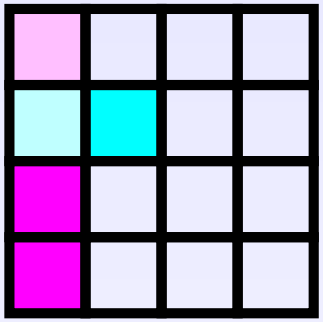


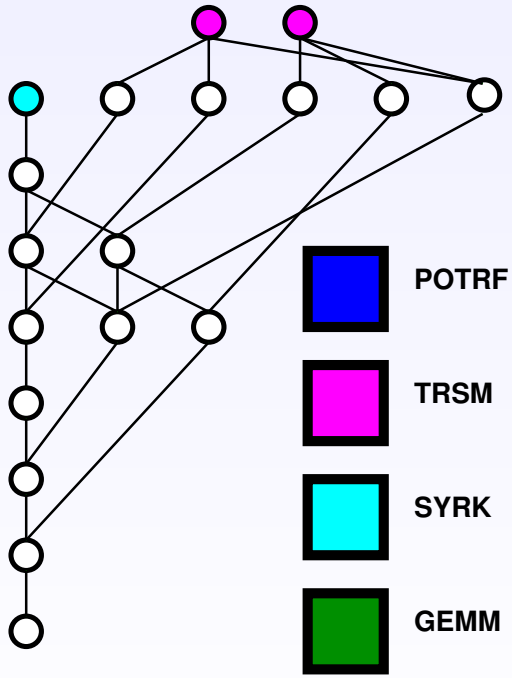
- Handles dependencies
- Handles scheduling (e.g. HEFT)

Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



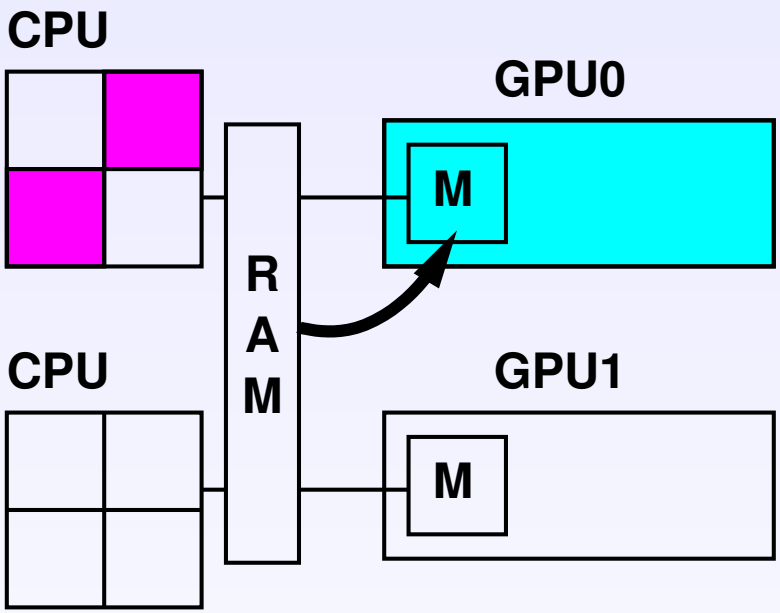


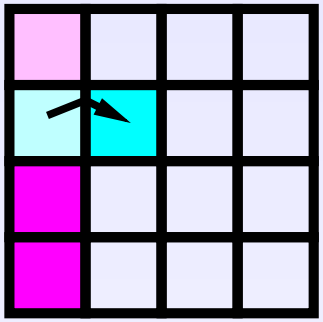


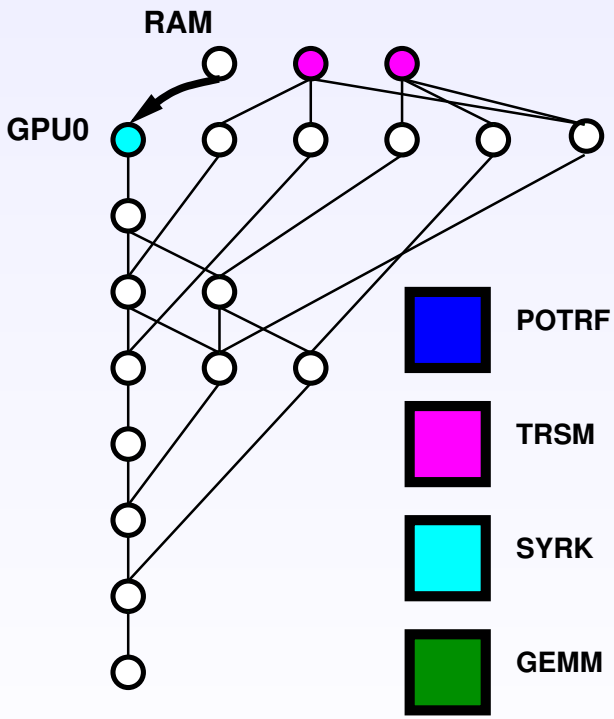
- Handles dependencies
- Handles scheduling (e.g. HEFT)

Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

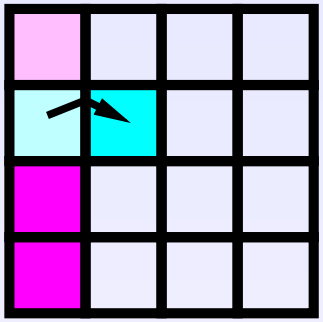




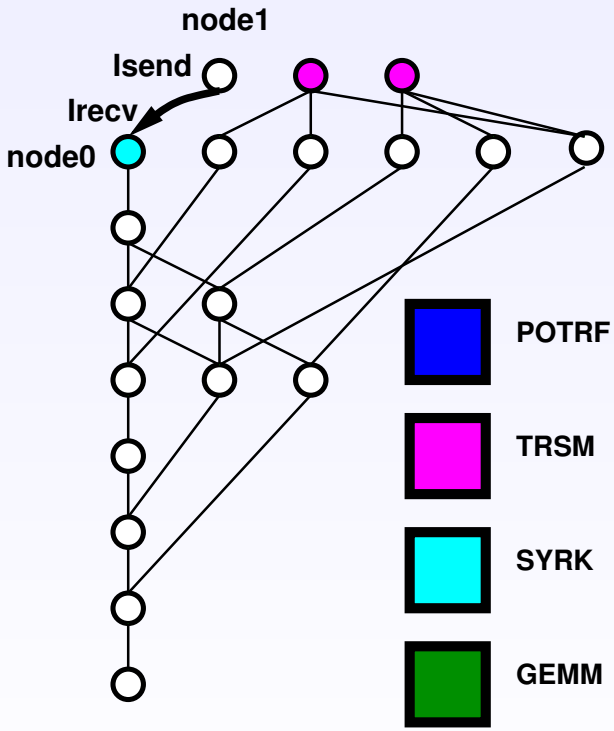


- Handles dependencies
- Handles scheduling (e.g. HEFT)
- Handles data consistency (MSI protocol)

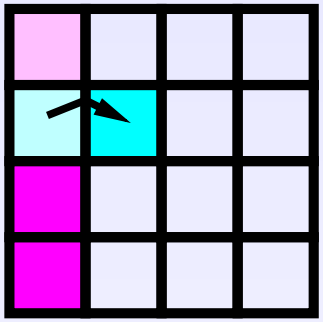
A new programming paradigm for clusters?



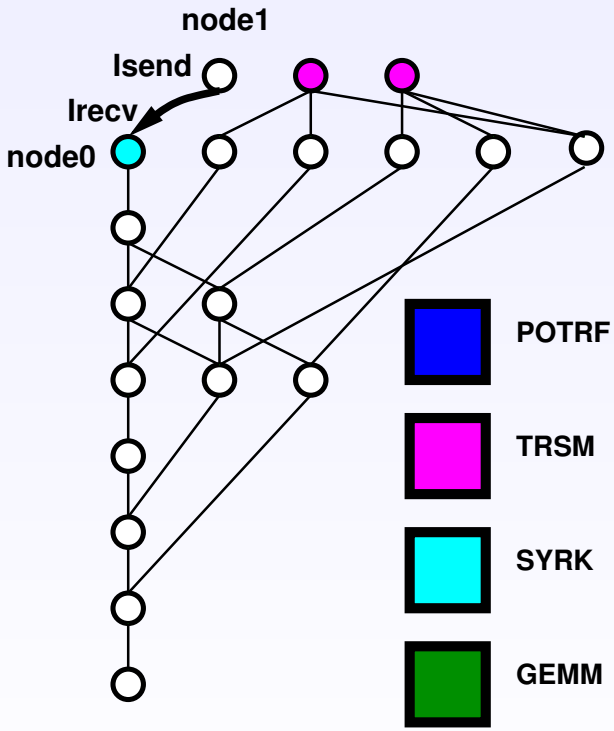
- Infering communications from the task graph



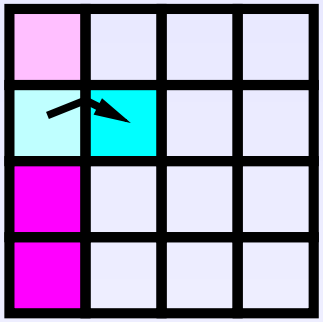
A new programming paradigm for clusters?



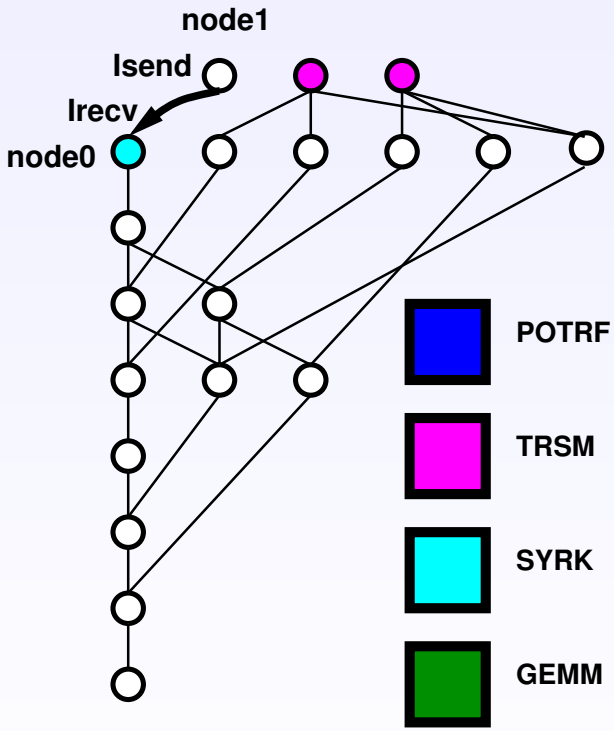
- Infering communications from the task graph
- How to establish the mapping?



A new programming paradigm for clusters?

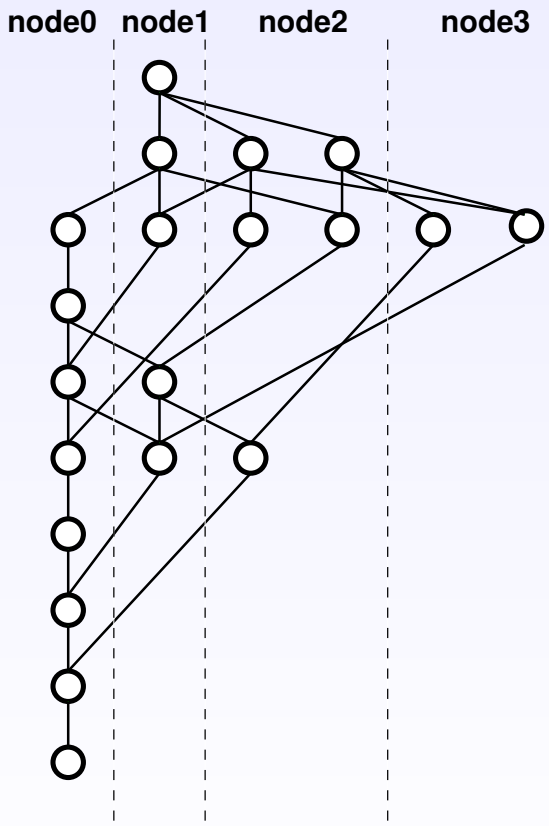


- Infering communications from the task graph
- How to establish the mapping?
- How to initiate communications?



