Exloiting multi-level parallelism on Intel KNL

Round Table KNL

Terry Cojean, STORM team

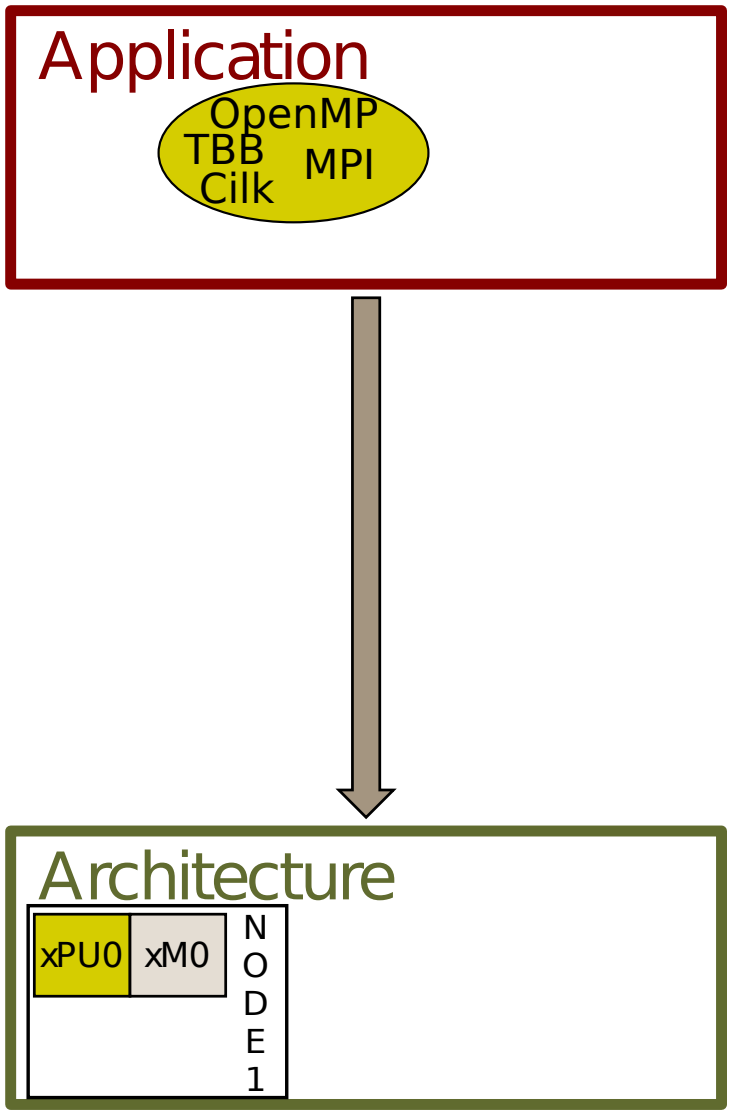
INRIA Bordeaux, LaBRI, Université de Bordeaux

INRIA Bordeaux

March 28^{th}, 2017

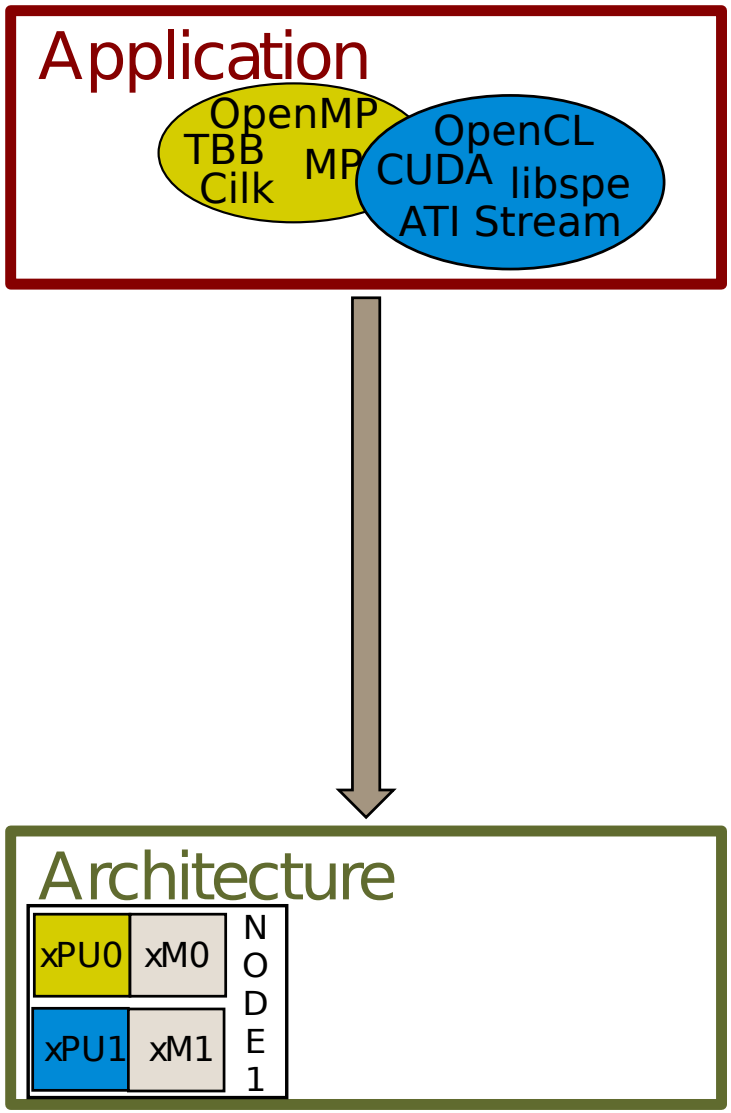
Outline

Application programming



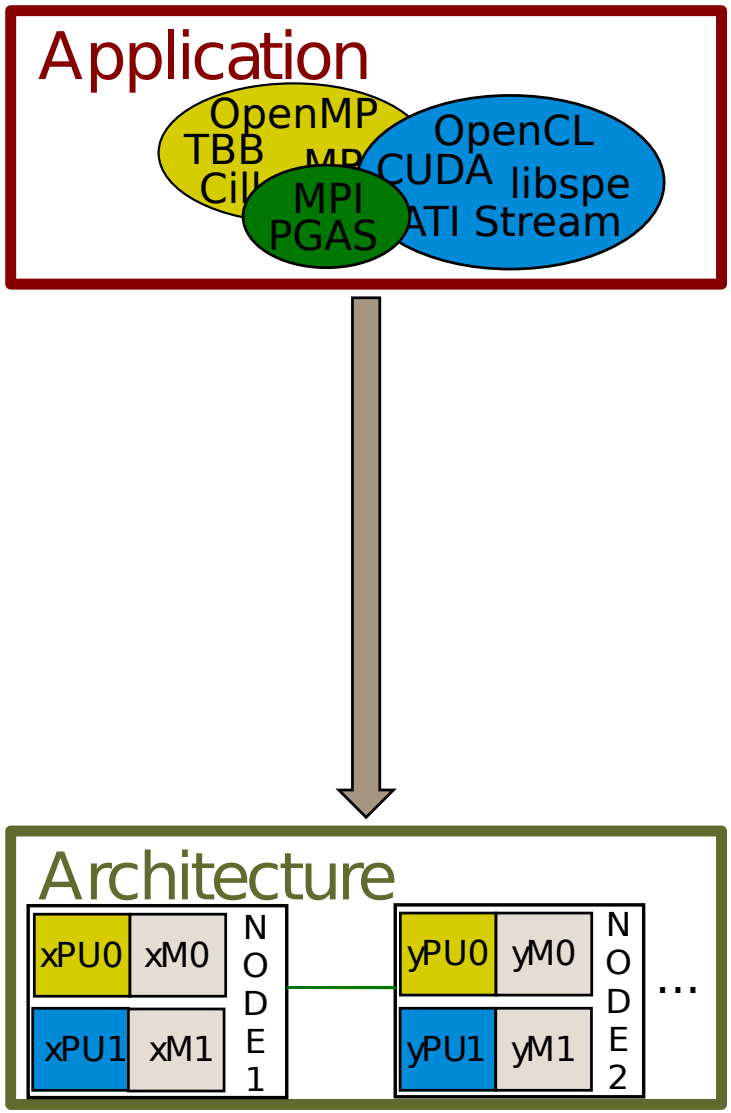
- The classical approach is based on a mixture of technologies (e.g., OpenMP)

Application programming



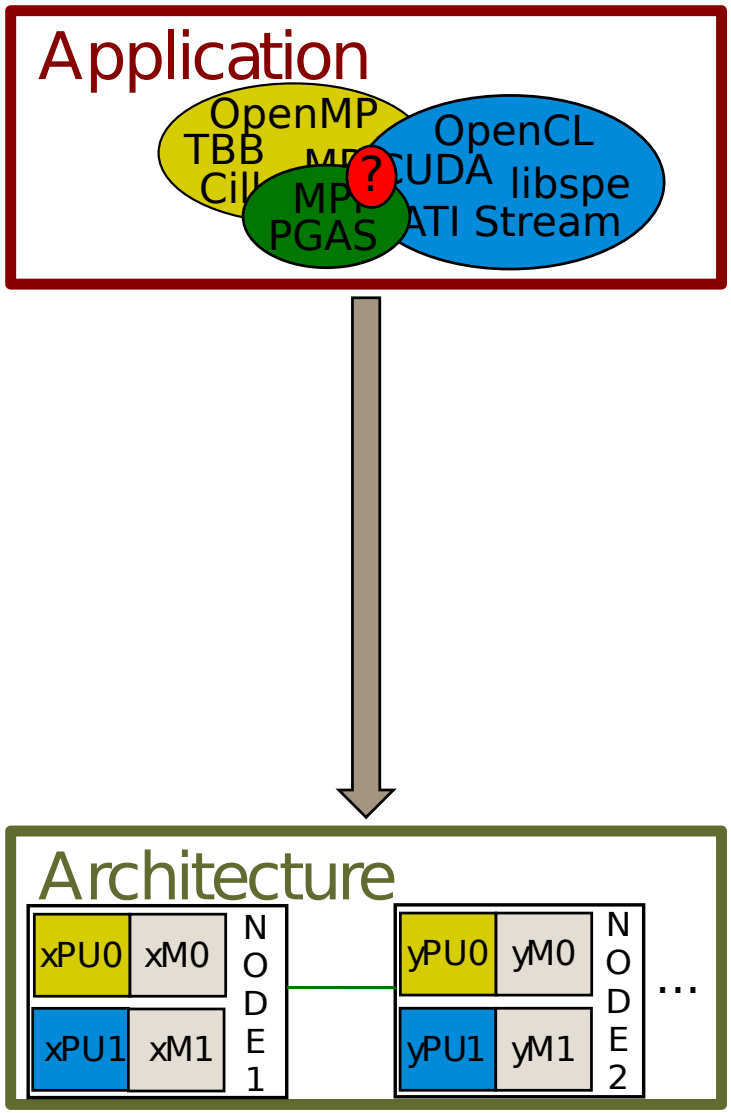
- The classical approach is based on a mixture of technologies (e.g., OpenMP+CUDA)

Application programming



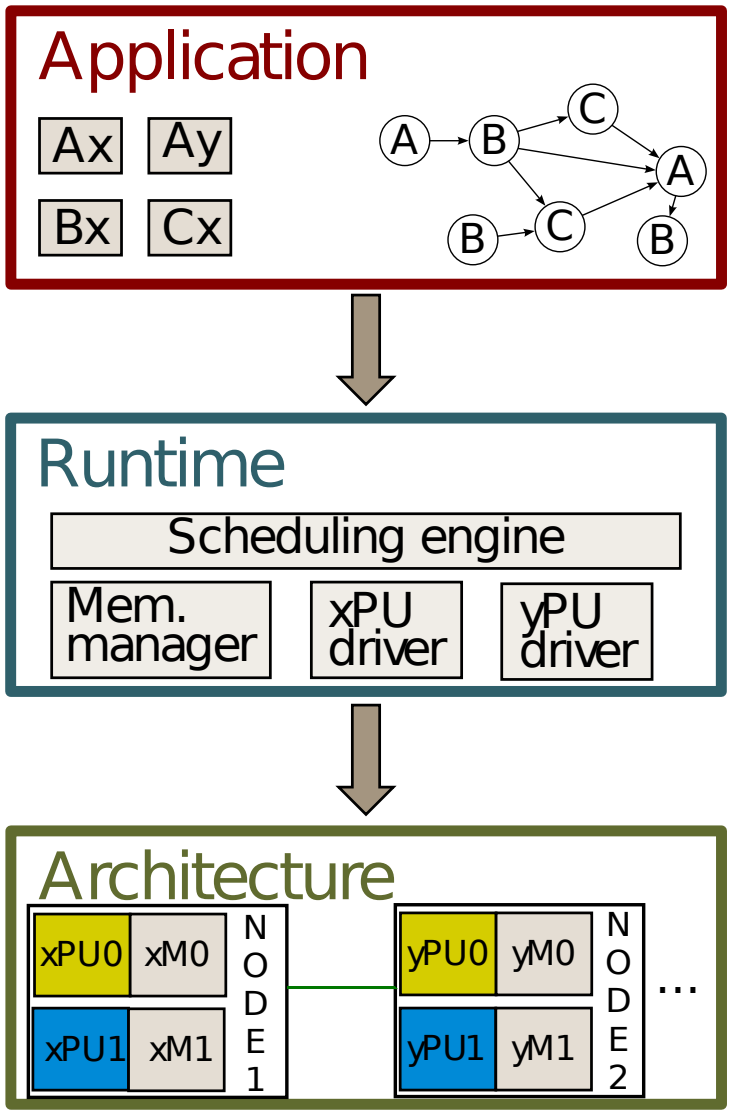
- The classical approach is based on a mixture of technologies (e.g., OpenMP+CUDA+MPI)

Application programming



- The classical approach is based on a mixture of technologies (e.g., OpenMP+CUDA+MPI)
  - requires a big programming effort.
  - is prone to (performance) portability issues.

