

## Overview of Distributed Linear Algebra on Hybrid Nodes over the StarPU Runtime

Emmanuel Agullo, Olivier Aumage, Mathieu Faverge, Nathalie Furmento, Florent Pruvost, Marc Sergent, Samuel Thibault

► **To cite this version:**

Emmanuel Agullo, Olivier Aumage, Mathieu Faverge, Nathalie Furmento, Florent Pruvost, et al.. Overview of Distributed Linear Algebra on Hybrid Nodes over the StarPU Runtime. SIAM Conference on Parallel Processing for Scientific Computing (SIAM PP 2014), Feb 2014, Portland, Oregon, United States. hal-00978602

**HAL Id: hal-00978602**

**<https://hal.inria.fr/hal-00978602>**

Submitted on 14 Apr 2014

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

# Overview of Distributed Linear Algebra on Hybrid Nodes over the StarPU Runtime

Emmanuel AGULLO, Olivier AUMAGE, Mathieu FAVERGE,  
Nathalie FURMENTO, Florent PRUVOST, Samuel THIBAUT,  
Marc SERGENT

MORSE Associated Team



**MORSE**

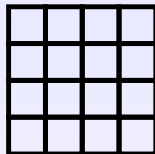


1. Introduction
2. Sequential task-based paradigm on a single node
3. Do we need a new programming paradigm for clusters?
4. Distributed Data Management
5. Comparison against state-of-the-art approaches
6. Conclusion and future work

- 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 almost the same code, and leave runtime handle data transfers?
  - ▶ Example: **Cholesky** factorization (DPOTRF)

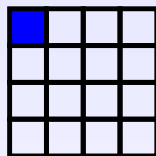
# Sequential task-based Cholesky on a single node

```
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();
```



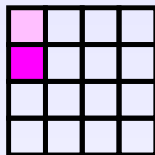
# Sequential task-based Cholesky on a single node

```
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();
```



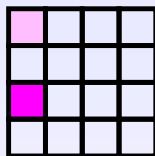
# Sequential task-based Cholesky on a single node

```
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();
```



# Sequential task-based Cholesky on a single node

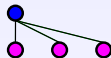
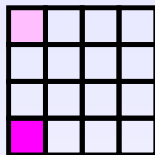
```
for (j = 0; j < N; j++) {  
  POTRF (RW,A[j][j]);  
  for (i = j+1; i < N; i++)  
    TRSM (RW,A[i][j], R,A[j][j]);  
  for (i = j+1; i < N; i++) {  
    SYRK (RW,A[i][i], R,A[i][j]);  
    for (k = j+1; k < i; k++)  
      GEMM (RW,A[i][k],  
           R,A[i][j], R,A[k][j]);  
  }  
}  
task_wait_for_all();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





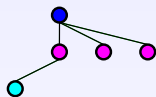
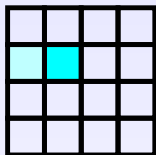
# Sequential task-based Cholesky on a single node

```
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();
```



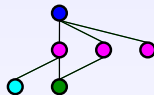
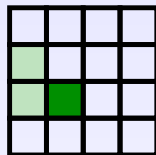
# Sequential task-based Cholesky on a single node

```
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();
```



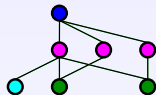
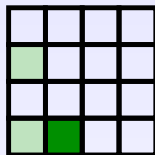
# Sequential task-based Cholesky on a single node

```
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();
```



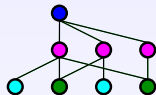
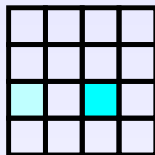
# Sequential task-based Cholesky on a single node

```
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();
```



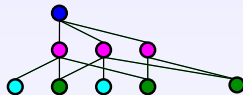
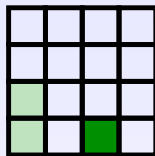
# Sequential task-based Cholesky on a single node