Mapping: Which node executes which tasks?

- The application provides the mapping



Data transfers between nodes

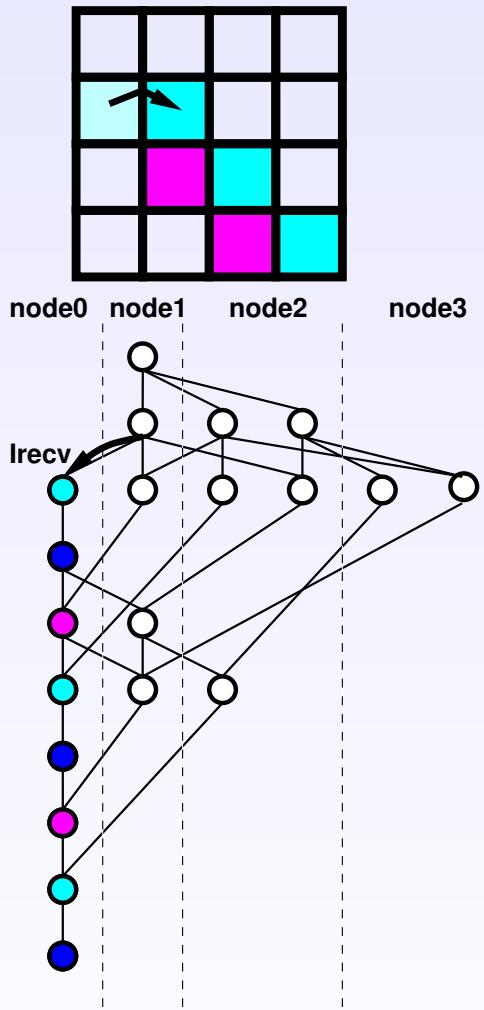
All nodes unroll the whole task graph

They determine tasks they will execute

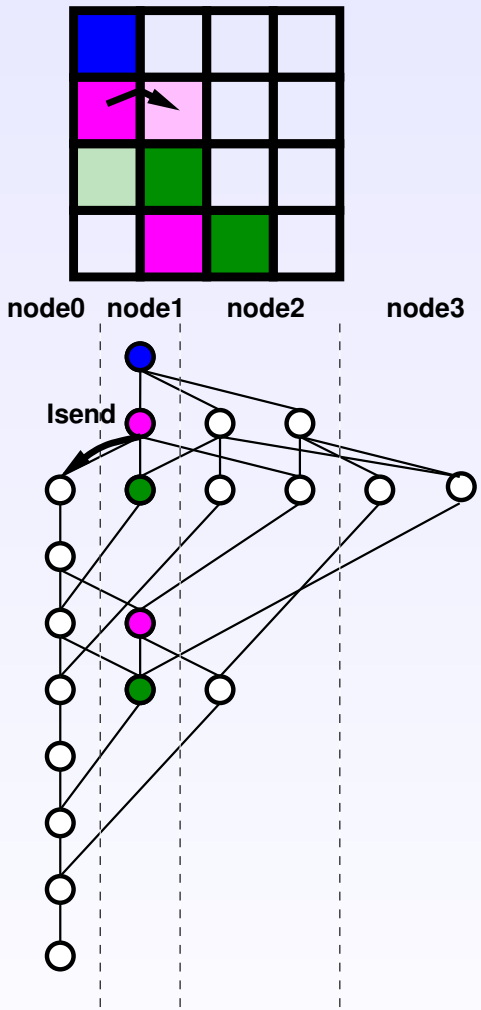
They can infer required communications

No negociation between nodes (not master-slave)

Unrolling can be pruned



Node 0 execution



Node 1 execution

Same paradigm for clusters (vs single node)

same code

```
for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j]);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j]);
  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j]);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
        R,A[i][j], R,A[k][j]);
  }
}
task_wait_for_all();
```

Same paradigm for clusters (vs single node)

Almost same code

- MPI communicator

```
for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD);
  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
        R,A[i][j], R,A[k][j], WORLD);
  }
}
task_wait_for_all();
```

Same paradigm for clusters (vs single node)

Almost same code

- MPI communicator
- Mapping function

```
int getnode(int i, int j) { return((i%p)*q + j%q); }


for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD, getnode(j,j));
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD, getnode(i,j));
  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD, getnode(i,i));
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
        R,A[i][j], R,A[k][j], WORLD, getnode(i,k));
  }
}
task_wait_for_all();
```

Same paradigm for clusters (vs single node)