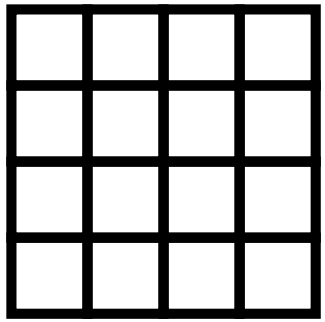
Application programming

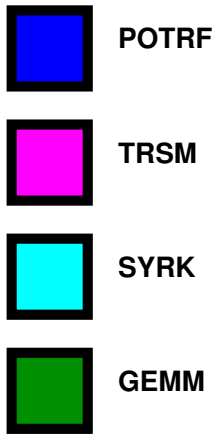


- The classical approach is based on a mixture of technologies (e.g., OpenMP+CUDA+MPI)
  - requires a big programming effort.
  - is prone to (performance) portability issues.
- runtimes provide an abstraction layer that hides the architecture details.
- the workload is expressed as a DAG (Directed Acyclic Graph) of tasks scheduled by the runtime.

Sequential Task Flow (STF) Cholesky algorithm submission

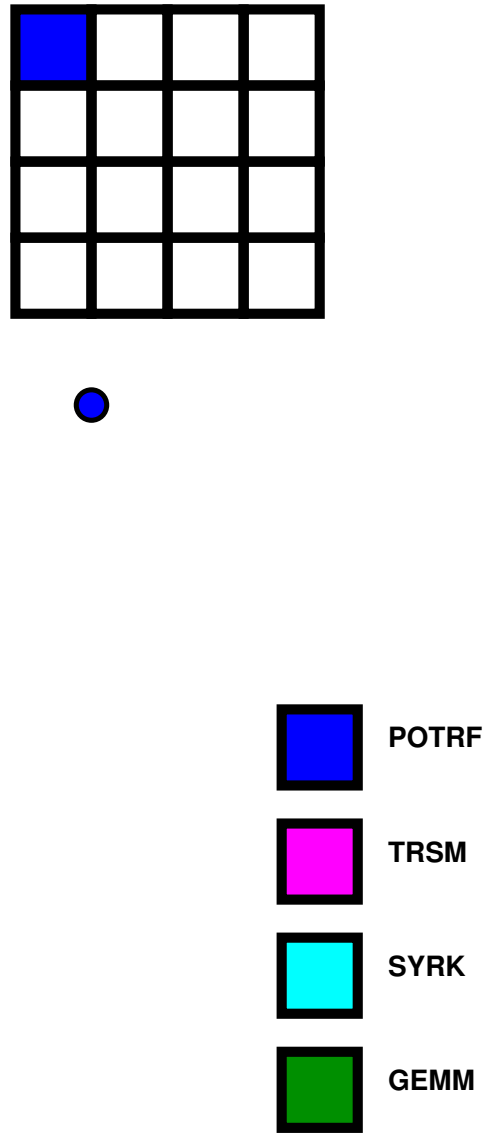
```
for (j = 0; j < N; j++) {
  submit(POTRF, A[j][j]:RW);
  for (i = j+1; i < N; i++)
    submit(TRSM, A[i][j]:RW, A[j][j]:R);
  for (i = j+1; i < N; i++) {
    submit(SYRK, A[i][i]:RW, A[i][j]:R);
    for (k = j+1; k < i; k++)
          submit(GEMM, A[i][k]:RW,
                       A[i][j]:R, A[k][j]:R);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





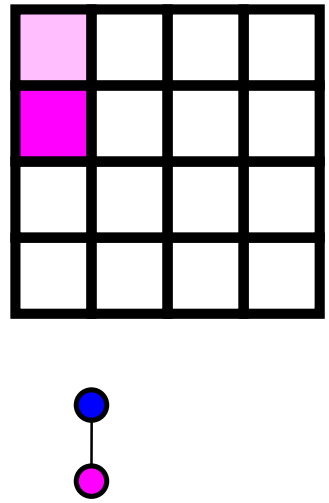
Sequential Task Flow (STF) Cholesky algorithm submission

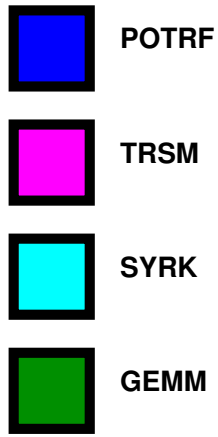
```
for (j = 0; j < N; j++) {
  submit(POTRF, A[j][j]:RW);
  for (i = j+1; i < N; i++)
    submit(TRSM, A[i][j]:RW, A[j][j]:R);
  for (i = j+1; i < N; i++) {
    submit(SYRK, A[i][i]:RW, A[i][j]:R);
    for (k = j+1; k < i; k++)
          submit(GEMM, A[i][k]:RW,
                       A[i][j]:R, A[k][j]:R);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



Sequential Task Flow (STF) Cholesky algorithm submission

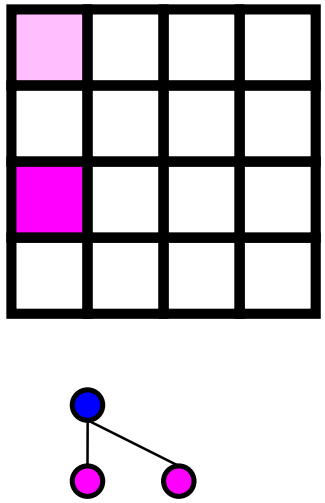
```
for (j = 0; j < N; j++) {
  submit(POTRF, A[j][j]:RW);
  for (i = j+1; i < N; i++)
    submit(TRSM, A[i][j]:RW, A[j][j]:R);
  for (i = j+1; i < N; i++) {
    submit(SYRK, A[i][i]:RW, A[i][j]:R);
    for (k = j+1; k < i; k++)
          submit(GEMM, A[i][k]:RW,
                       A[i][j]:R, A[k][j]:R);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





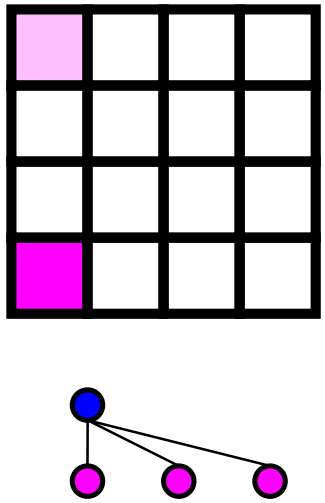
Sequential Task Flow (STF) Cholesky algorithm submission

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



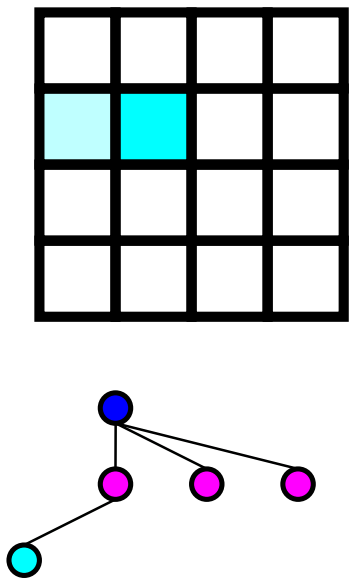
Sequential Task Flow (STF) Cholesky algorithm submission

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



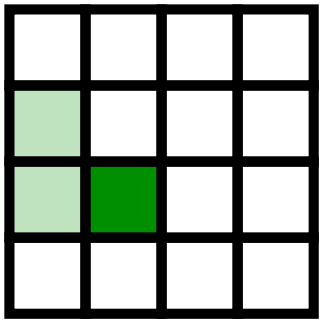
Sequential Task Flow (STF) Cholesky algorithm submission

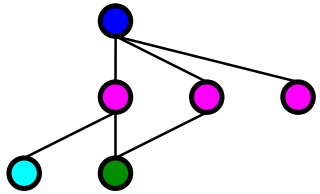
```
for (j = 0; j < N; j++) {
  submit(POTRF, A[j][j]:RW);
  for (i = j+1; i < N; i++)
    submit(TRSM, A[i][j]:RW, A[j][j]:R);
  for (i = j+1; i < N; i++) {
    submit(SYRK, A[i][i]:RW, A[i][j]:R);
    for (k = j+1; k < i; k++)
          submit(GEMM, A[i][k]:RW,
                       A[i][j]:R, A[k][j]:R);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

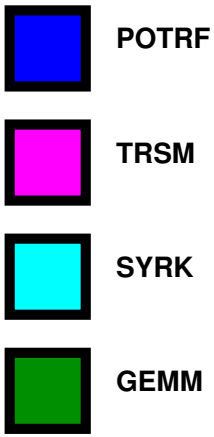


Sequential Task Flow (STF) Cholesky algorithm submission

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

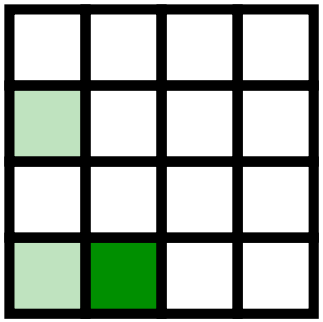


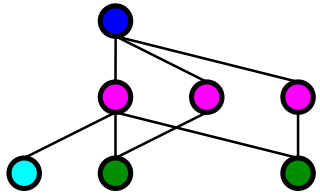


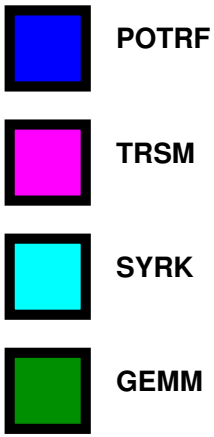


Sequential Task Flow (STF) Cholesky algorithm submission

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

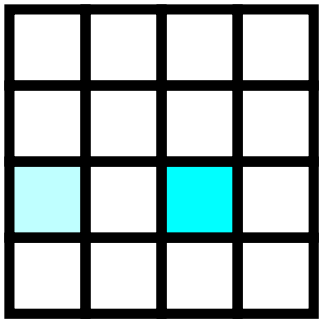


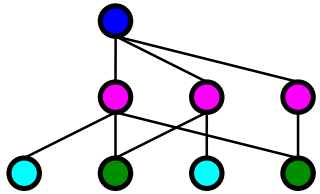


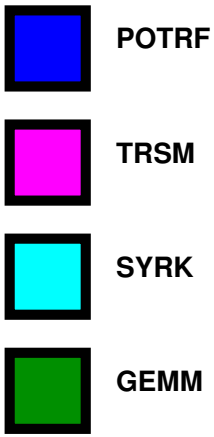


Sequential Task Flow (STF) Cholesky algorithm submission

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

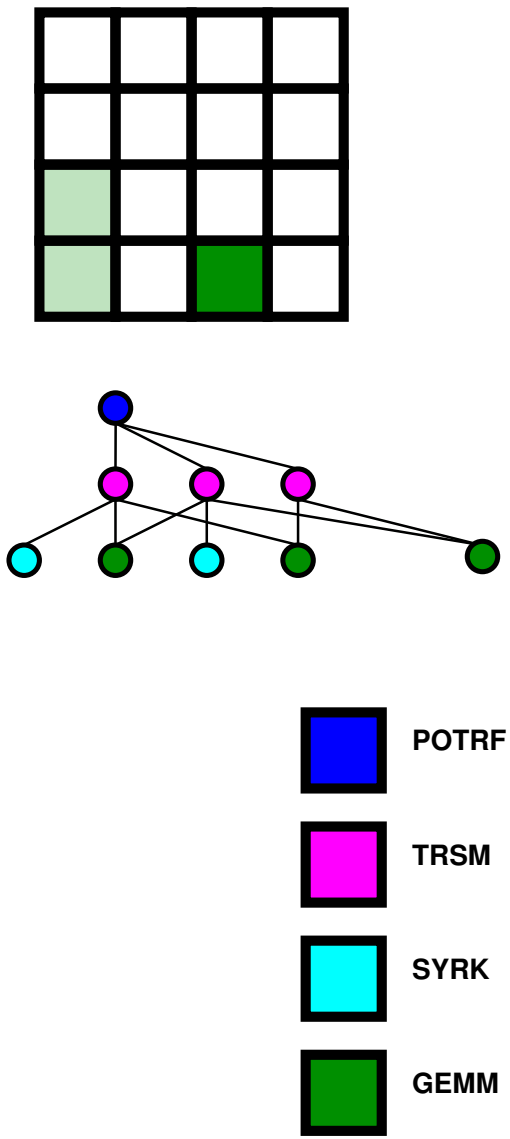






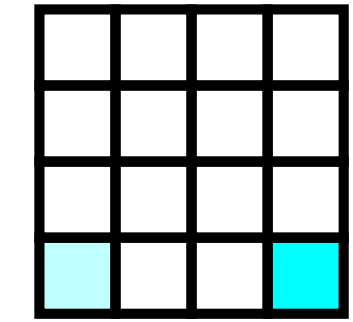
Sequential Task Flow (STF) Cholesky algorithm submission

