PTG: an abstraction for unhindered parallelism

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Overview

- Why a New Abstraction?
- Data-Flow Programming
- Parameterized Task Graphs in PaRSEC
- Comparing PTG against Competing Abstractions
- Task Affinity and Scheduling in PaRSEC
- PaRSEC Performance

Why a New Abstraction?

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  - Parallelism
  - Load balancing

Coarse Grain Parallelism

- Coarse Grain Parallelism with explicit message passing
- Essentially serial code with some explicit calls to a communication library
- Communication/computation overlap hard to expose: must be specified explicitly by the programmer
- Tends to lead to bulk-synchronous parallel programs

Data-Flow Programming

Data-Flow Programming

- Work units modeled as a graph, rather than sequentially
- Edges define data flow
- Runtime can automatically schedule tasks and overlap communication/computation

Data-Flow Programming

- Units of work are tasks
- Programs are collections of tasks & data-flow
- Reduced control flow

Parameterized Task Graph (PTG)

Parameterized Task Graph

- Originally by Cosnard et al. (1995, 1999)
- Program as a collection of task *classes*
- Representation independent of problem size

PTG Task Classes

- Class name
- Parameters and valid value ranges
- Affinity (to data)
- Precedence constraints: data input/output & logic
- Code region

PTG Ping-Pong

```
PING(s)
  s = 0..max_steps-1
  : A(s)
  RW   A0 <- A(s)
          -> A0 PONG(s)
  READ A1 <- (s != 0) ? PONG(s-1)
BODY verify_response(A0, A1); END

PONG(s)
  s = 0..max_steps-2
  : A(s+1)
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PTG Comparisons

Dynamic Task Graph

- Asynchronous tasks generated by code at runtime
- Dynamic discovery of task graph
- Used by other task execution runtimes:
    - Legion
    - StarPU
    - OpenMP
    - PaRSEC, as an extension (see Hoque et al., ScalA17)

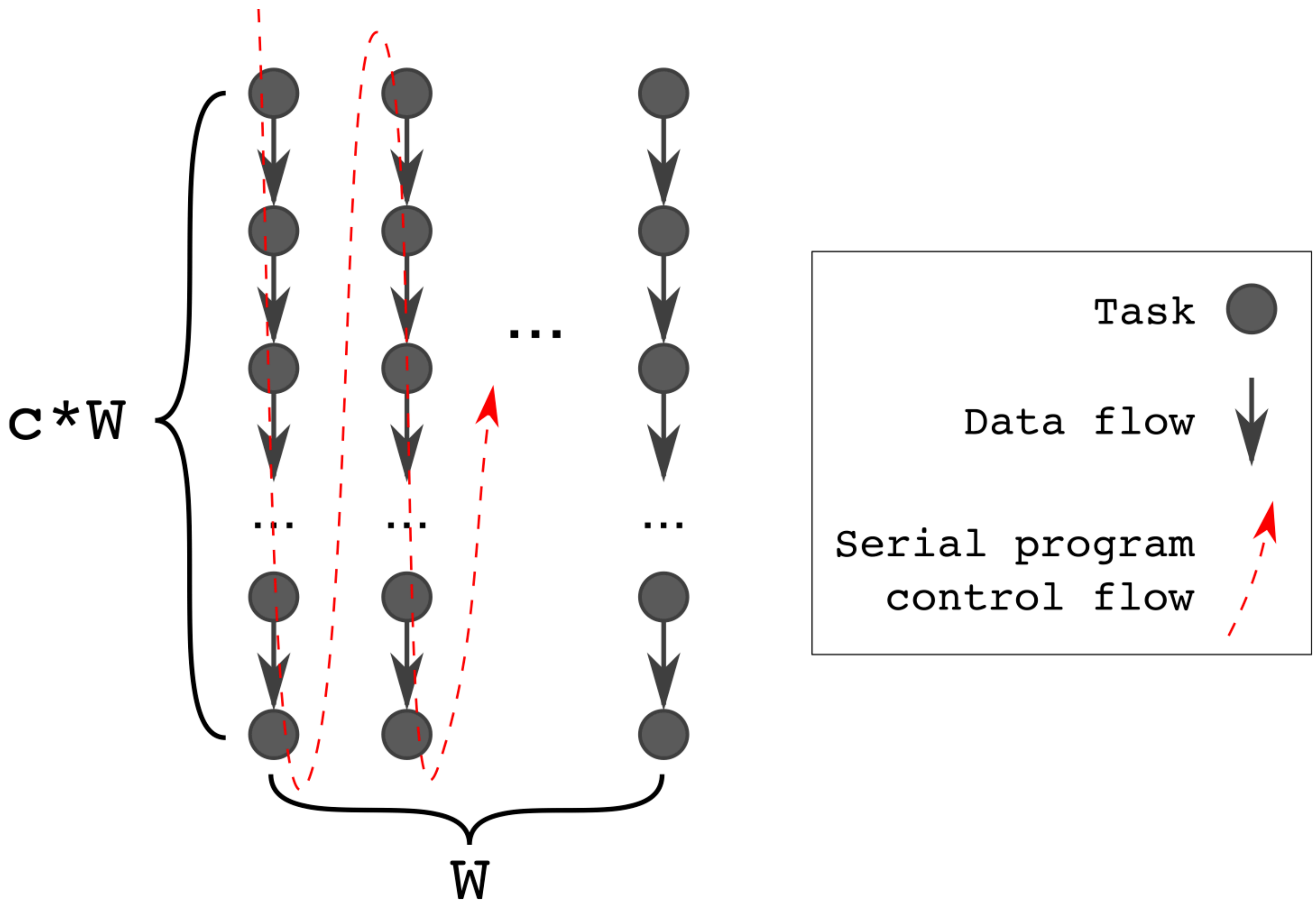
Dynamic Task Graph