Almost same code

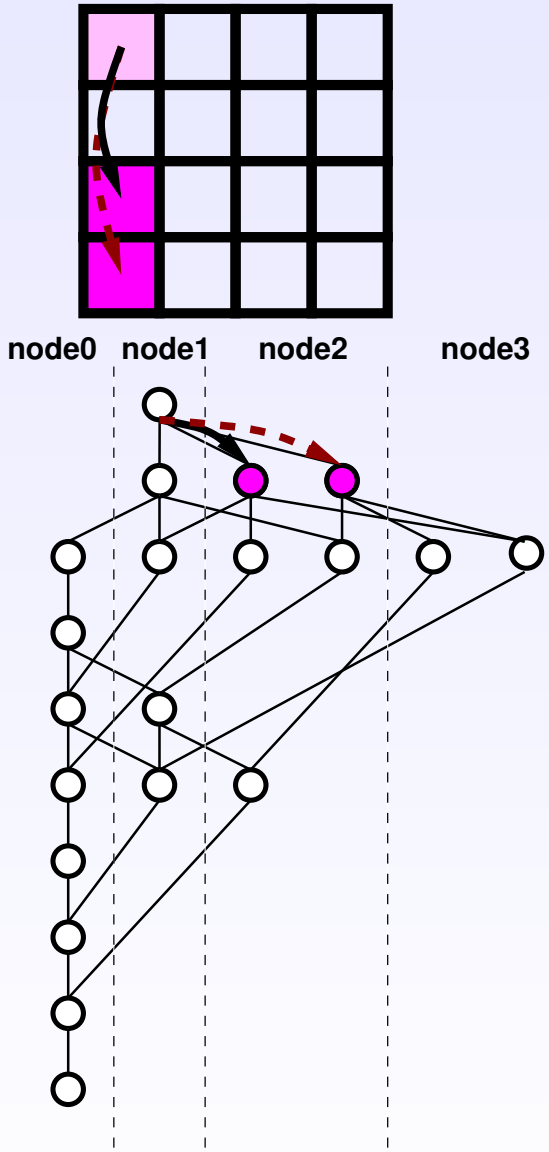
- MPI communicator
- Mapping function

```
int getnode(int i, int j) { return((i%p)*q + j%q); }
set_rank(A, getnode);

for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD);
  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
        R,A[i][j], R,A[k][j], WORLD);
  }
}
task_wait_for_all();
```

Data transfers and cache system

- Duplicate data transfers.
- Let us avoid them
- It means caching the received data
- And drop it later
  - When written to
  - As advised by application



Cache flush

```
int getnode(int i, int j) { return((i%p)*q + j%q); }
set_rank(A, getnode);
for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD);

  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
            R,A[i][j], R,A[k][j], WORLD);

  }
}

task_wait_for_all();
```

Cache flush

```
int getnode(int i, int j) { return((i%p)*q + j%q); }
set_rank(A, getnode);
for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD);
  flush(A[j][j]);
  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
            R,A[i][j], R,A[k][j], WORLD);
      flush(A[i][j]);
  }
}

task_wait_for_all();
```

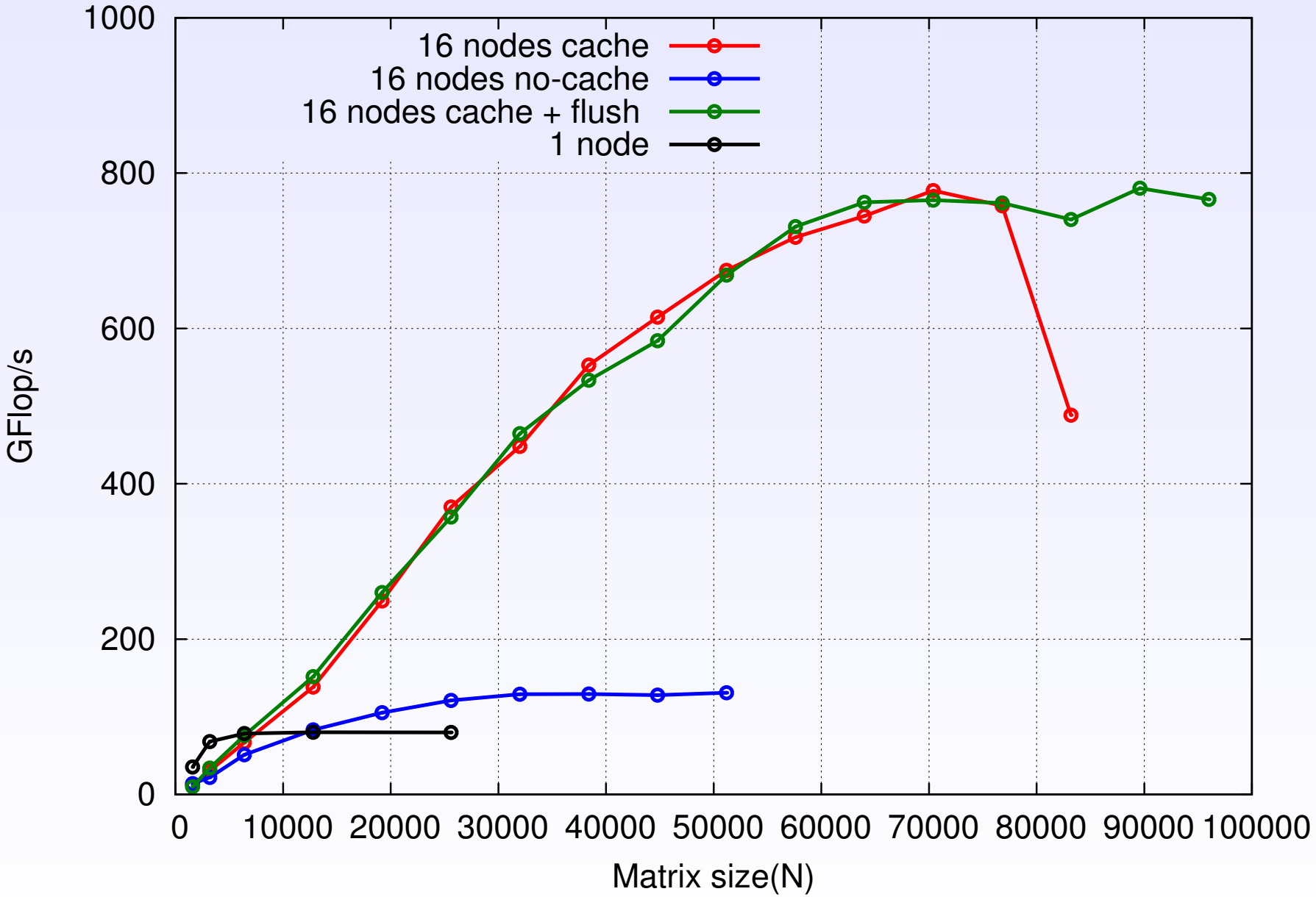
Cache flush

```
int getnode(int i, int j) { return((i%p)*q + j%q); }
set_rank(A, getnode);
for (j = 0; j < N; j++) {
  POTRF (RW,A[j][j], WORLD);
  for (i = j+1; i < N; i++)
    TRSM (RW,A[i][j], R,A[j][j], WORLD);

  for (i = j+1; i < N; i++) {
    SYRK (RW,A[i][i], R,A[i][j], WORLD);
    for (k = j+1; k < i; k++)
      GEMM (RW,A[i][k],
            R,A[i][j], R,A[k][j], WORLD);

  }
}
flush_all();
task_wait_for_all();
```