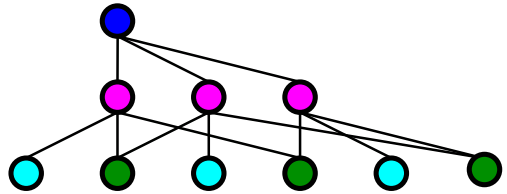
```
for (j = 0; j < N; j++) {
  submit(POTRF, A[j][j]:RW);
  for (i = j+1; i < N; i++)
    submit(TRSM, A[i][j]:RW, A[j][j]:R);
  for (i = j+1; i < N; i++) {
    submit(SYRK, A[i][i]:RW, A[i][j]:R);
    for (k = j+1; k < i; k++)
          submit(GEMM, A[i][k]:RW,
                       A[i][j]:R, A[k][j]:R);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

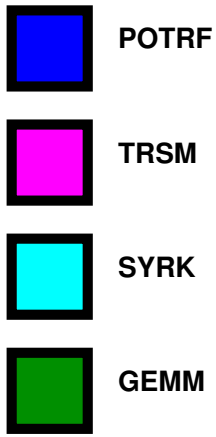


Sequential Task Flow (STF) Cholesky algorithm submission

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

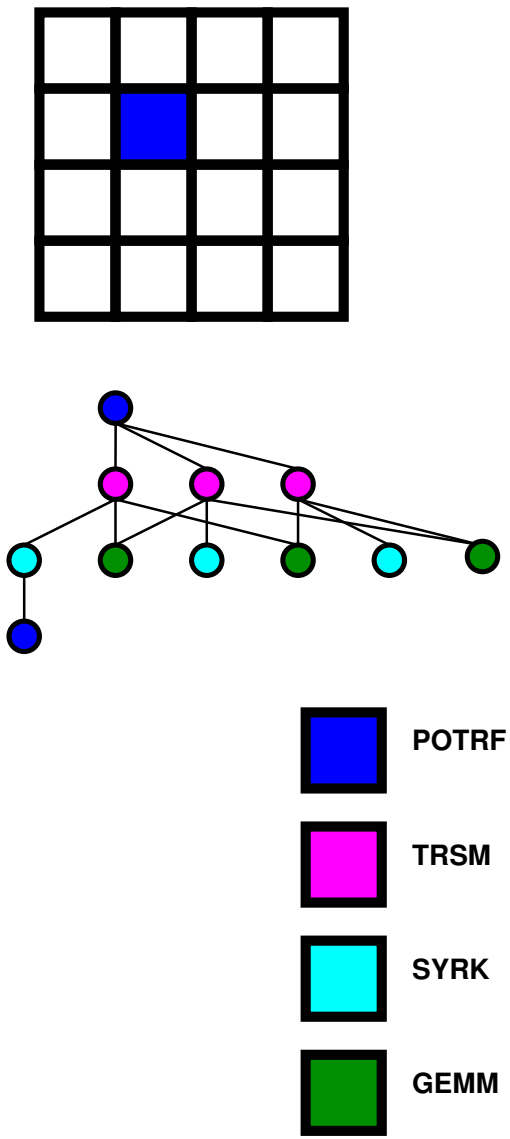






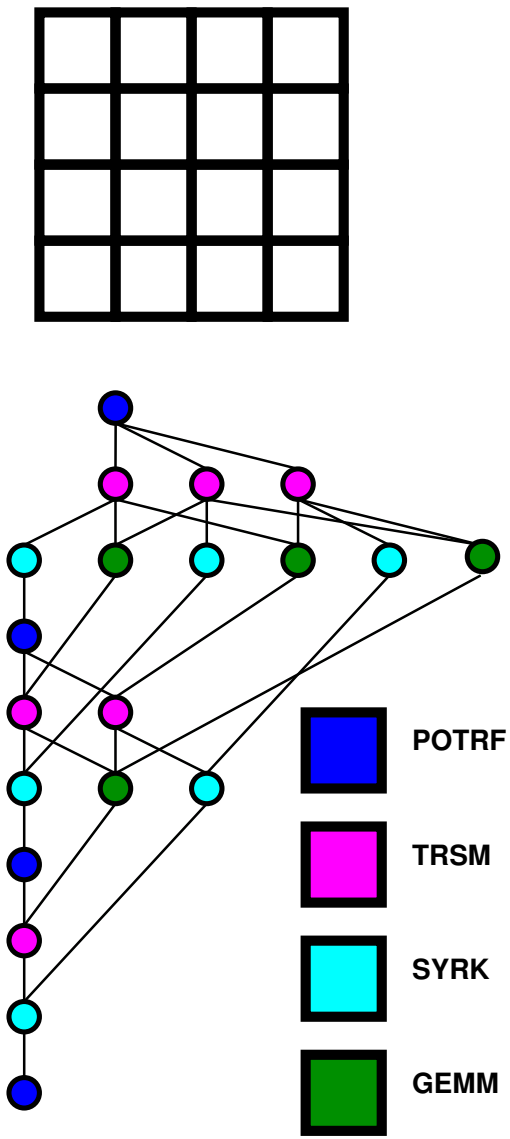
Sequential Task Flow (STF) Cholesky algorithm submission

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

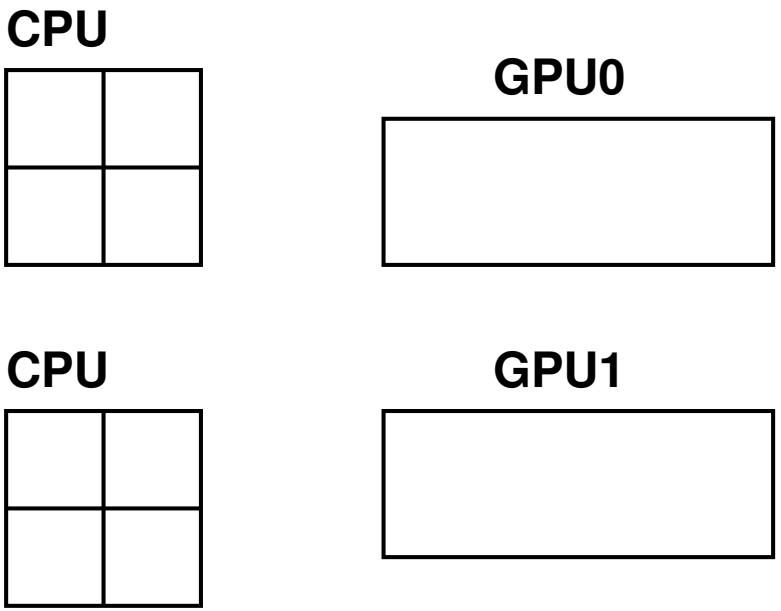


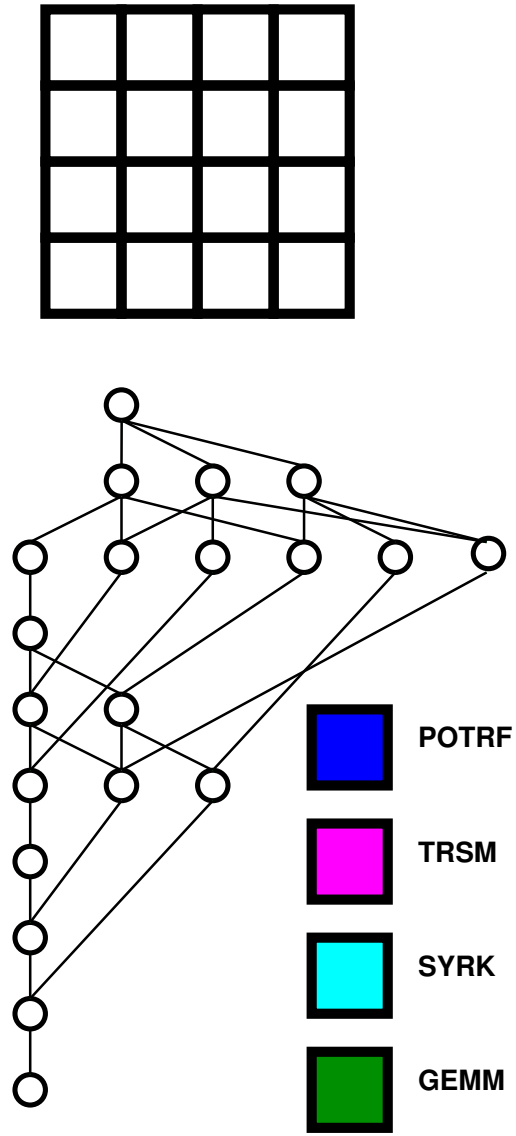
Sequential Task Flow (STF) Cholesky algorithm submission

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

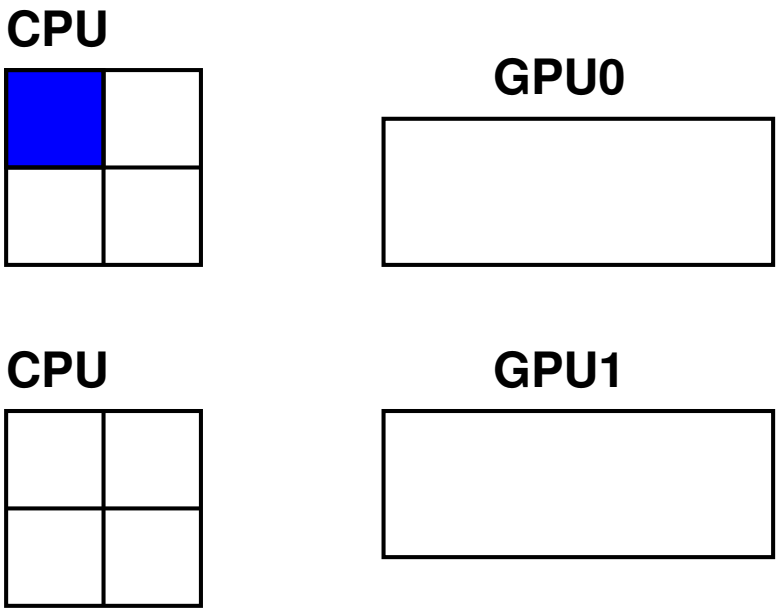


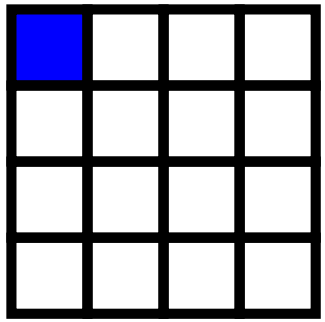
Tasks execution on a heterogeneous node

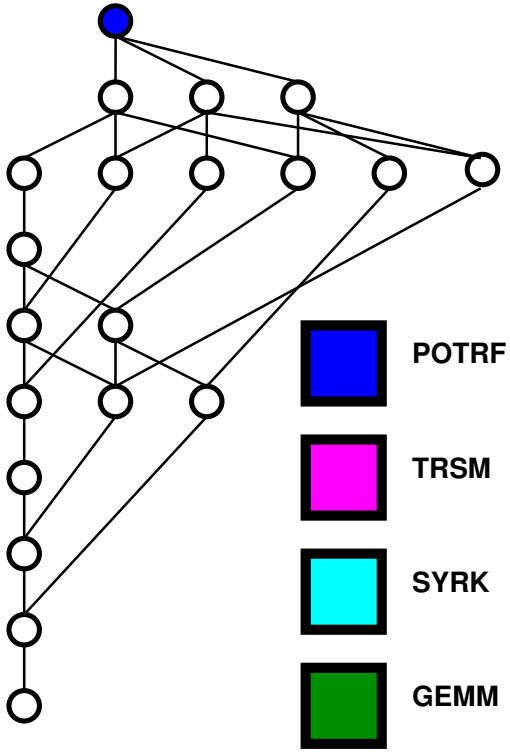




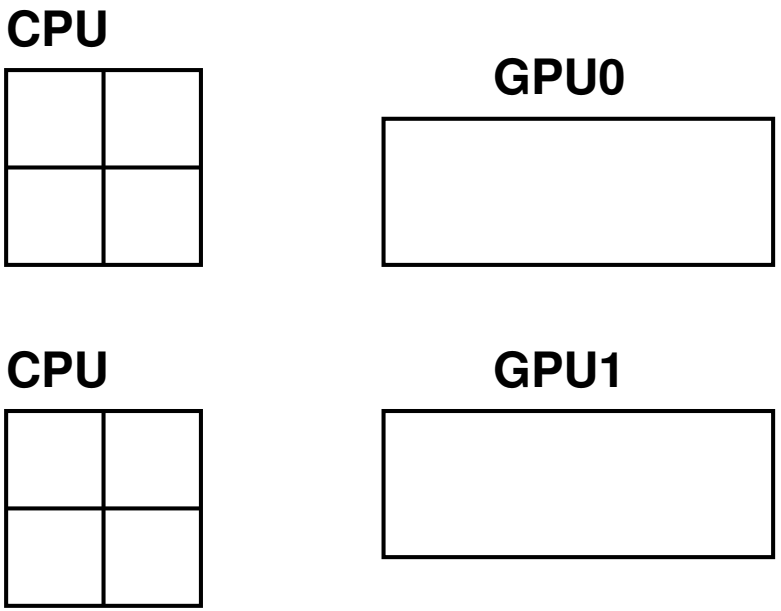
Tasks execution on a heterogeneous node

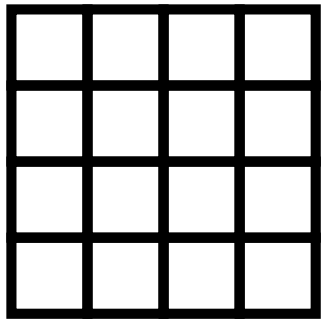


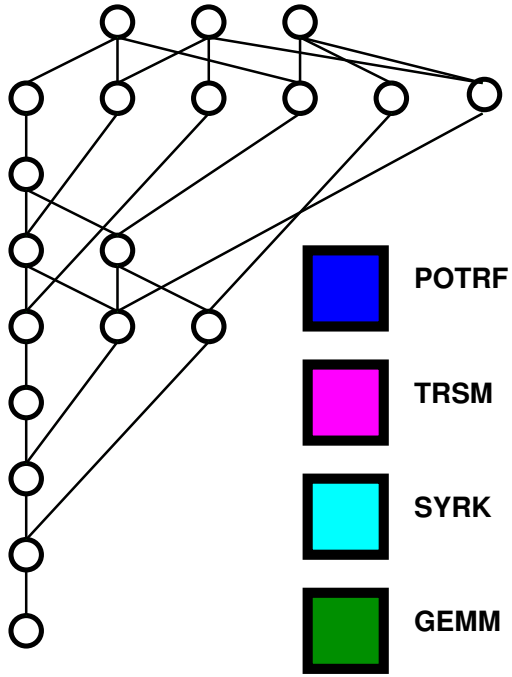




