

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

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MORSE Associated Team



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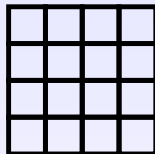


1. Introduction
2. Sequential task-based paradigm on a single node
3. Do we need a new programming paradigm for clusters?
4. Distributed Data Management
5. Comparison against state-of-the-art approaches
6. Conclusion and future work

- 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)

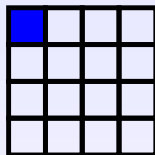
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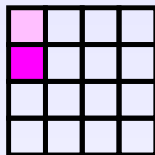
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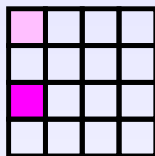
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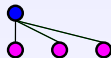
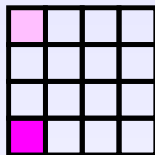
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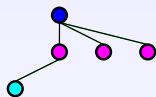
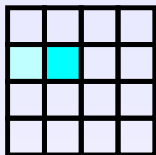
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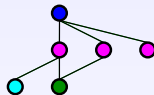
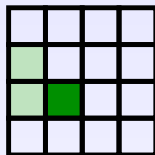
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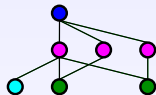
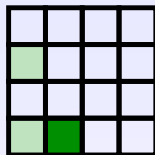
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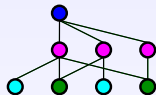
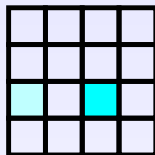
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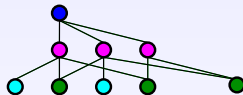
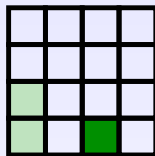
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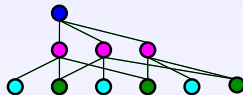
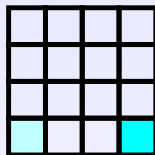
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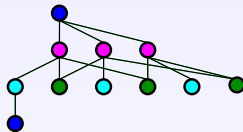
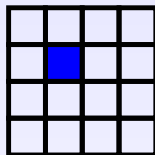
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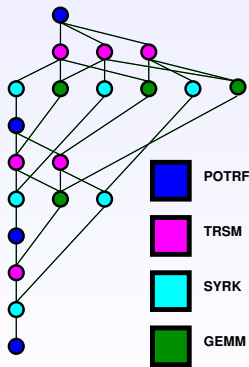
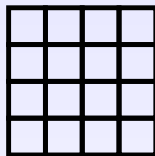
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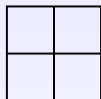
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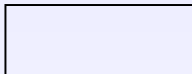
Runtime parallel execution on a heterogeneous node

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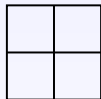
CPU



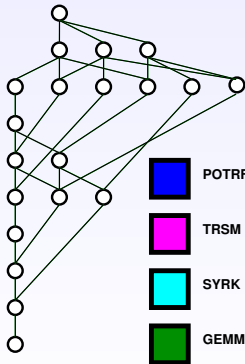
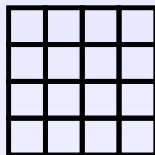
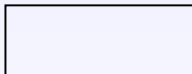
GPU0