```
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();
```



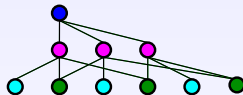
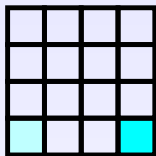
# Sequential task-based Cholesky on a single node

```
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();
```



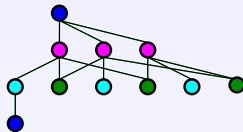
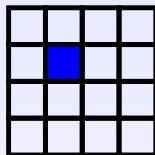
# Sequential task-based Cholesky on a single node

```
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();
```



# Sequential task-based Cholesky on a single node

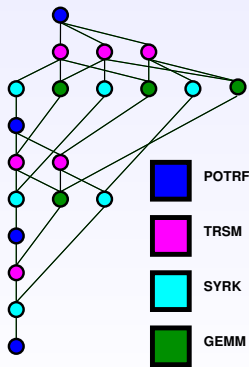
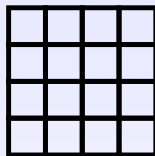
```
for (j = 0; j < N; j++) {  
  POTRF (RW,A[j][j]);  
  for (i = j+1; i < N; i++)  
    TRSM (RW,A[i][j], R,A[j][j]);  
  for (i = j+1; i < N; i++) {  
    SYRK (RW,A[i][i], R,A[i][j]);  
    for (k = j+1; k < i; k++)  
      GEMM (RW,A[i][k],  
           R,A[i][j], R,A[k][j]);  
  }  
}  
task_wait_for_all();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