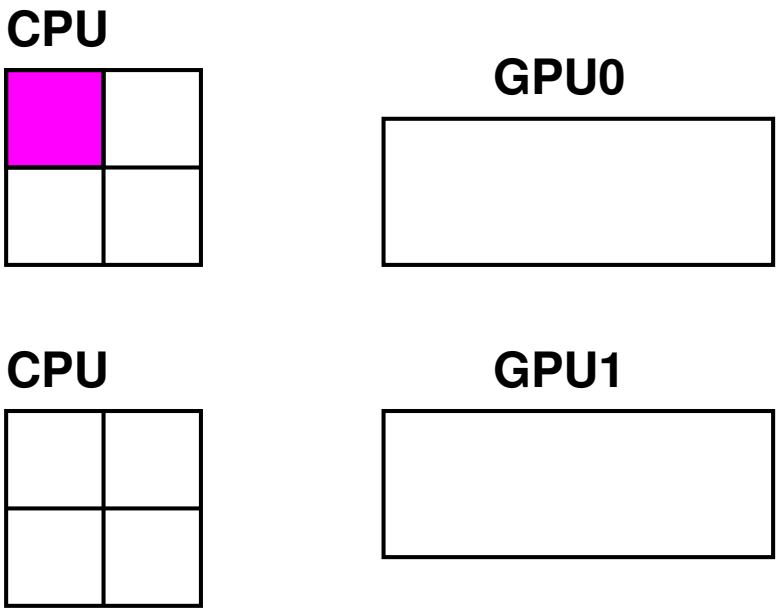
Tasks execution on a heterogeneous node

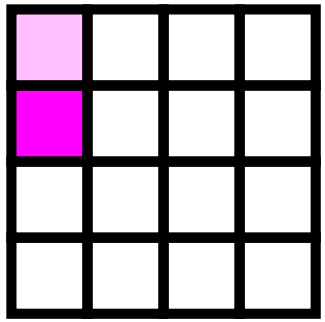


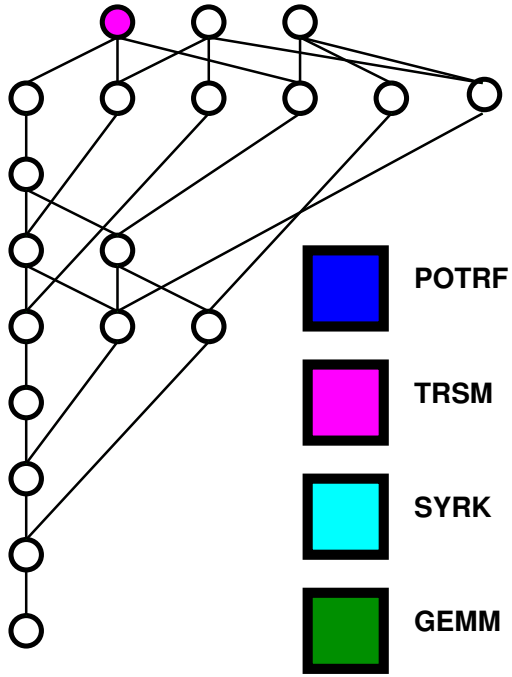




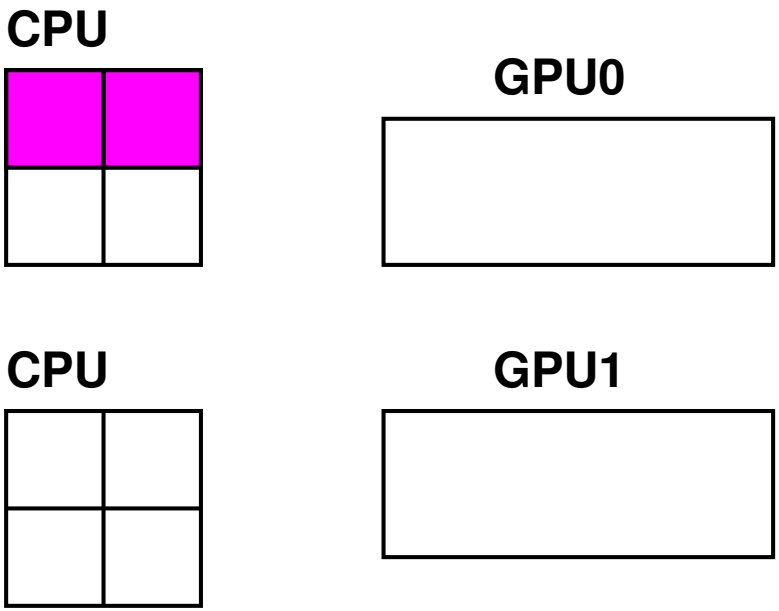
Tasks execution on a heterogeneous node

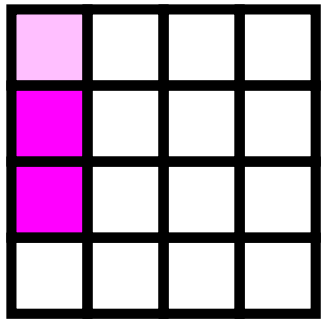


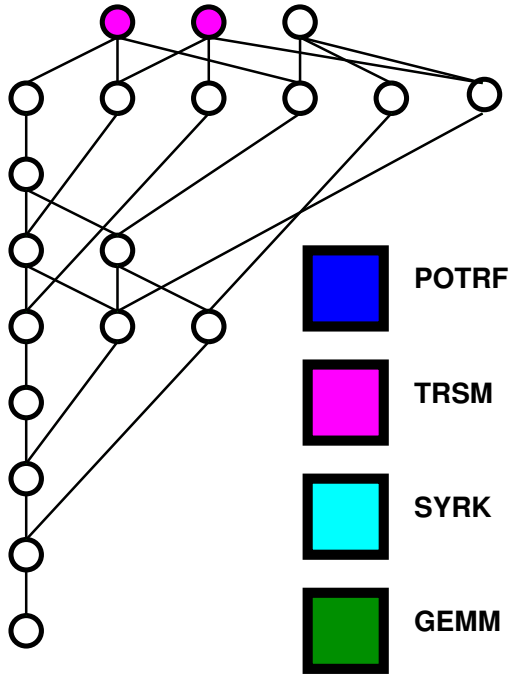




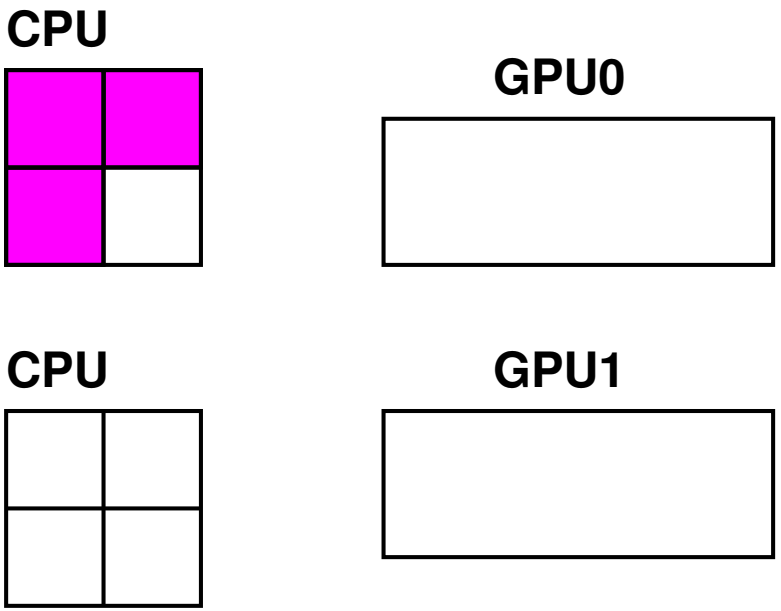
Tasks execution on a heterogeneous node

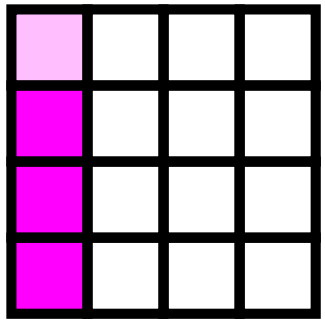


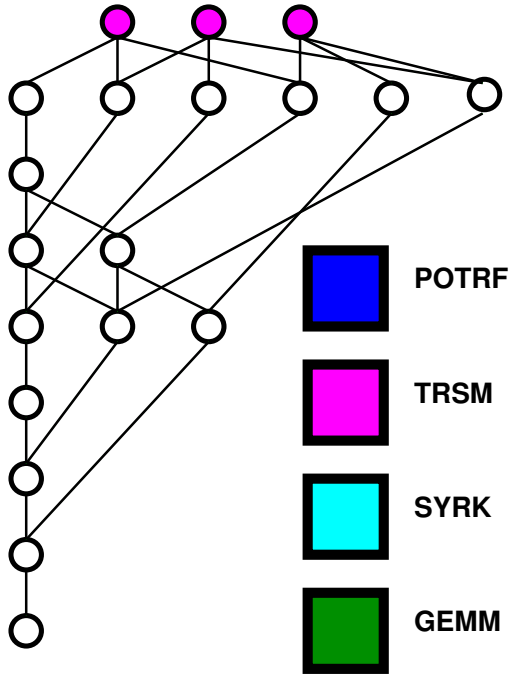




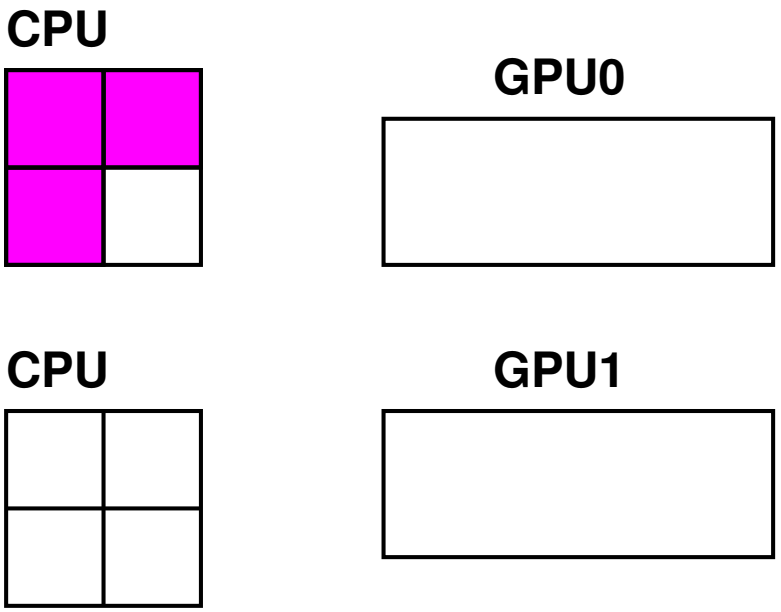
Tasks execution on a heterogeneous node

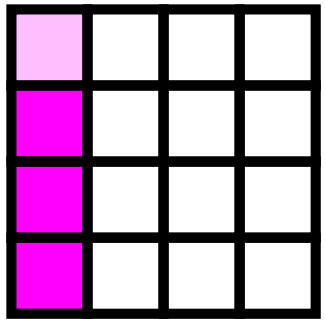


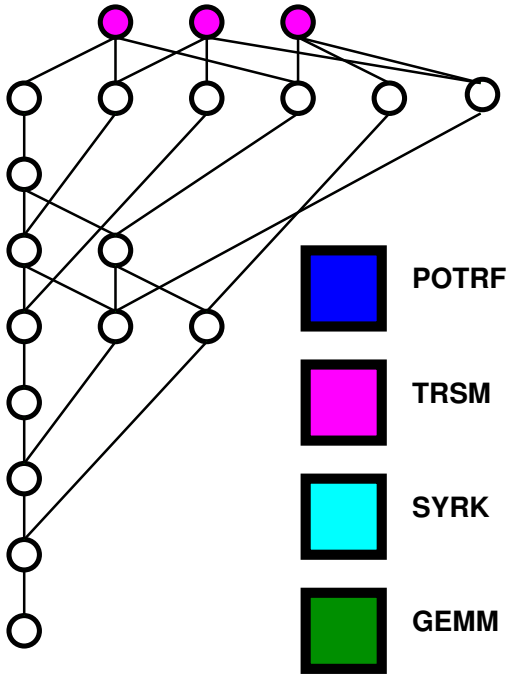




Tasks execution on a heterogeneous node

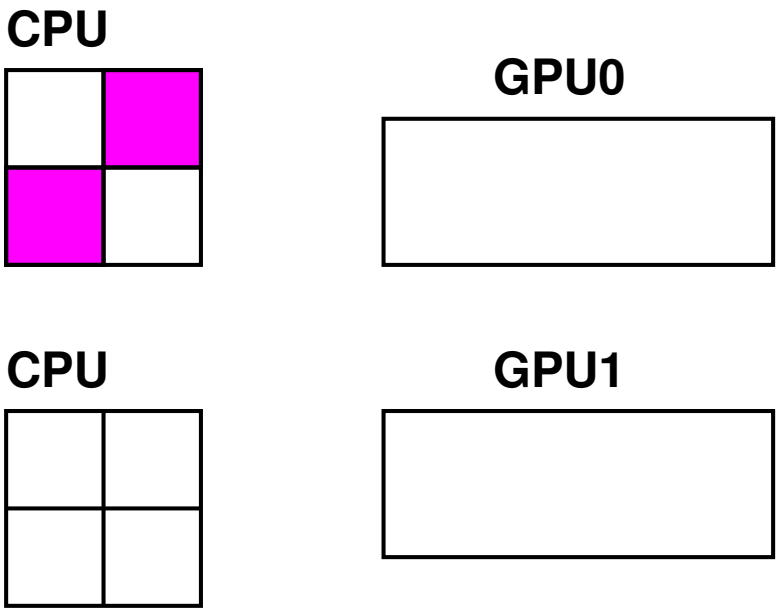


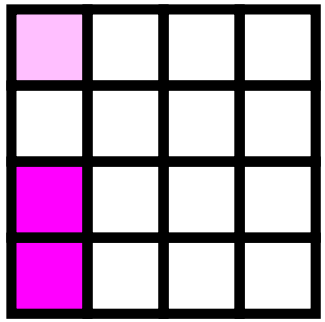


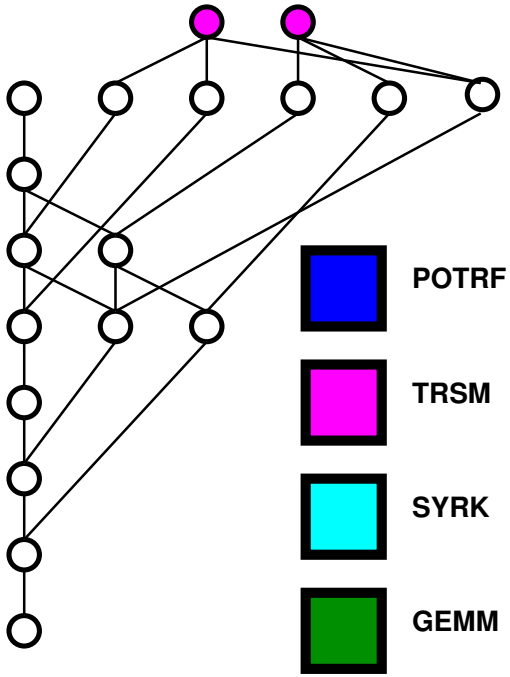


- Handles dependencies

Tasks execution on a heterogeneous node

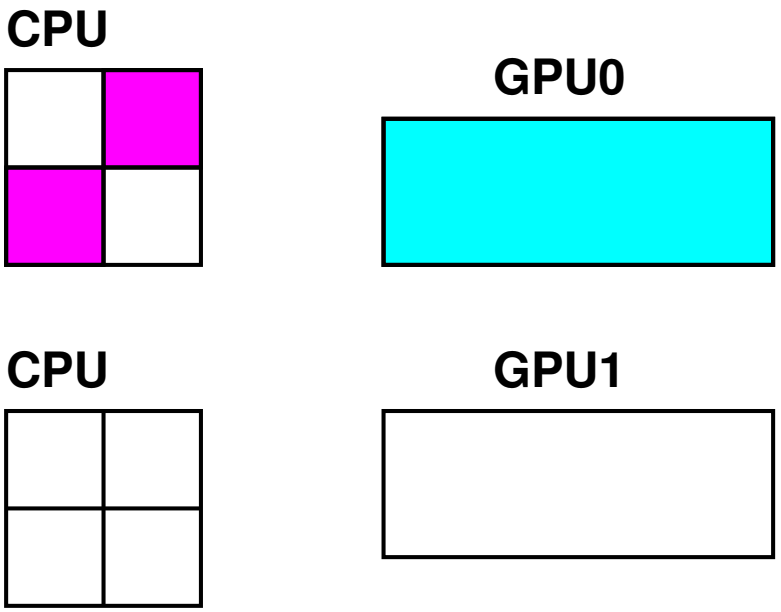


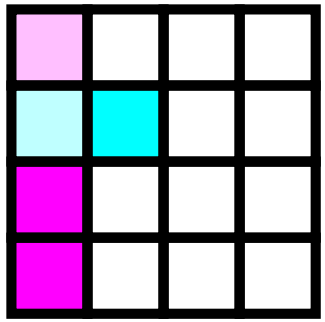


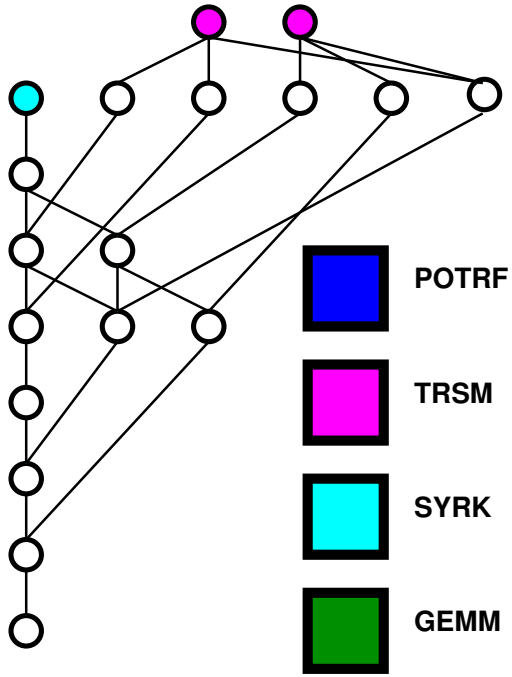


- Handles dependencies

Tasks execution on a heterogeneous node

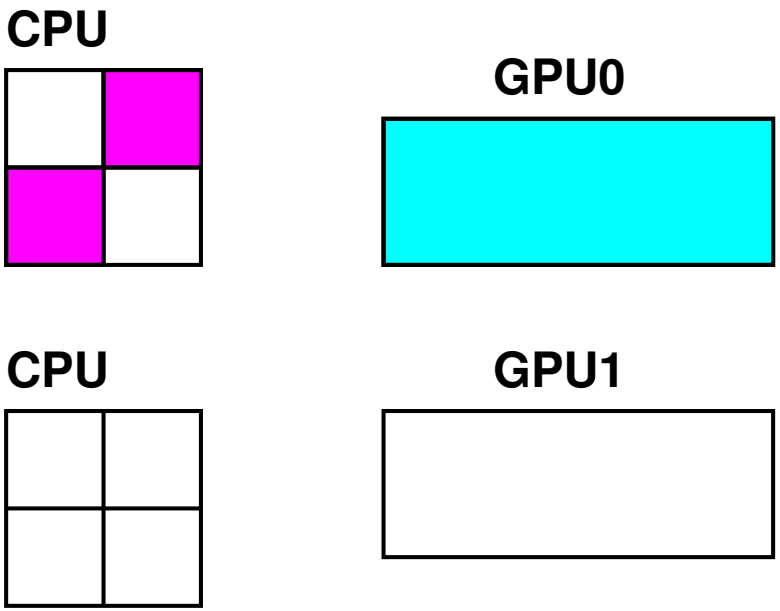


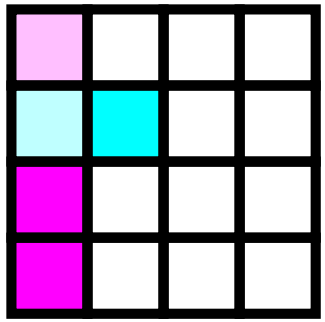


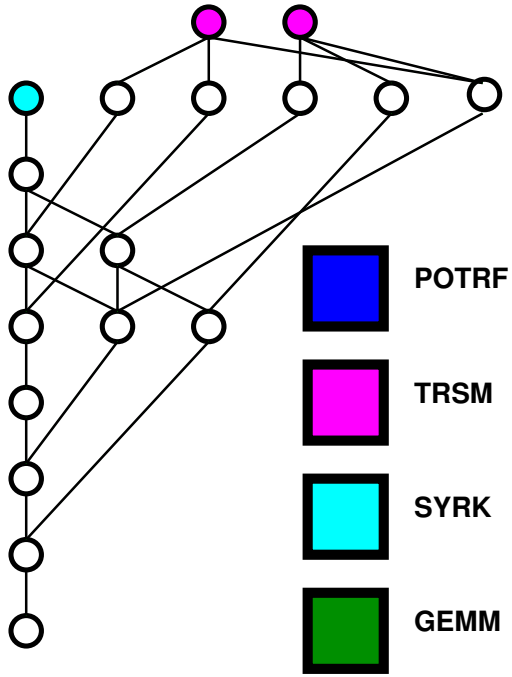


- Handles dependencies

Tasks execution on a heterogeneous node