Cache effect, Cholesky Factorization, tile size 320

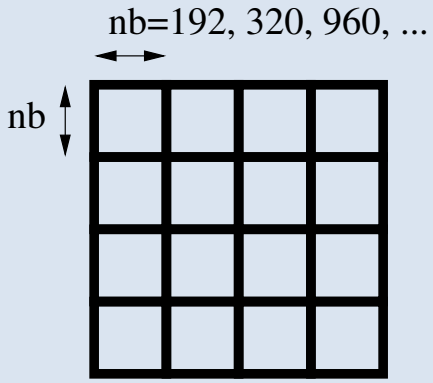


Interaction with StarPU

- StarPU-MPI is actually a separate library on top of StarPU
- MPI communications are technically very much like tasks running on CPU
  - StarPU automatically fetches data from GPU as needed
  - StarPU automatically pushes data to GPU as needed

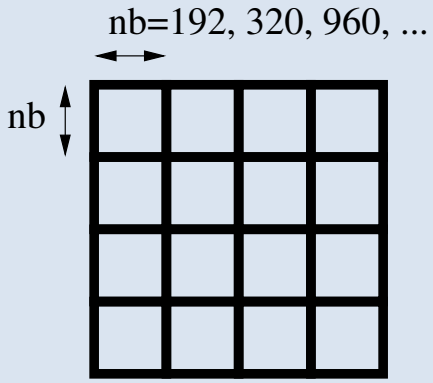
Experimental Setup on TGCC CEA Curie

- Double-precision **Cholesky**
  - Scalapack
  - Dplasma/PaRSEC
  - **Magma-morse/StarPU**
- 64 nodes



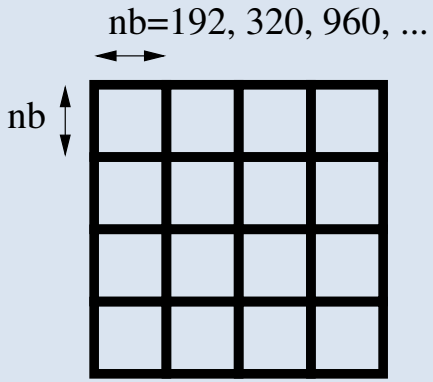
Experimental Setup on TGCC CEA Curie

- Double-precision **Cholesky**
  - Scalapack
  - Dplasma/PaRSEC
  - **Magma-morse/StarPU**
- 64 nodes
  - 2 Intel Westmere @ 2.66 GHz (8 cores per node)
- Homogeneous tile size: 192x192