CPU



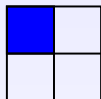
GPU1



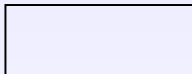
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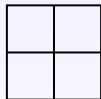
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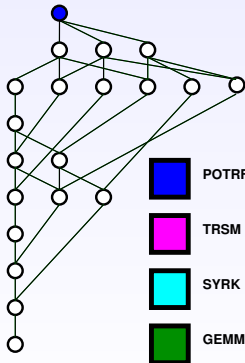
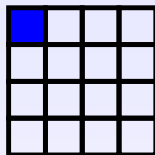
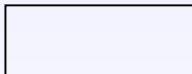
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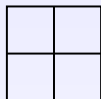
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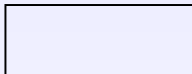
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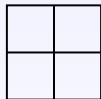
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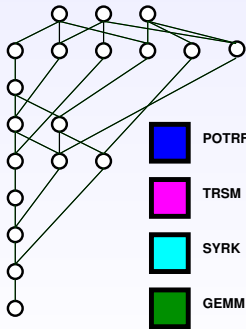
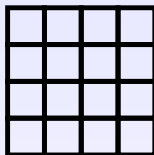
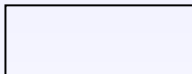
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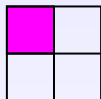
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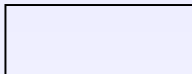
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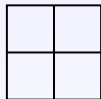
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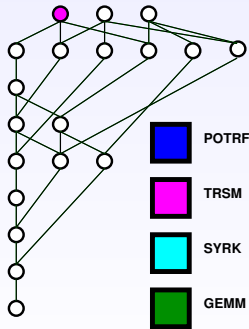
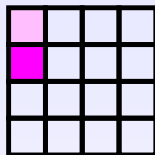
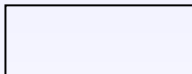
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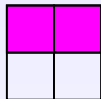
GPU1



Runtime parallel execution on a heterogeneous node

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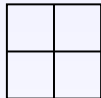
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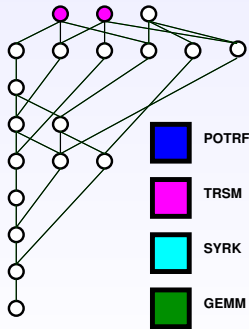
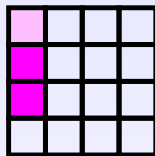
GPU0



CPU



GPU1



Runtime parallel execution on a heterogeneous node

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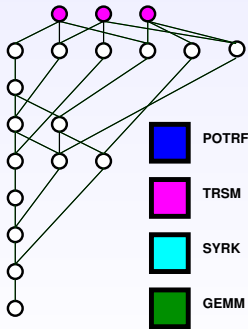
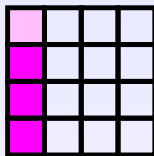
GPU0



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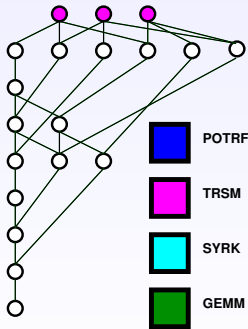
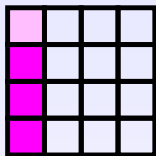
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GPU1



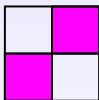
- Handles dependencies



Runtime parallel execution on a heterogeneous node

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GPU0



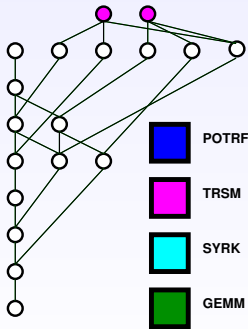
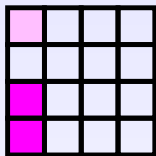
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GPU1



- Handles dependencies



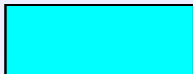
Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



GPU0



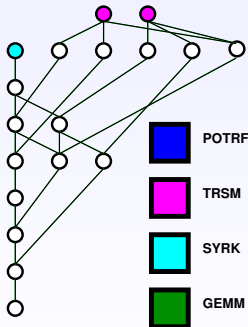
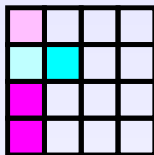
CPU



GPU1



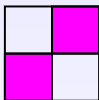
- Handles dependencies



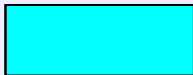
Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