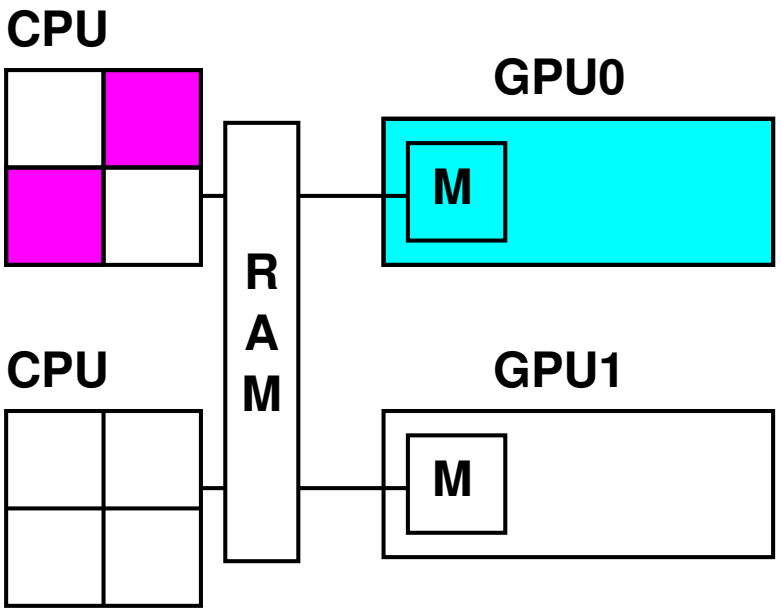


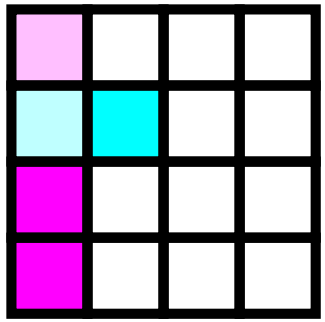




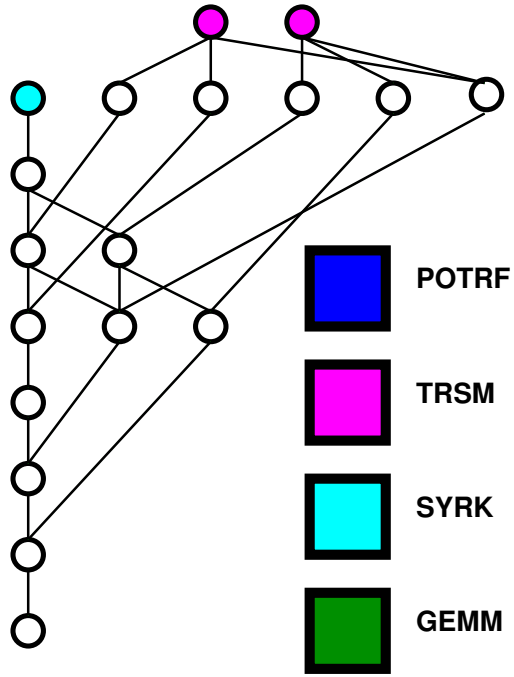
- Handles dependencies
- Handles scheduling: depends on user chosen scheduler

Tasks execution on a heterogeneous node

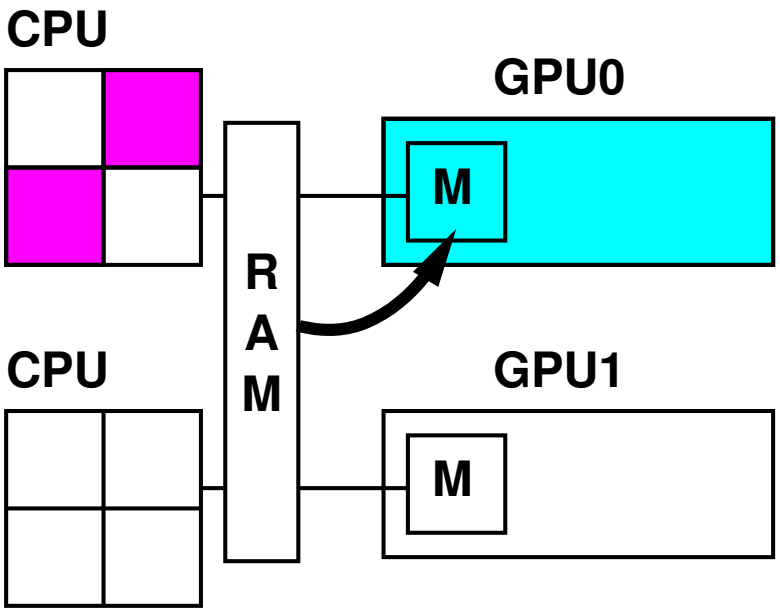


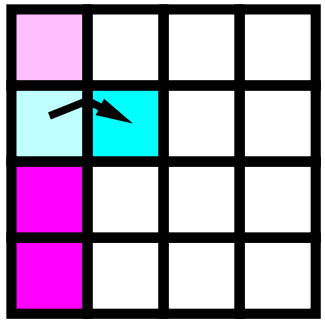


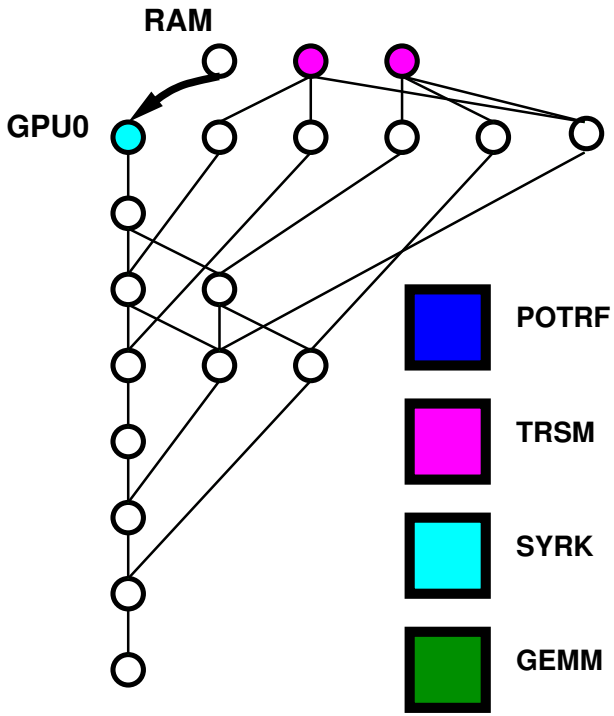
- Handles dependencies
- Handles scheduling: depends on user chosen scheduler



Tasks execution on a heterogeneous node

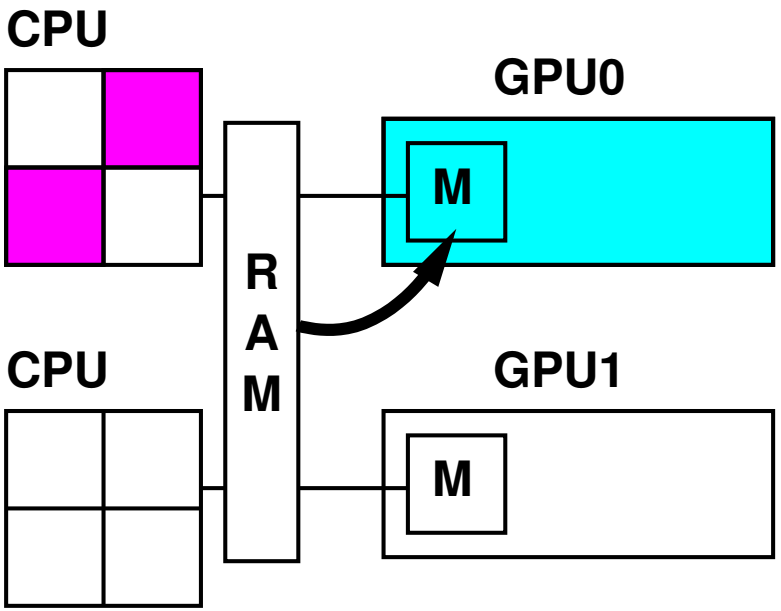


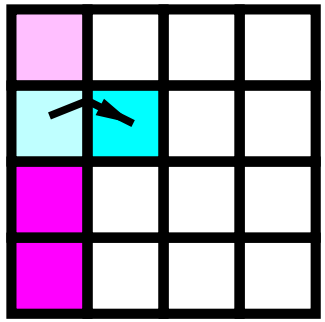


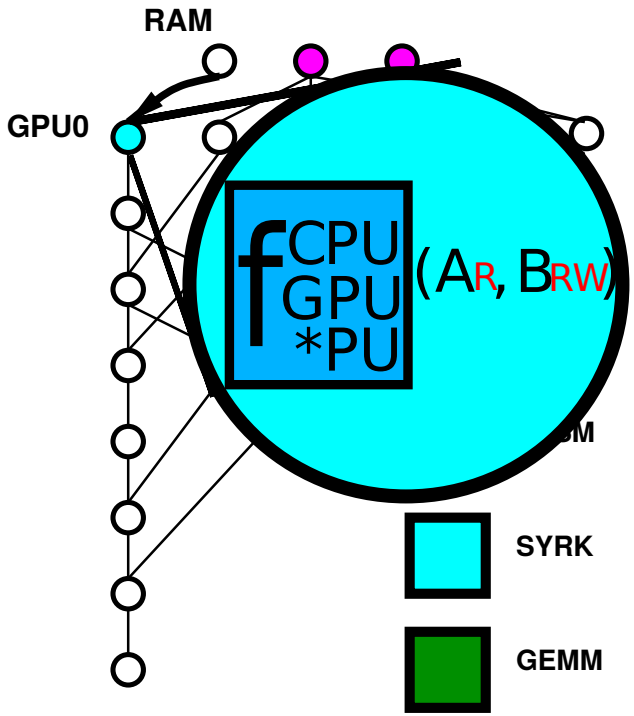


- Handles dependencies
- Handles scheduling: depends on user chosen scheduler
- Handles data consistency

Tasks execution on a heterogeneous node



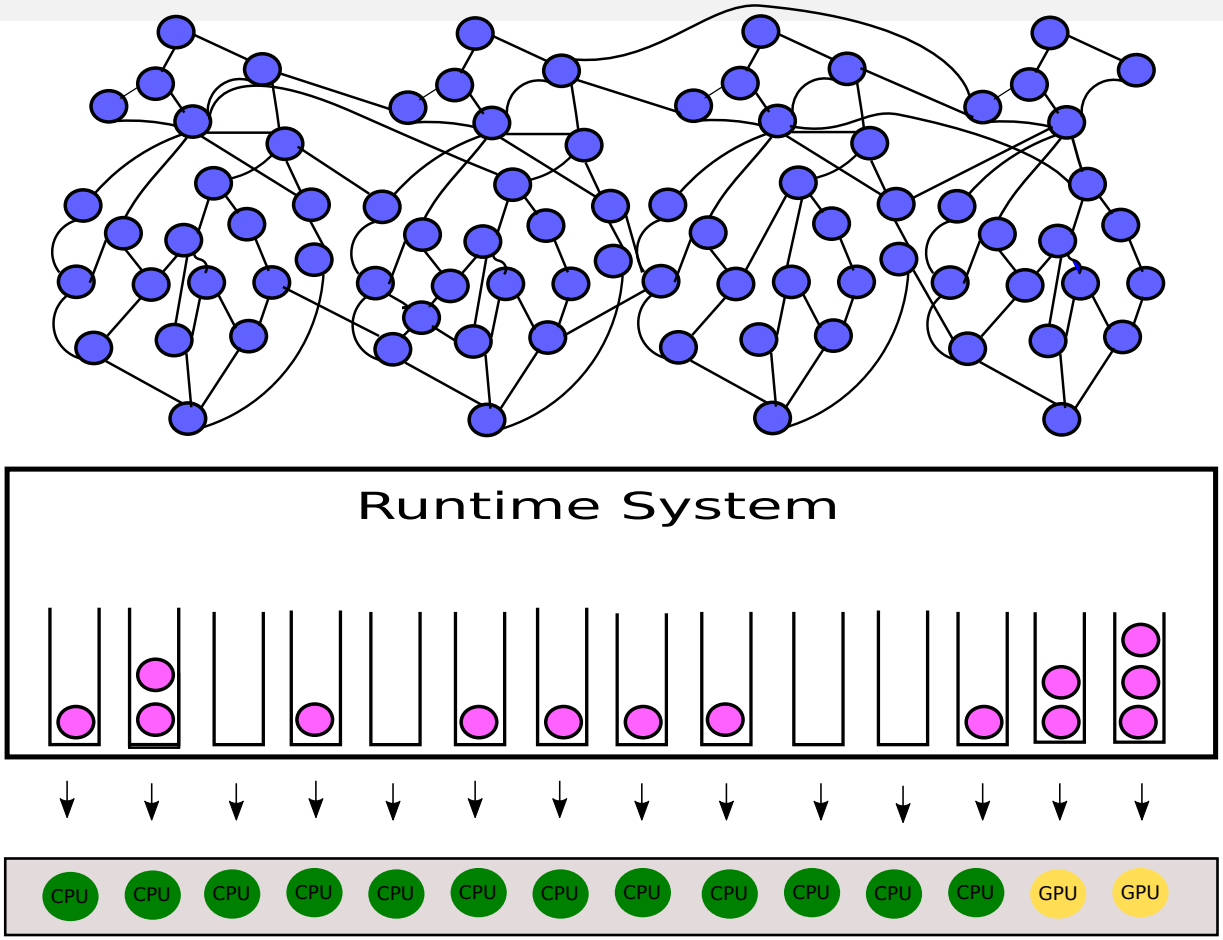




- Handles dependencies
- Handles scheduling: depends on user chosen scheduler
- Handles data consistency
- But what is a task precisely?

Outline

Overly simplistic global view of the StarPU Model

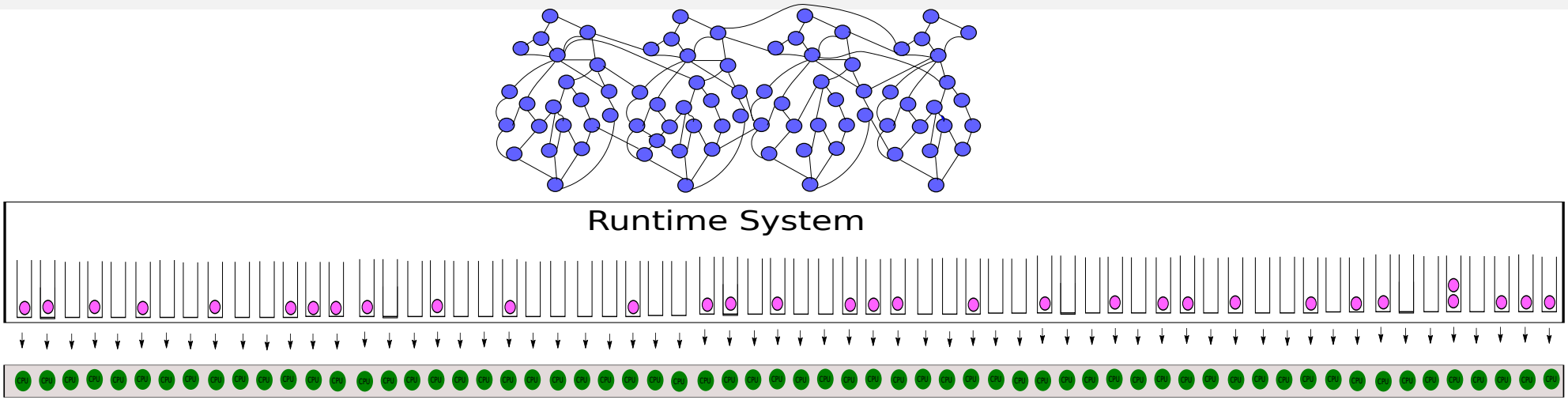


- Tasks are pushed to the runtime
- Tasks are spread on resources according to the scheduler (e.g. HEFT, WS policies)
- Workers (CPU cores/GPU/...) execute their tasks

The KNL


Machine (112GB total)
Package P#0
NUMANode P#0 (24GB)
NUMANode P#1 (24GB)