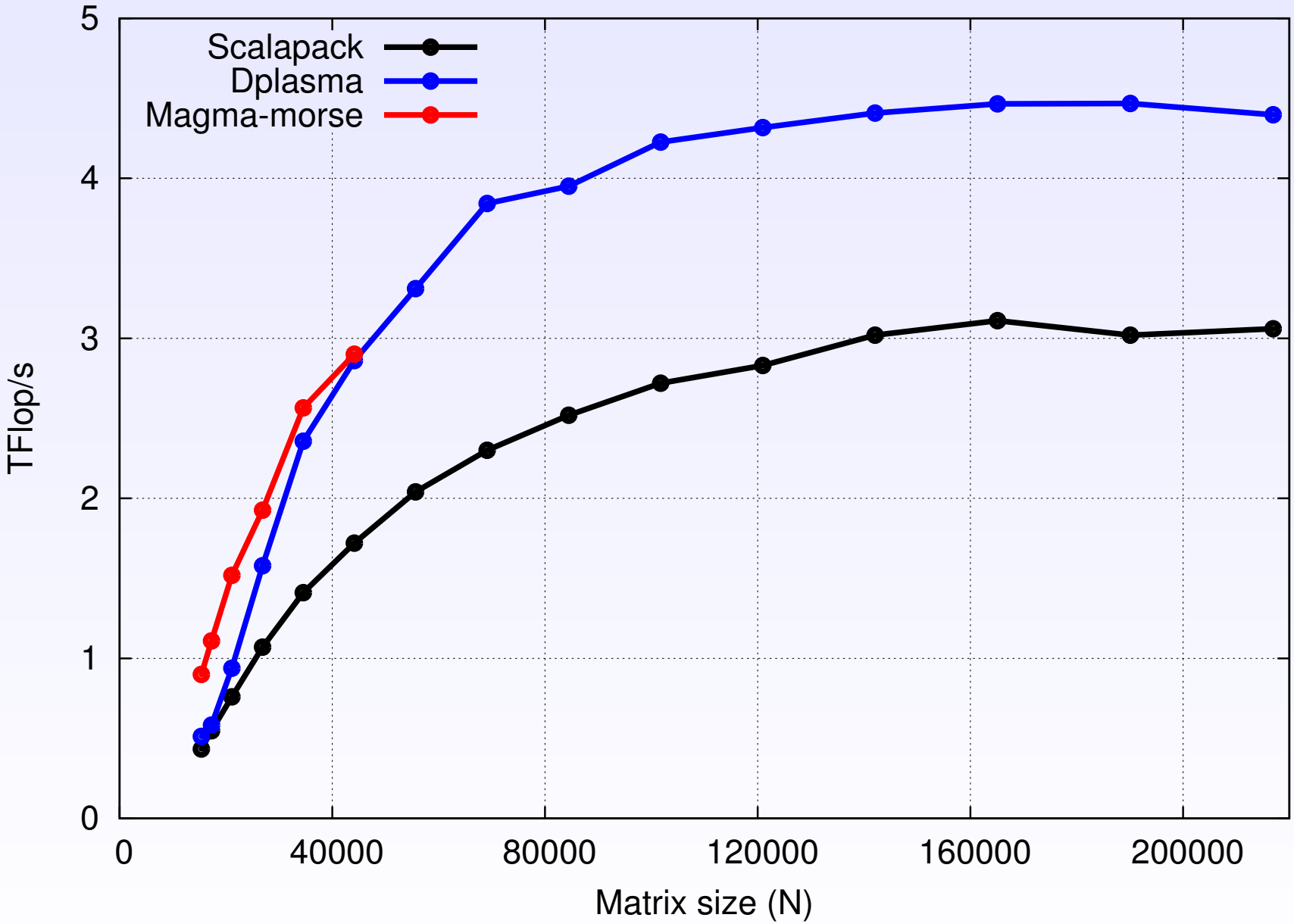


Experimental Setup on TGCC CEA Curie

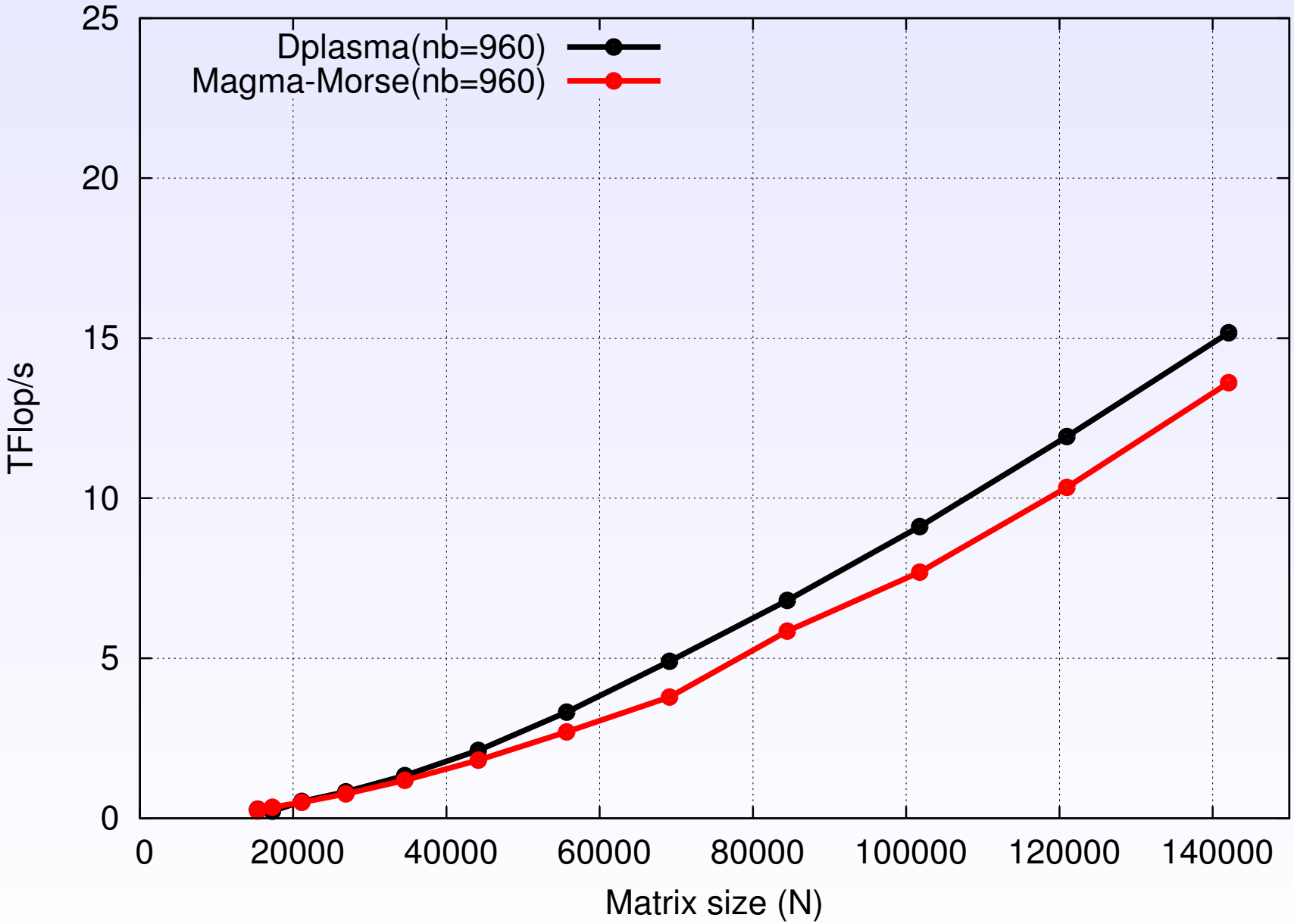
- Double-precision **Cholesky**
  - Scalapack
  - Dplasma/PaRSEC
  - **Magma-morse/StarPU**
- 64 nodes
  - 2 Intel Westmere @ 2.66 GHz (8 cores per node)
  - 2 Nvidia Tesla M2090 (2 GPUs per node)
- Homogeneous tile size: 192x192
- Heterogeneous tile sizes: 320x320 / 960x960