# Sequential task-based Cholesky on a single node

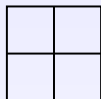
```
for (j = 0; j < N; j++) {  
  POTRF (RW,A[j][j]);  
  for (i = j+1; i < N; i++)  
    TRSM (RW,A[i][j], R,A[j][j]);  
  for (i = j+1; i < N; i++) {  
    SYRK (RW,A[i][i], R,A[i][j]);  
    for (k = j+1; k < i; k++)  
      GEMM (RW,A[i][k],  
           R,A[i][j], R,A[k][j]);  
  }  
}  
task_wait_for_all();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



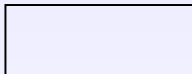
# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

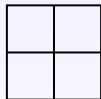
**CPU**



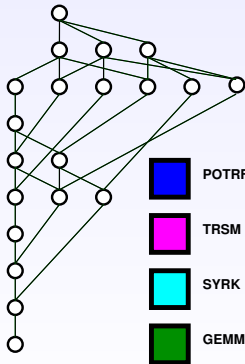
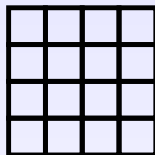
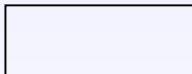
**GPU0**



**CPU**



**GPU1**



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



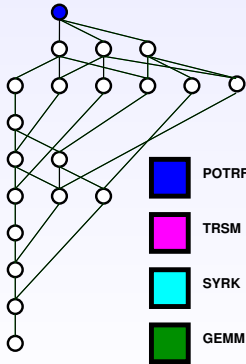
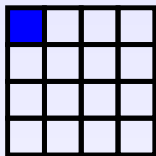
GPU0



CPU



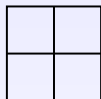
GPU1



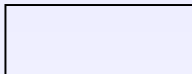
# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

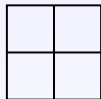
**CPU**



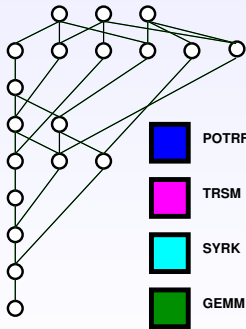
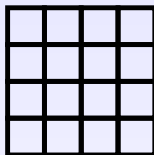
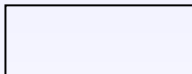
**GPU0**



**CPU**



**GPU1**



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



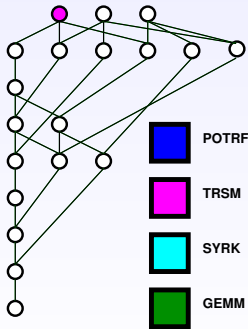