NUMANode P#3 (24GB)
NUMANode P#2 (24GB)
NUMANode P#4 (4096MB)
NUMANode P#5 (4096MB)
NUMANode P#6 (4096MB)
NUMANode P#7 (4096MB)
PCI 8086:1521
eno2i0
PCI 8086:1521
eno2i1
PCI 1a03:2000
card0
controlD64
PCI 8086:0953
PCI 8086:8d02
sda
Host: knl
Indexes: physical
Date: mer. 14 sept. 2016 13:09:33 CEST

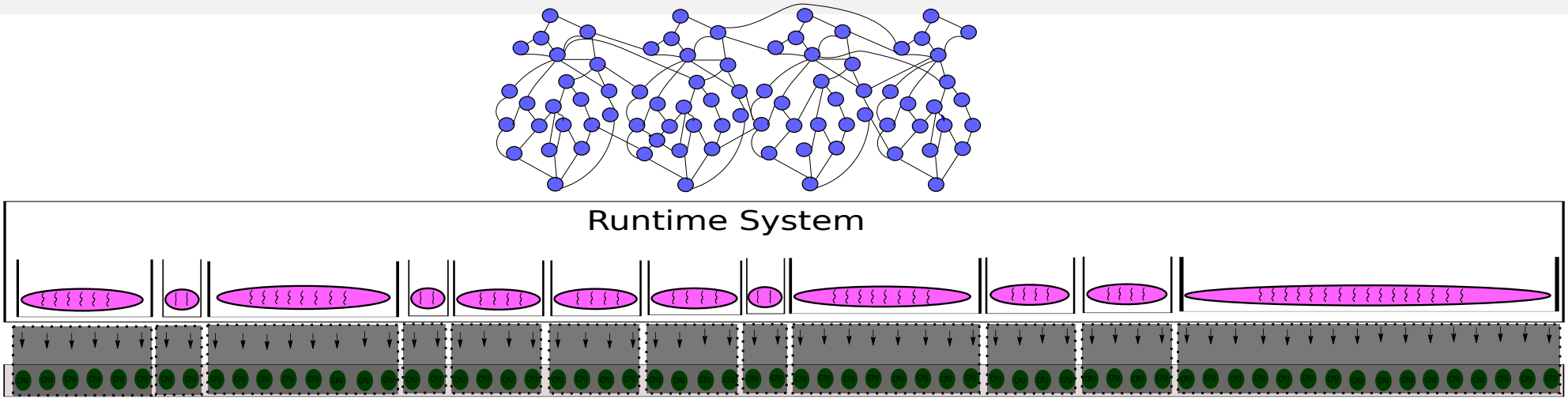
Slight changes to the model for efficient KNL usage



- Huge amount of cores
- Is scheduling independently on 64 cores pertinent ?
- We might be fine now but what about a KNL like machine with even more cores ?

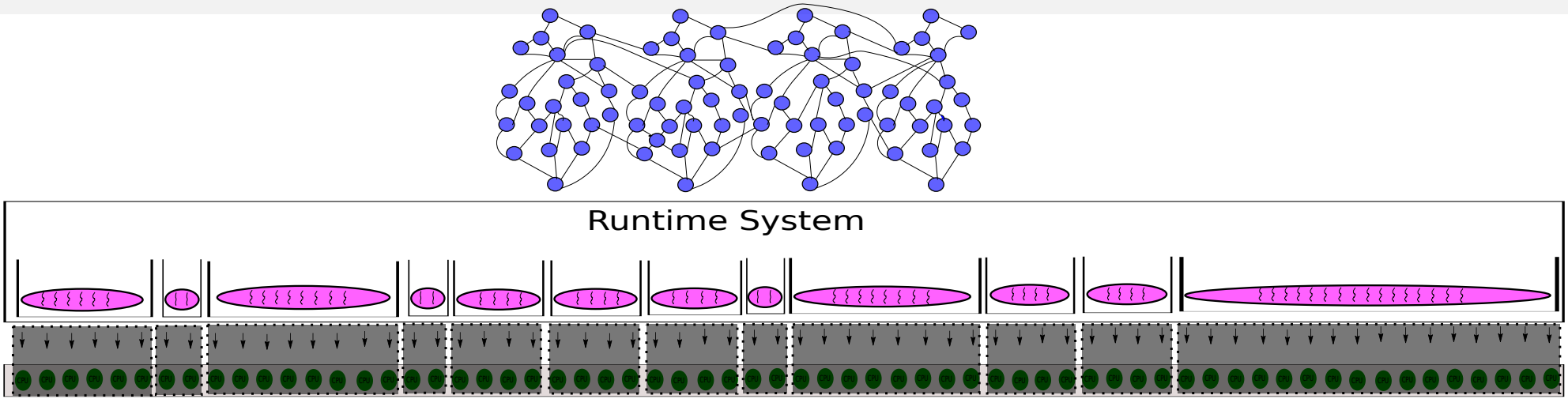
- We could increase machine efficiency
- Shared L2 cache means a need for shared work
- Independent tasks such as StarPU's are bad for work sharing

Solution: adapting the machine to the problem



- Same tasks pushed to StarPU
- Like before, schedulers spread tasks to resources
- The only differences are
  - Somehow we view a group of cores together
  - Tasks are parallel : we can execute them on multiple resources

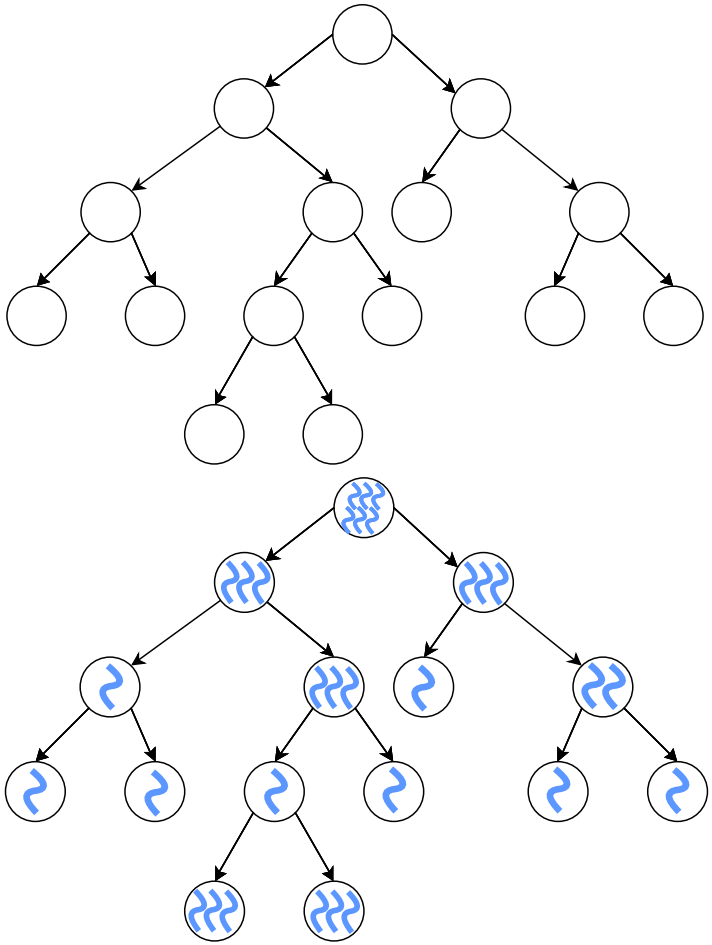
Solution: adapting the machine to the problem



- Same tasks pushed to StarPU
- Like before, schedulers spread tasks to resources
- The only differences are
  - Somehow we view a group of cores together
  - Tasks are parallel : we can execute them on multiple resources