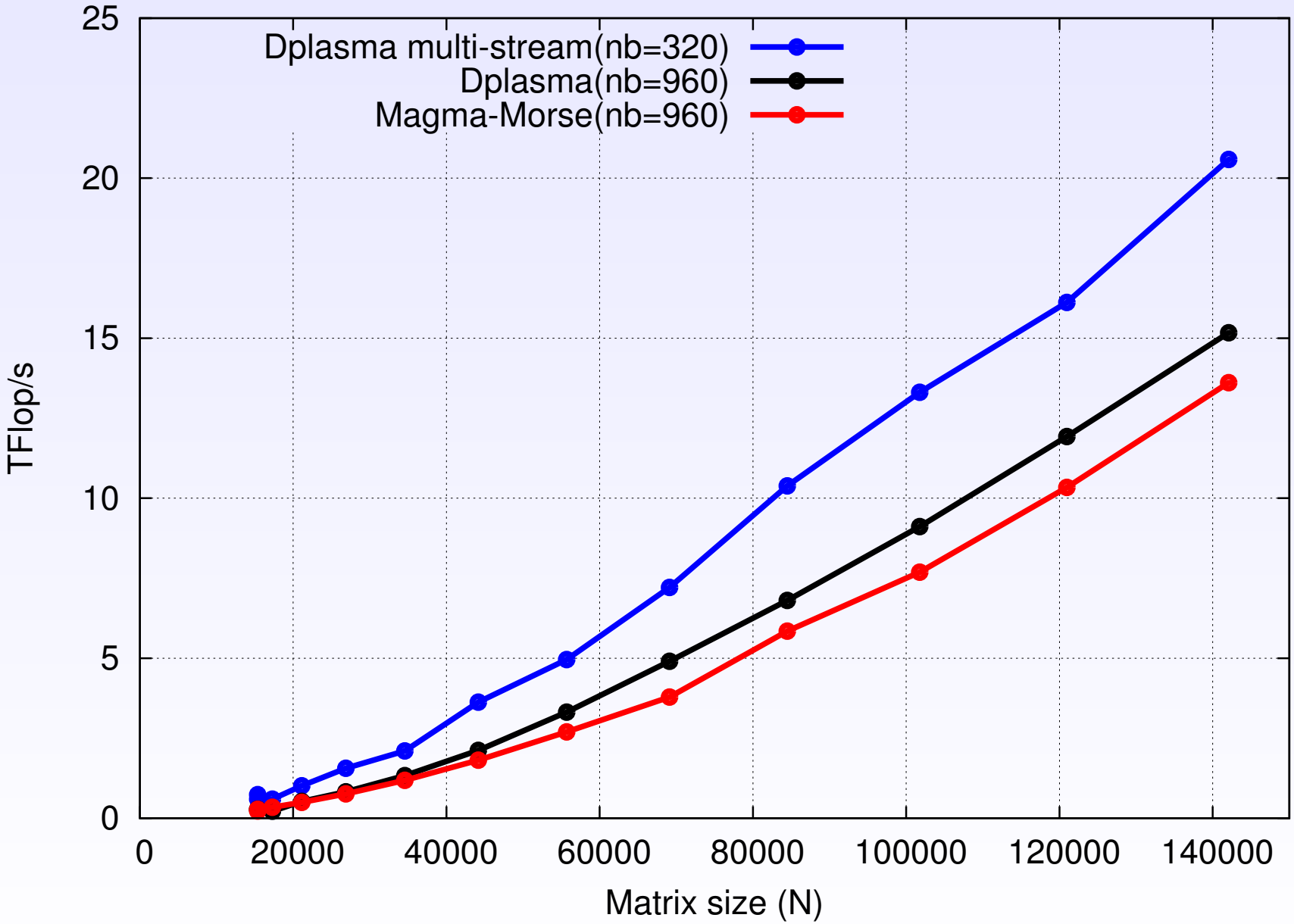
64 homogeneous nodes (8 cores per node)



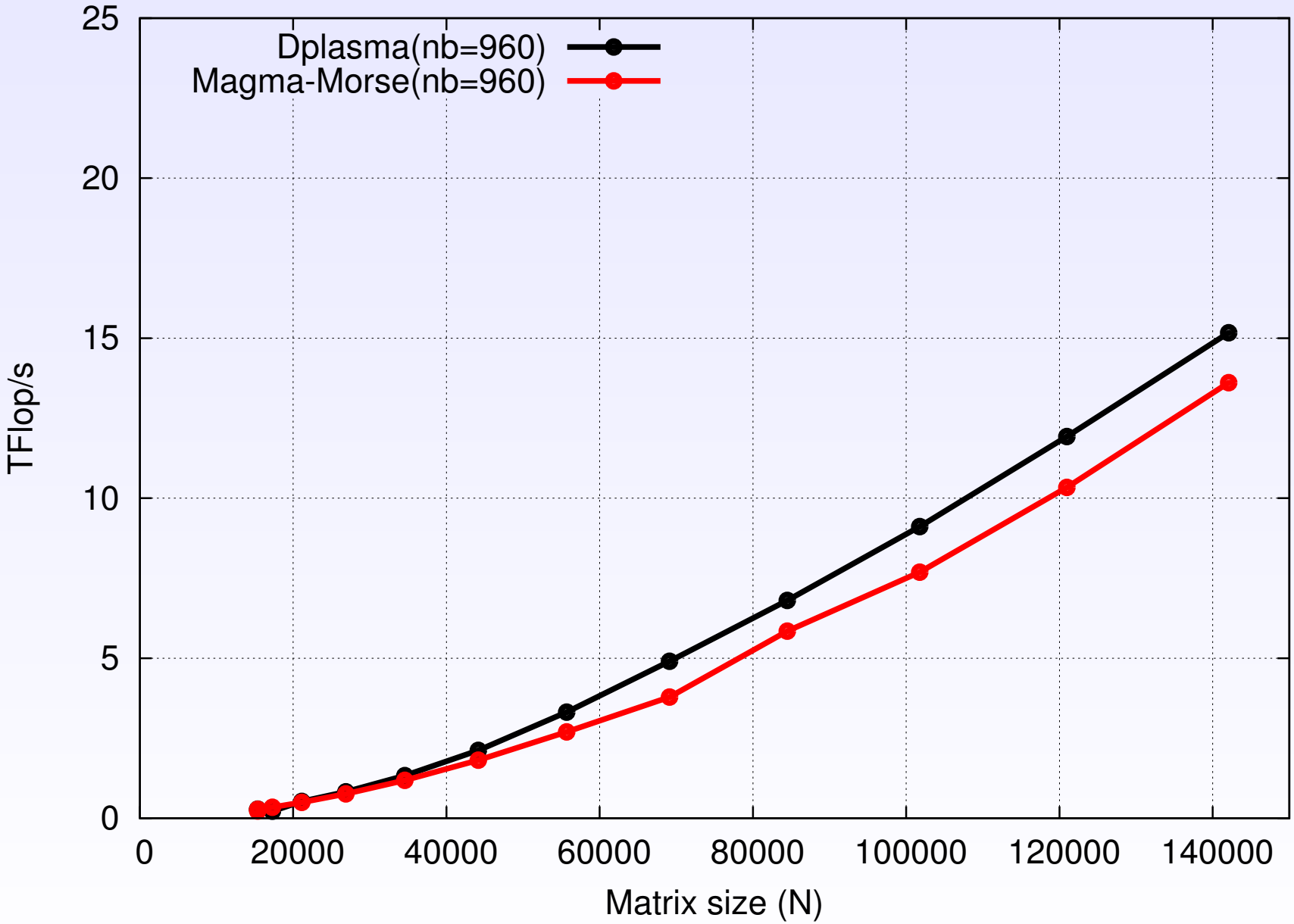
64 heterogeneous nodes (8 cores + 2 GPUs per node)