CPU



GPU0



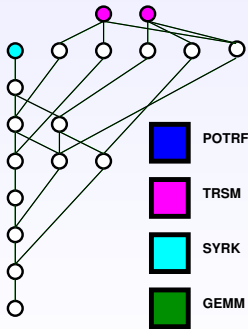
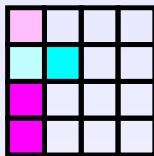
CPU



GPU1

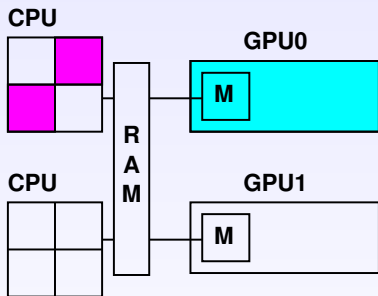


- Handles dependencies
- Handles scheduling (e.g. HEFT)

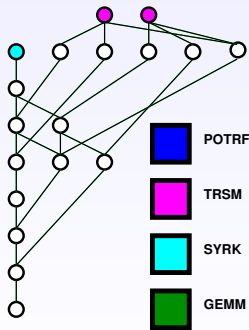
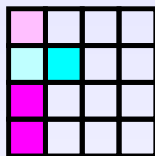


Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```

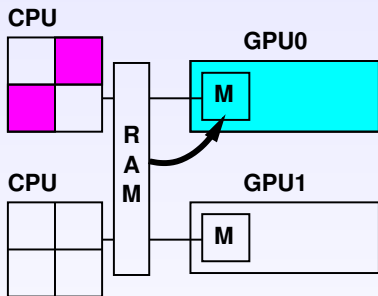


- Handles dependencies
- Handles scheduling (e.g. HEFT)

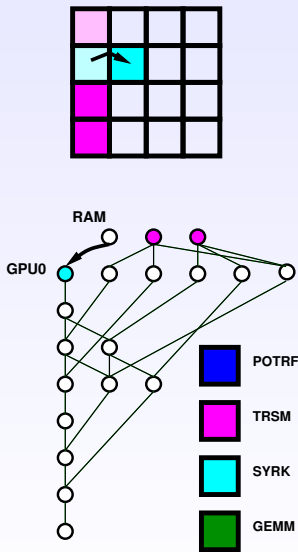


Runtime parallel execution on a heterogeneous node

```
task_wait_for_all();
```



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



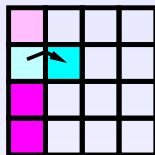
Sequential task-based paradigm for single node

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

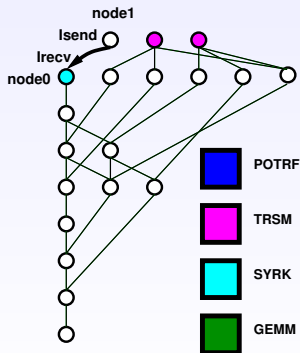
Sequential task-based paradigm for single node

- 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?

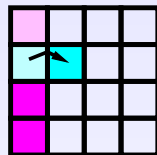
Do we need a new paradigm for clusters?



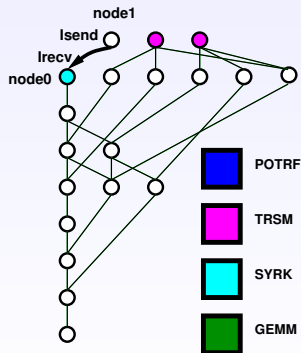
- How to express communications?



Do we need a new paradigm for clusters?

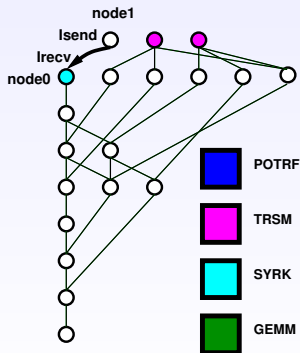
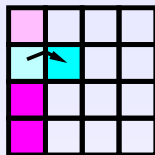


- How to express communications?
- How to establish the mapping?