- These parallel tasks are executed on top of the resources by **another** runtime (e.g. OpenMP)
- The way it works internally is a black-box to StarPU
- StarPU only ensures that the internal runtime uses the resources allocated to it.

Parallel tasks model

Idea 1: adapting the machine to the problem.
Idea 2: delegate some of the work to another runtime.



Parallel tasks model : precisely what we need

- Theoretical model proposed in the 90s
- Scarcely used in practice

A task has a new parameter: the amount of threads/resources allocated to it.

Here:

- Task parallelism: StarPU
- Internal parallelism: can be anything. Good candidate: OpenMP (Parallel BLAS, efficient cache reuse, . . .)

Outline

Experimental setup

Machine

- All experiments were run on KNL 7210
- Configuration was SNC-4 cached
- Preliminary results show the same pattern on KNL 7230

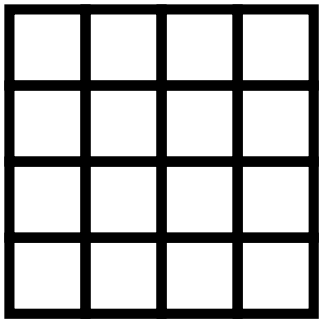
Software

- We use Intel compiler and MKL 17
- Chameleon : a Dense Linear Algebra software on top of multiple runtime systems developed by HiePACS team.
- Here we use Chameleon on top of the StarPU runtime system.

Methodology

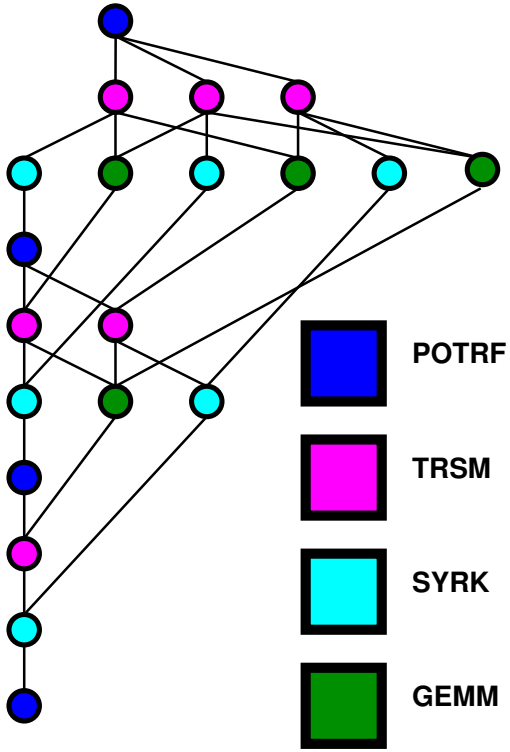
- First, study and understand the kernel performances
- Secondly, benchmark Chameleon's Cholesky factorization with StarPU using different core group size