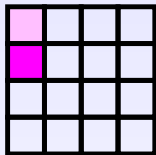
GPU0



CPU



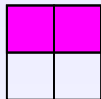
GPU1



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

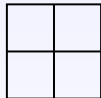
CPU



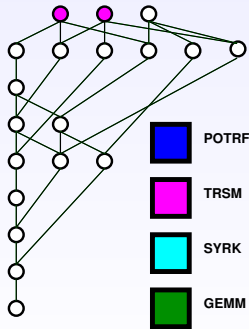
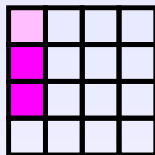
GPU0



CPU



GPU1



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

**CPU**



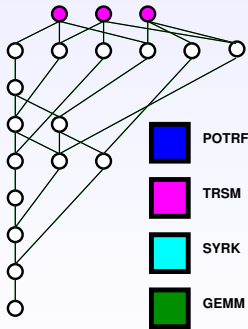
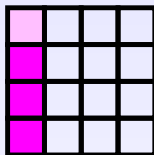
**GPU0**



**CPU**



**GPU1**



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



GPU0



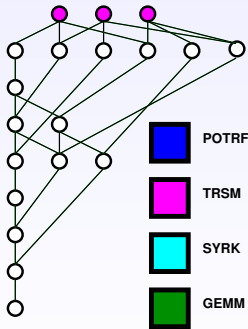
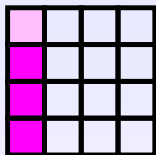
CPU



GPU1



- Handles dependencies

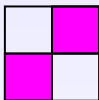




# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



GPU0



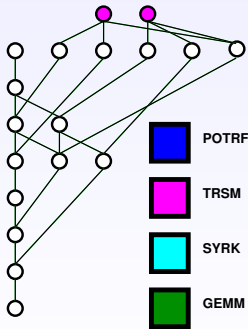
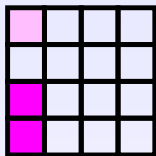
CPU



GPU1



- Handles dependencies



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



GPU0



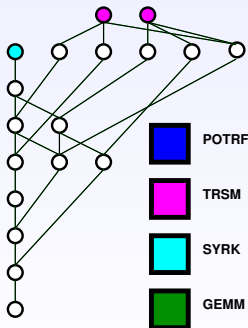
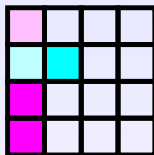
CPU



GPU1



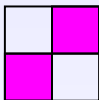
- Handles dependencies



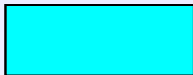
# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



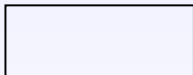
GPU0



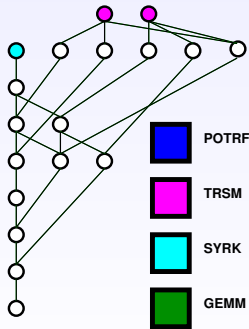
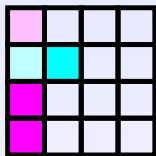