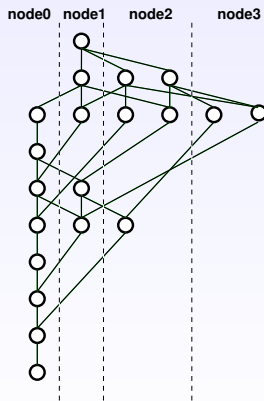
Do we need a new paradigm for clusters?

- 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



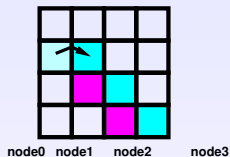
Data transfers between nodes

All nodes unroll the whole task graph

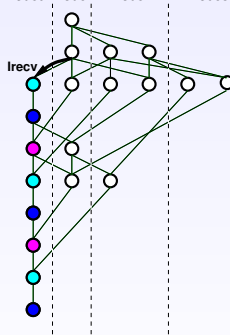
They determine tasks they will execute

They can infer required communications

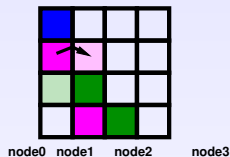
No synchronization between nodes



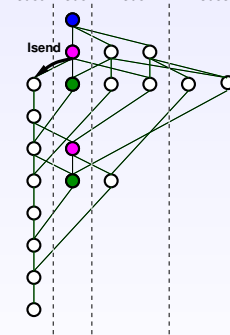
node0 node1 node2 node3



Node 0 execution



node0 node1 node2 node3



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)

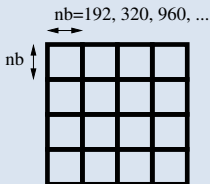
Almost same code

- MPI communicator
- Mapping function

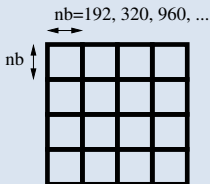
```
int getnode(int i, int j) { return((i%p)*q + j%q); }  
set_rank(A, getnode);
```

```
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();
```

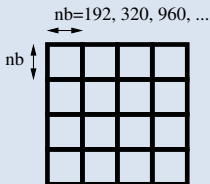
- Double-precision **Cholesky**
 - ▶ Scalapack
 - ▶ Dplasma/Parsec
 - ▶ **Magma-morse/StarPU**
- 64 nodes



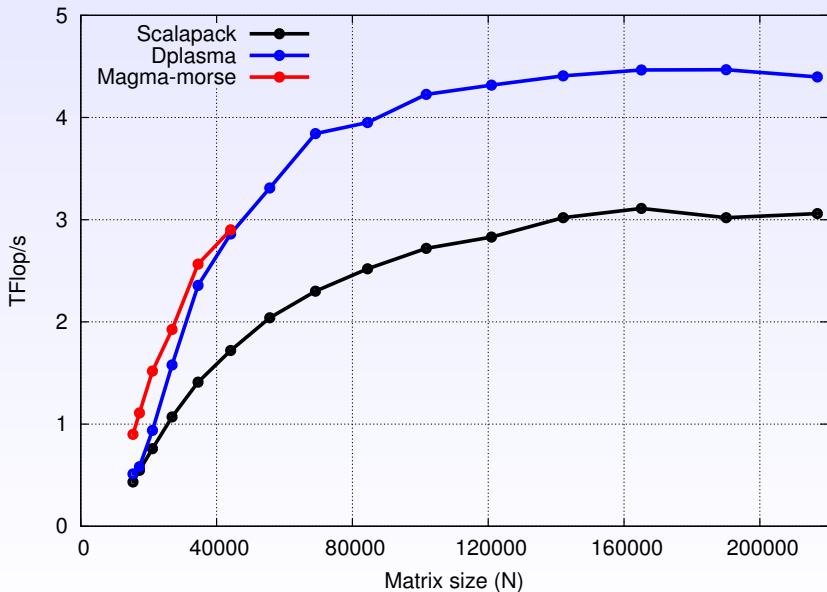
- Double-precision **Cholesky**
 - ▶ Scalapack
 - ▶ Dplasma/Parsec
 - ▶ **Magma-morse/StarPU**
- 64 nodes
 - ▶ 2 Intel Westmere @ 2.66 GHz (8 cores per node)
- Homogeneous tile size: 192x192