  - Create bigger resources
  - Run the whole execution on these big resources

Cholesky tiled factorization

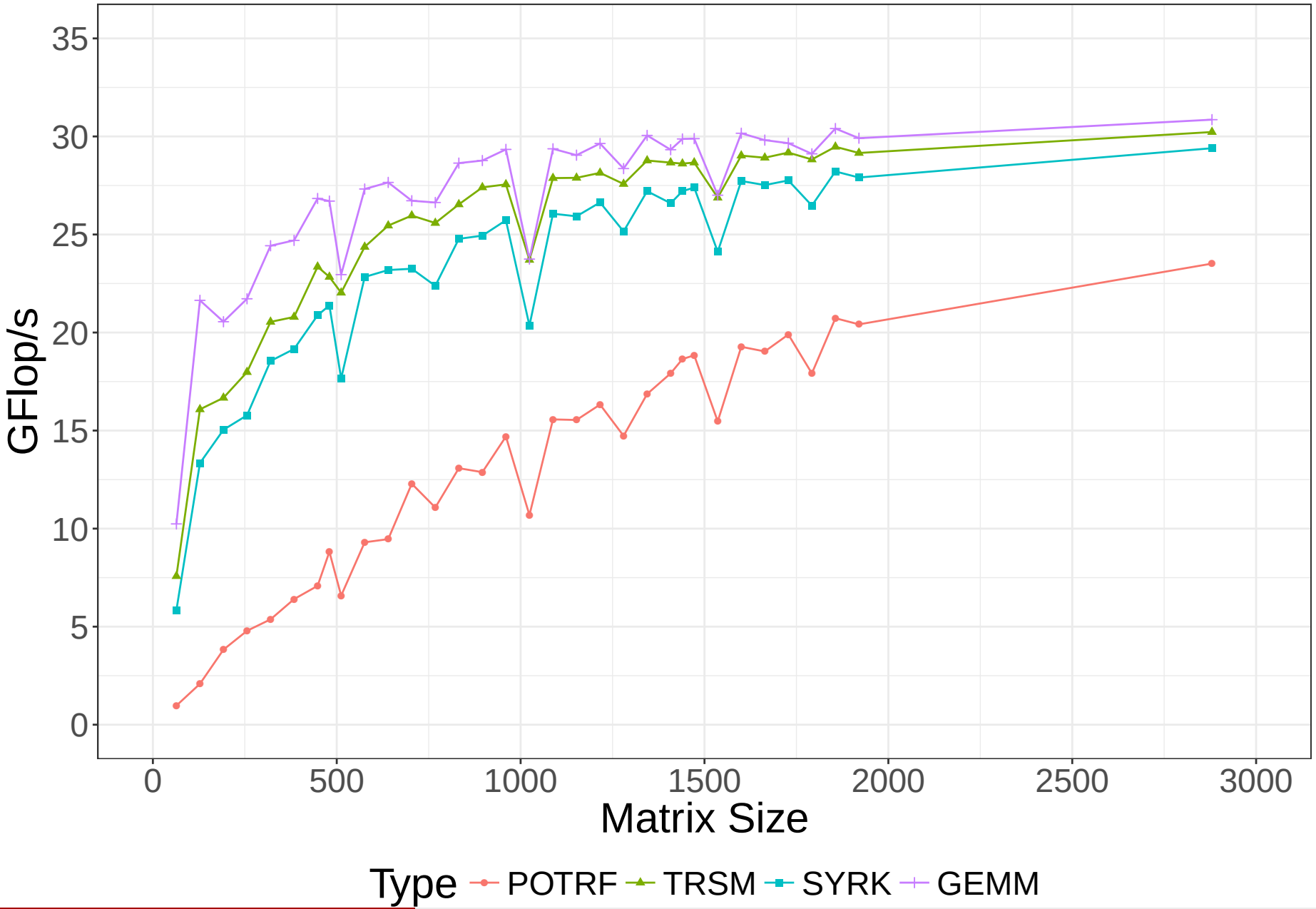


Here are the problems we will look at

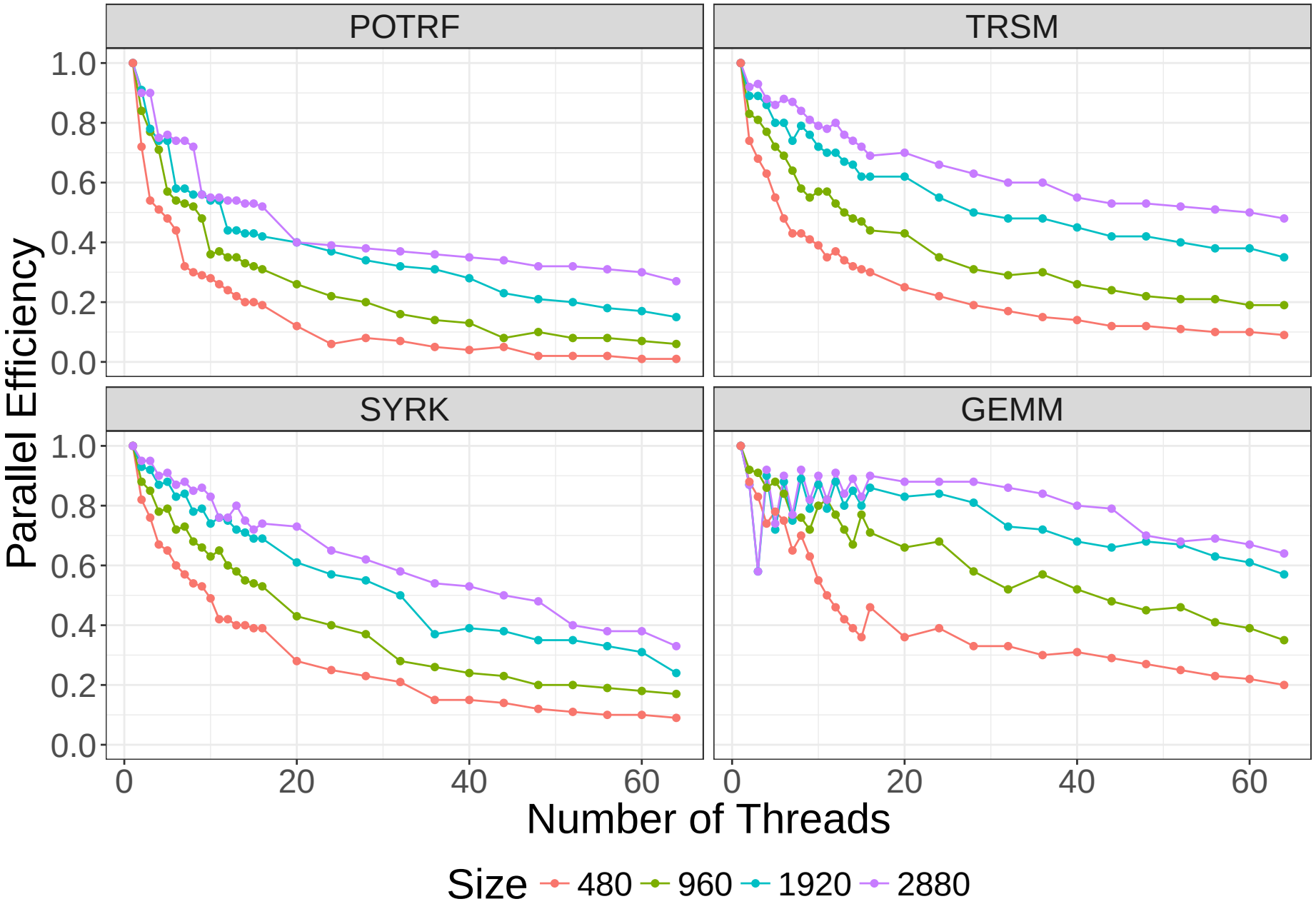
1. What is the best tile size performance wise?
2. What is the impact of parallelism loss (bigger tile size)?



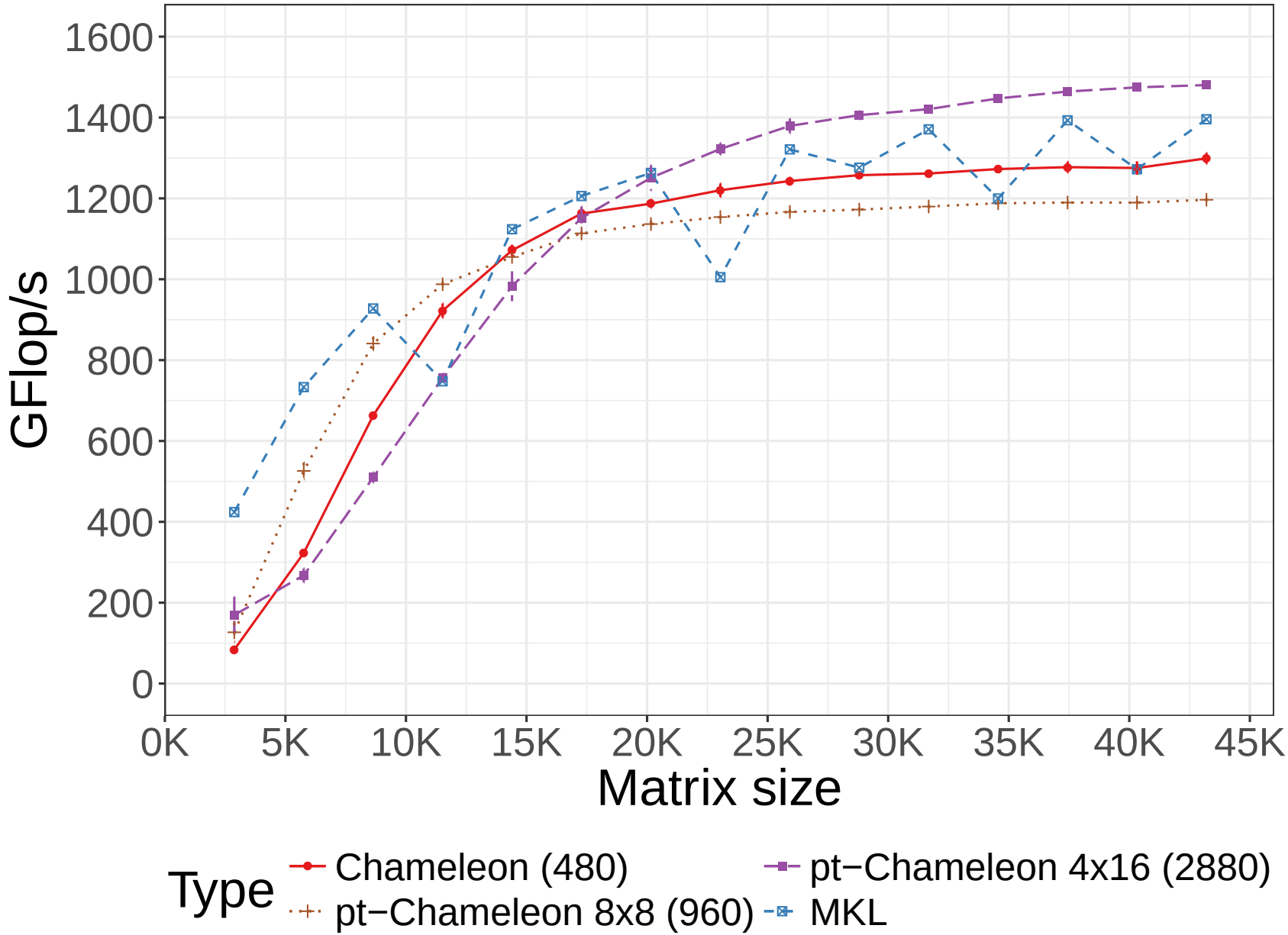
Cholesky kernels performance with one core on KNL 7210



Cholesky kernels parallel efficiency on KNL 7210

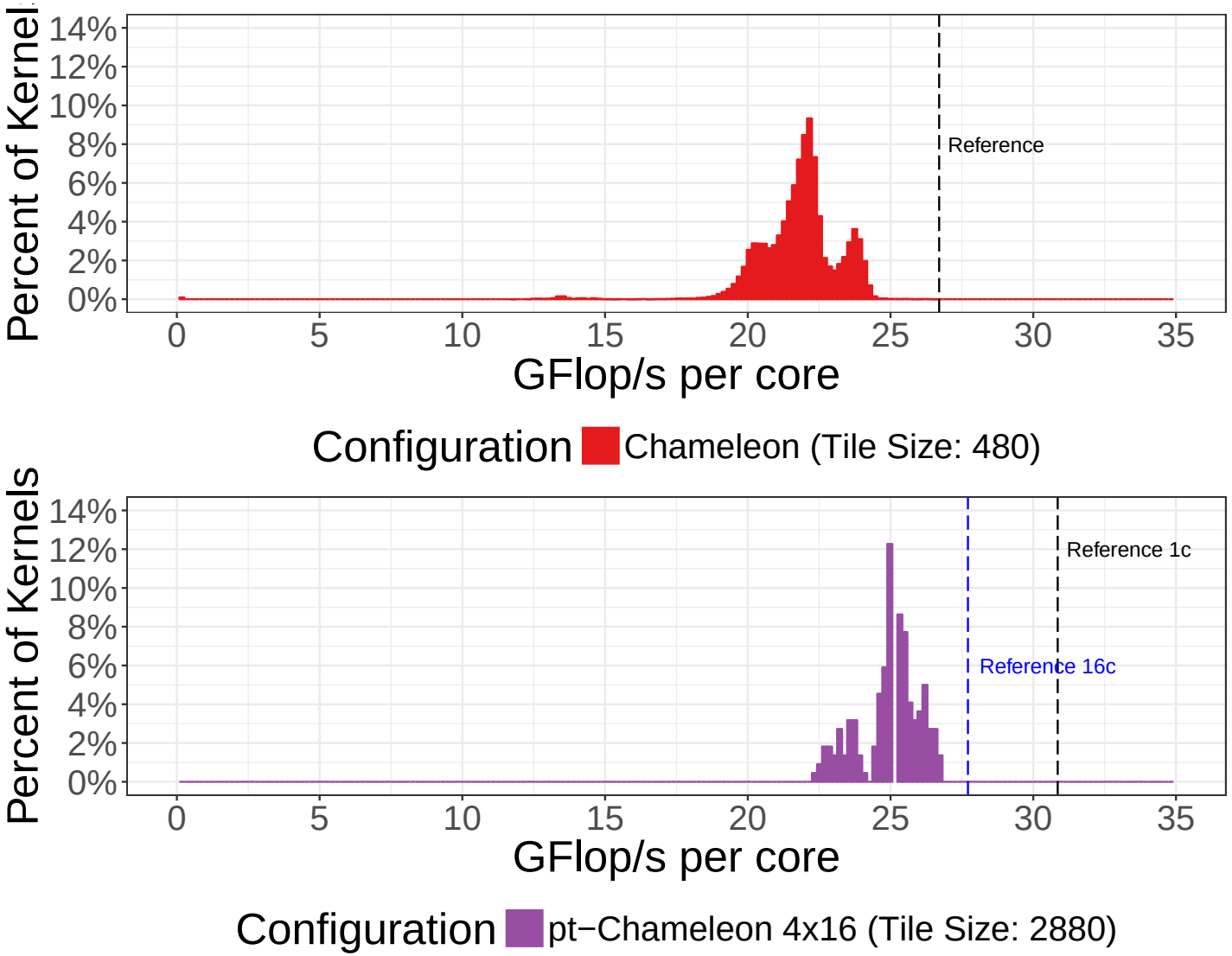


Comparison with MKL and Plasma



Understanding results: actual DGEMM kernels performance

Matrix Size 34K, performance of DGEMM kernels of Cholesky Factorization



Conclusion

On the KNL

- Feed it lots of work
- Beware of high contention
- SNC-4 is fairly good performance wise
- Cache mode is fine for BLAS3

On the use of parallel tasks

- Less resources, work sharing between cores
- Allows to reduce various contentions, very effective on KNL
- Allows to increase task granularity for better performance
- We can beat MKL, by using MKL...

Ongoing and Future Work

- Adapt group size at different phases of the execution
- Profit from group size heterogeneity similarly to CPU/GPU
- Integrate this model into OpenMP?