CPU



GPU1

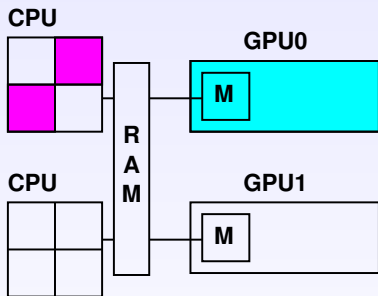


- Handles dependencies
- Handles scheduling (e.g. HEFT)

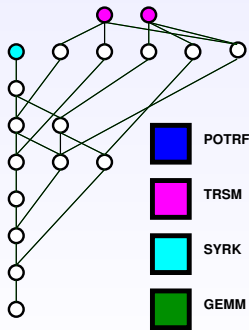
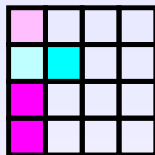


# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

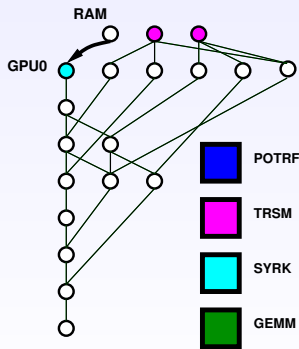
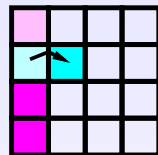
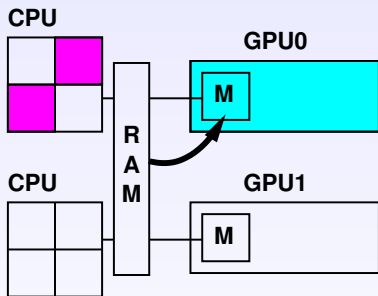


- Handles dependencies
- Handles scheduling (e.g. HEFT)



# Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



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

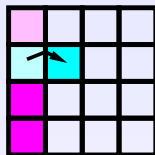
## **Sequential task-based paradigm for single node**

- Sequential source code
- Runtime infers task dependencies from data dependencies
- Runtime drives and optimizes execution

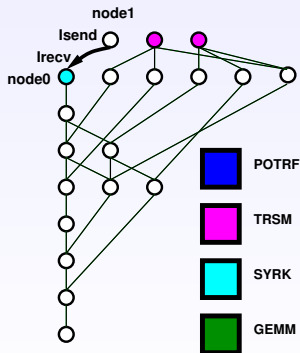
## Sequential task-based paradigm for single node

- Sequential source code
  - Runtime infers task dependencies from data dependencies
  - Runtime drives and optimizes execution
- 
- How about clusters?
    - ▶ Do we really need a new programming paradigm?

# Do we need a new paradigm for clusters?

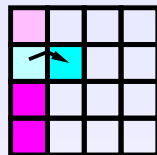


- How to express communications?

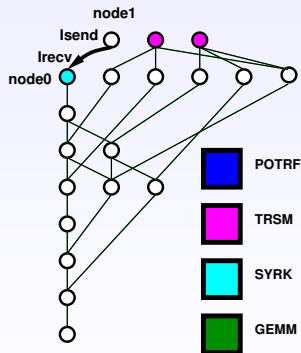




# Do we need a new paradigm for clusters?

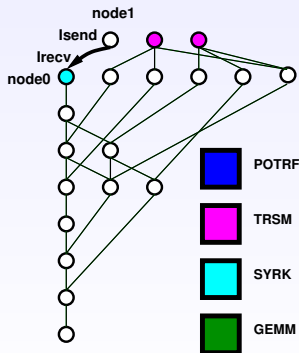
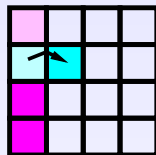