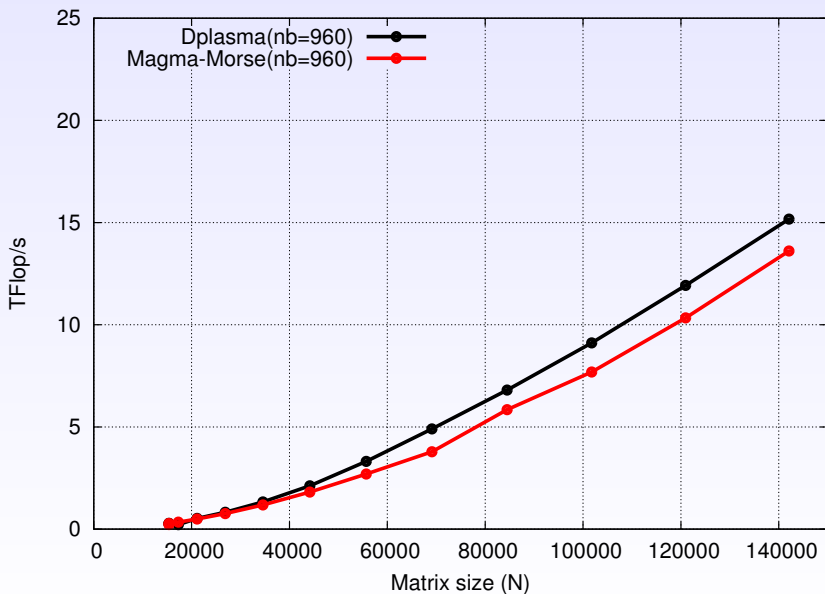
- Double-precision **Cholesky**
 - ▶ Scalapack
 - ▶ Dplasma/Parsec
 - ▶ **Magma-morse/StarPU**
- 64 nodes
 - ▶ 2 Intel Westmere @ 2.66 GHz (8 cores per node)
 - ▶ 2 Nvidia Tesla M2090 (2 GPUs per node)
- Homogeneous tile size: 192x192
- Heterogeneous tile sizes: 320x320 / 960x960



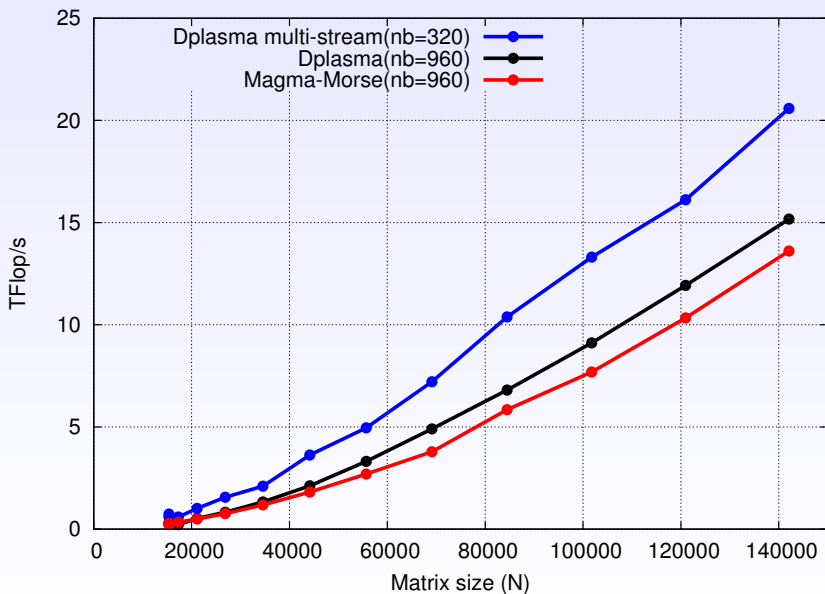
64 homogeneous nodes (8 cores per node)