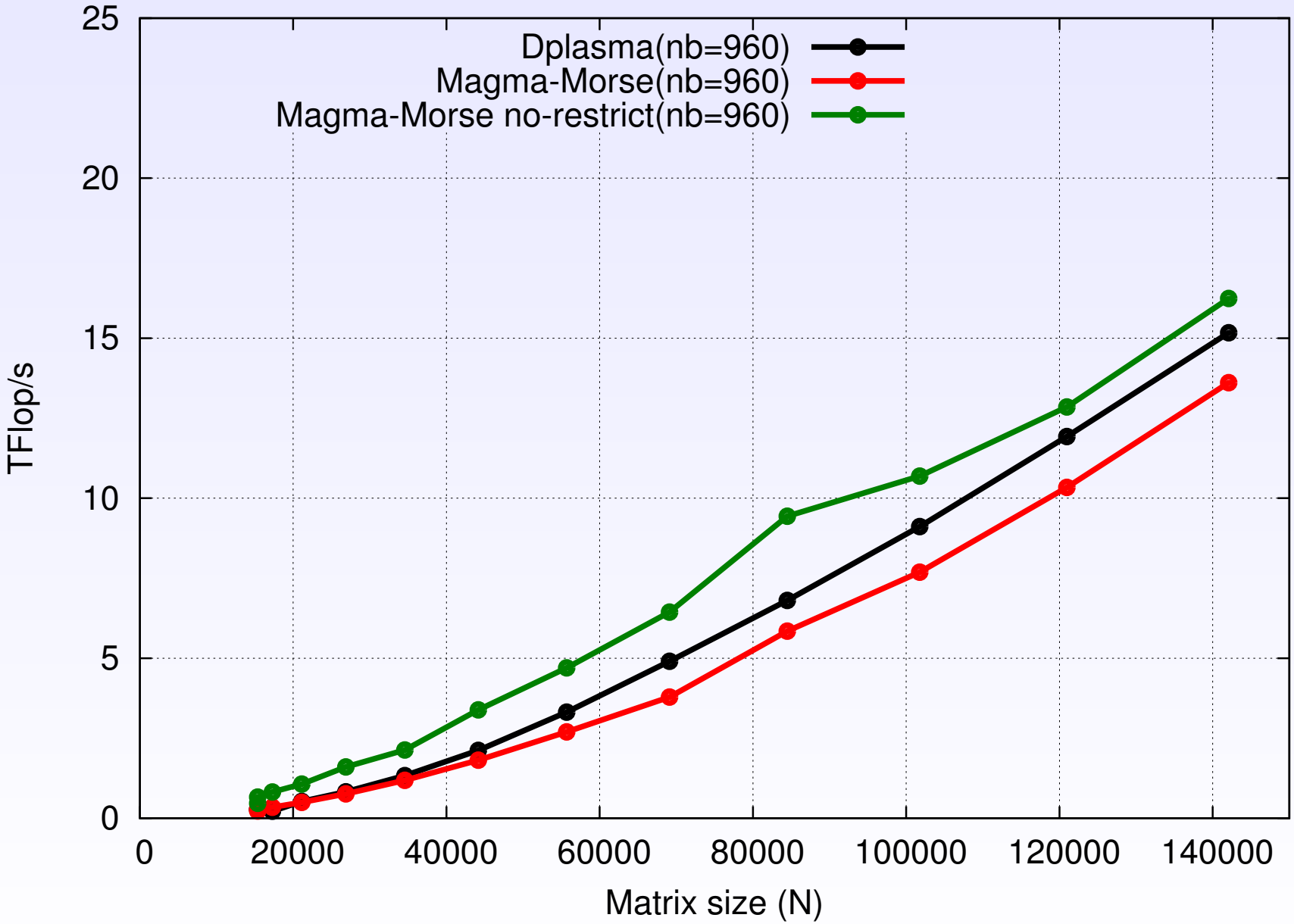
64 heterogeneous nodes (8 cores + 2 GPUs per node)



64 heterogeneous nodes (8 cores + 2 GPUs per node)



64 heterogeneous nodes (8 cores + 2 GPUs per node)



Conclusion

Contribution

- **Almost no code changes vs single node**
- **Competitive performance**

Future work

- Dynamic inter-node load balancing
- Automatic pruning

Related work

- Sparse direct solvers (see Pierre's talk)
- Krylov methods, hybrid (direct+iterative) solvers, FMM, H-matrix
- Explicit cases
- See OpenMP 3.1 & 4.0 standards

Thanks

MORSE: http://icl.cs.utk.edu/morse/
StarPU: http://runtime.bordeaux.inria.fr/StarPU/

Open postdoctoral positions @ INRIA Bordeaux

Pruning the task graph traversal