- How to express communications?
- How to establish the mapping?



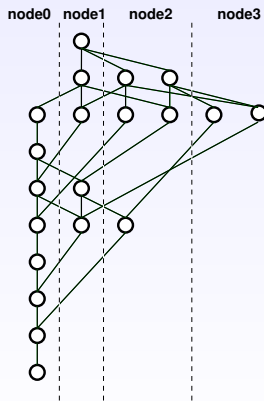
# Do we need a new paradigm for clusters?

- How to express communications?
- How to establish the mapping?
- How communications will be initiated?



# Mapping: Which node executes which tasks?

- The application provides the mapping



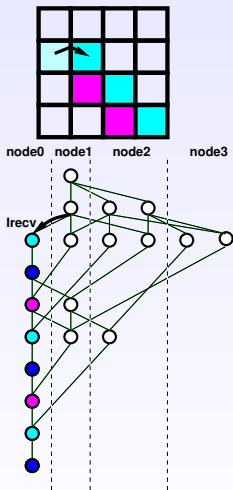
# Data transfers between nodes

All nodes unroll the whole task graph

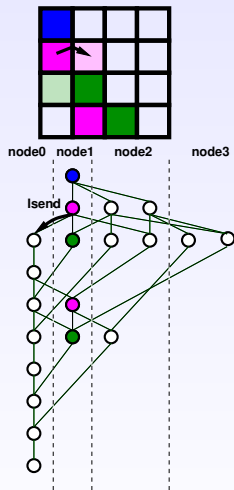
They determine tasks they will execute

They can infer required communications

No synchronization between nodes



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

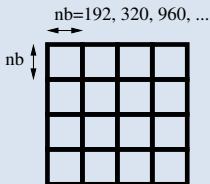
- MPI communicator
- Mapping function

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

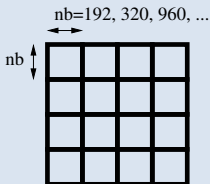
for (j = 0; j < N; j++) {
    POTRF (RW,A[j][j], WORLD);
    for (i = j+1; i < N; i++)
        TRSM (RW,A[i][j], R,A[j][j], WORLD);
    for (i = j+1; i < N; i++) {
        SYRK (RW,A[i][i], R,A[i][j], WORLD);
        for (k = j+1; k < i; k++)
            GEMM (RW,A[i][k],
                R,A[i][j], R,A[k][j],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



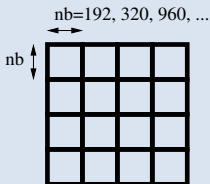
- Double-precision **Cholesky**
  - ▶ Scalapack
  - ▶ Dplasma/Parsec
  - ▶ **Magma-morse/StarPU**