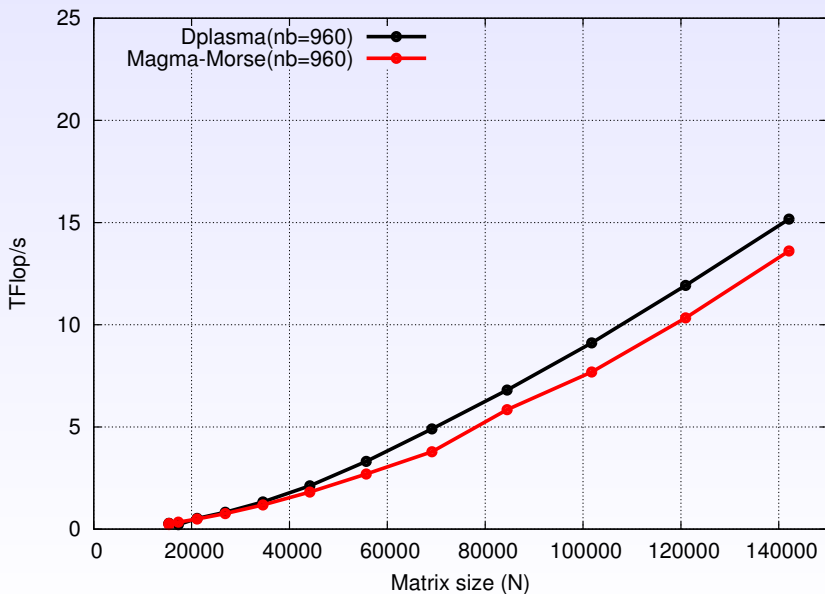
64 heterogeneous nodes (8 cores + 2 GPUs per node)



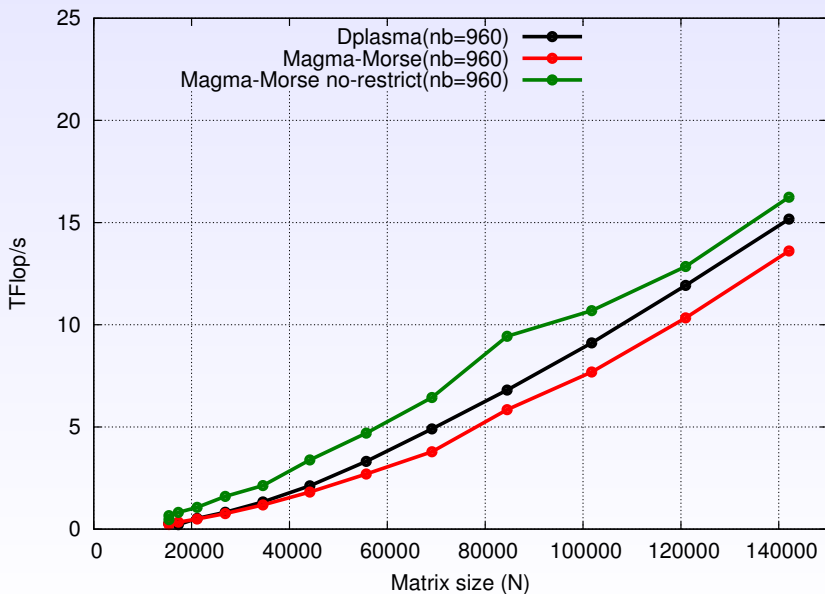
64 heterogeneous nodes (8 cores + 2 GPUs per node)



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/>