- 64 nodes



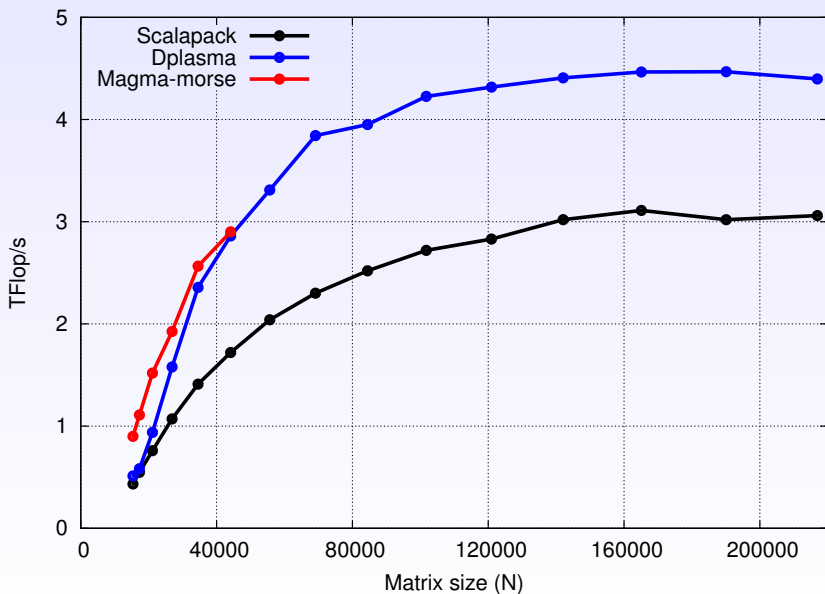
- Double-precision **Cholesky**
  - ▶ Scalapack
  - ▶ Dplasma/Parsec
  - ▶ **Magma-morse/StarPU**
- 64 nodes
  - ▶ 2 Intel Westmere @ 2.66 GHz (8 cores per node)
- Homogeneous tile size: 192x192



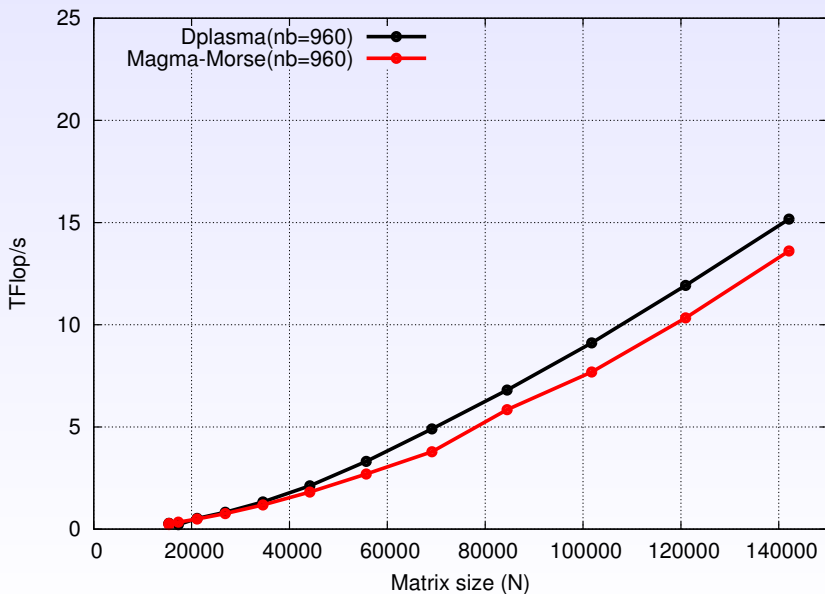
- Double-precision **Cholesky**
  - ▶ Scalapack
  - ▶ Dplasma/Parsec
  - ▶ **Magma-morse/StarPU**
- 64 nodes
  - ▶ 2 Intel Westmere @ 2.66 GHz (8 cores per node)
  - ▶ 2 Nvidia Tesla M2090 (2 GPUs per node)
- Homogeneous tile size: 192x192
- Heterogeneous tile sizes: 320x320 / 960x960



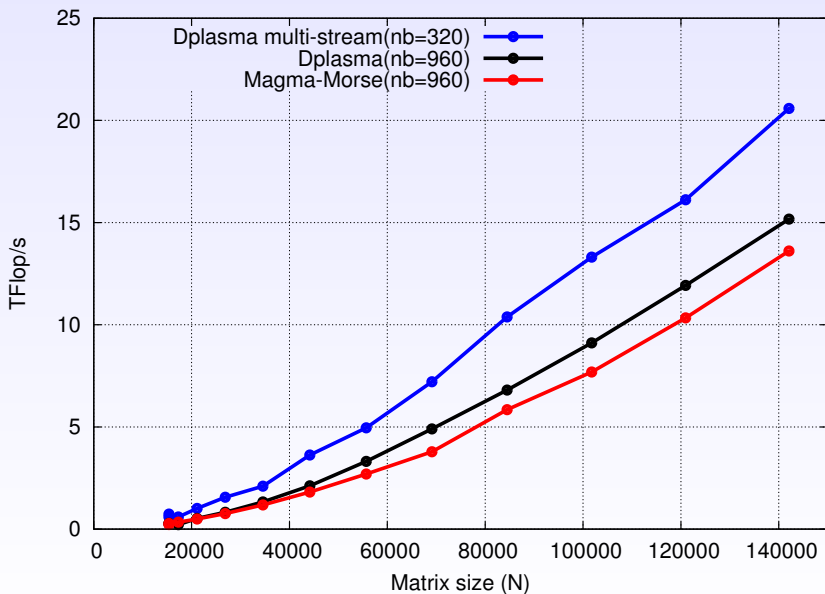
# 64 homogeneous nodes (8 cores per node)



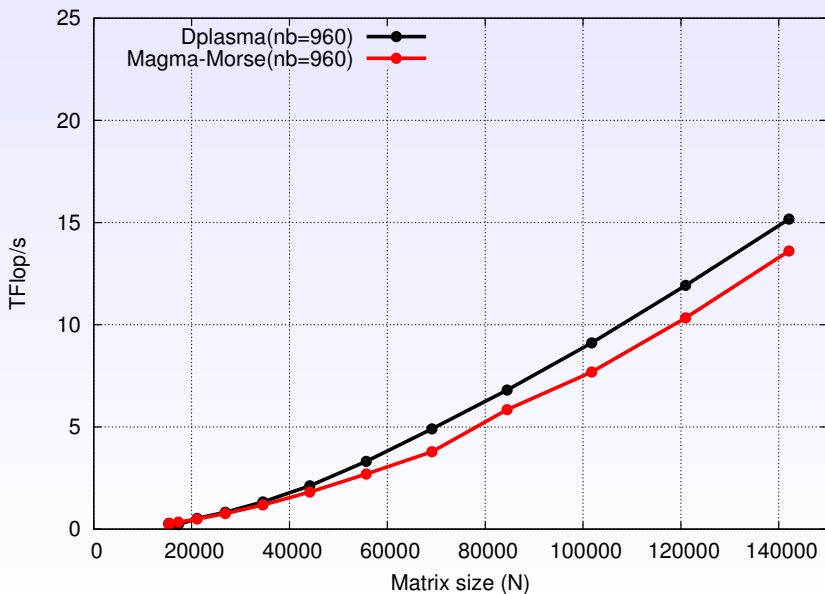
# 64 heterogeneous nodes (8 cores + 2 GPUs per node)



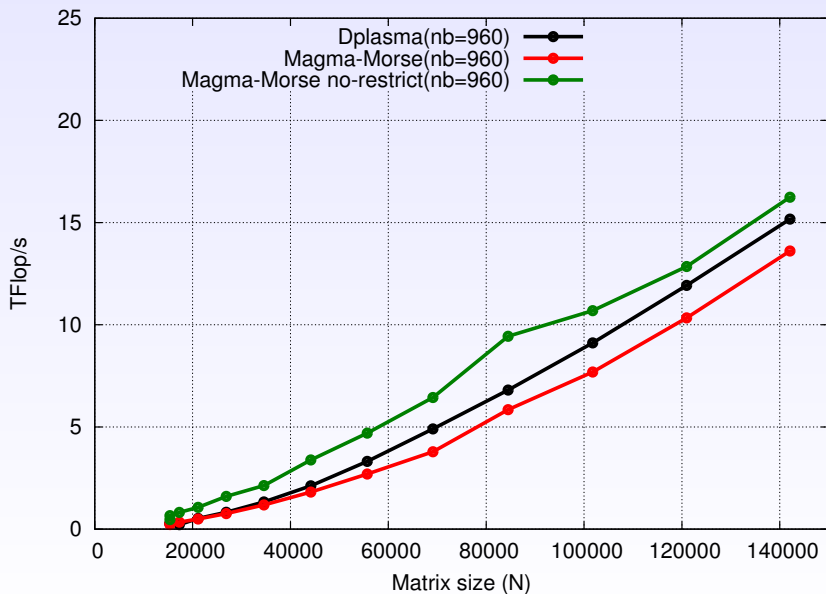
# 64 heterogeneous nodes (8 cores + 2 GPUs per node)



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



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





## Contribution

- Harnessing cluster of hybrid nodes
- Sequential task-based paradigm
- **Almost no code changes vs single node**
- **Competitive performance**

## Future work

- Extension to other LAPACK-like routines
- Release it into MAGMA library
- Dynamic inter-node load balancing

**Morse:** <http://icl.cs.utk.edu/morse/>

**StarPU:** <http://runtime.bordeaux.inria.fr/StarPU/>