```
for (k = 0; k < MT; k++) {
  Insert_Task( geqrt, A[k][k], INOUT, T[k][k], OUTPUT);
  for (m = k+1; m < MT; m++) {
    Insert_Task( tsqrt, A[k][k], INOUT | REGION_D|REGION_U,
                        A[m][k], INOUT | LOCALITY,
                        T[m][k], OUTPUT);
    }
    for (n = k+1; n < NT; n++) {
        Insert_Task( unmqr, A[k][k], INPUT | REGION_L,
                            T[k][k], INPUT,
                            A[k][m], INOUT);
        for (m = k+1; m < MT; m++) {
            Insert_Task( tsmqr, A[k][n], INOUT,
                                A[m][n], INOUT | LOCALITY,
                                A[m][k], INPUT,
                                T[m][k], INPUT);
        }
    }
}
```

DTG Drawbacks

- Task instances unknown prior to discovery
- Memory requirements grow with problem size; task instances require independent memory
- Skeleton program that submits tasks to runtime; must build DAG based on dynamic properties of the program
- Fixed-size window of executing tasks can be used to reduce memory requirements, but restricts parallelism
- Restricted by control flow adherence

PTG vs DTG: Chains



PTG vs DTG: Chains

```
for (i=0; i<W; i++) {
    Task1( RW:Data[i][0] );

    for (j=1; j<c*W; j++) {
        Task2( R:Data[i][j-1], W:A[i][j] );
    }
}
```

PTG vs DTG: Chains

```
Task1(i)
  i = 0..W-1
  : Data(i,0)
  A <- Data(i,0)
    -> A Task2(i,1)
BODY ... END

Task2(i,j)
  i  = 0..W-1
  j  = 1..c*W-1
  : Data(i,j)
  A <- (j == 1)    ? A Task1(i)
    <- (j > 1)     ? A Task2(i,j-1)
    -> (j < c*W-1) ? A Task2(i,j+1)
    -> Data(i,j)
BODY ... END
```

PTG vs DTG: Chains

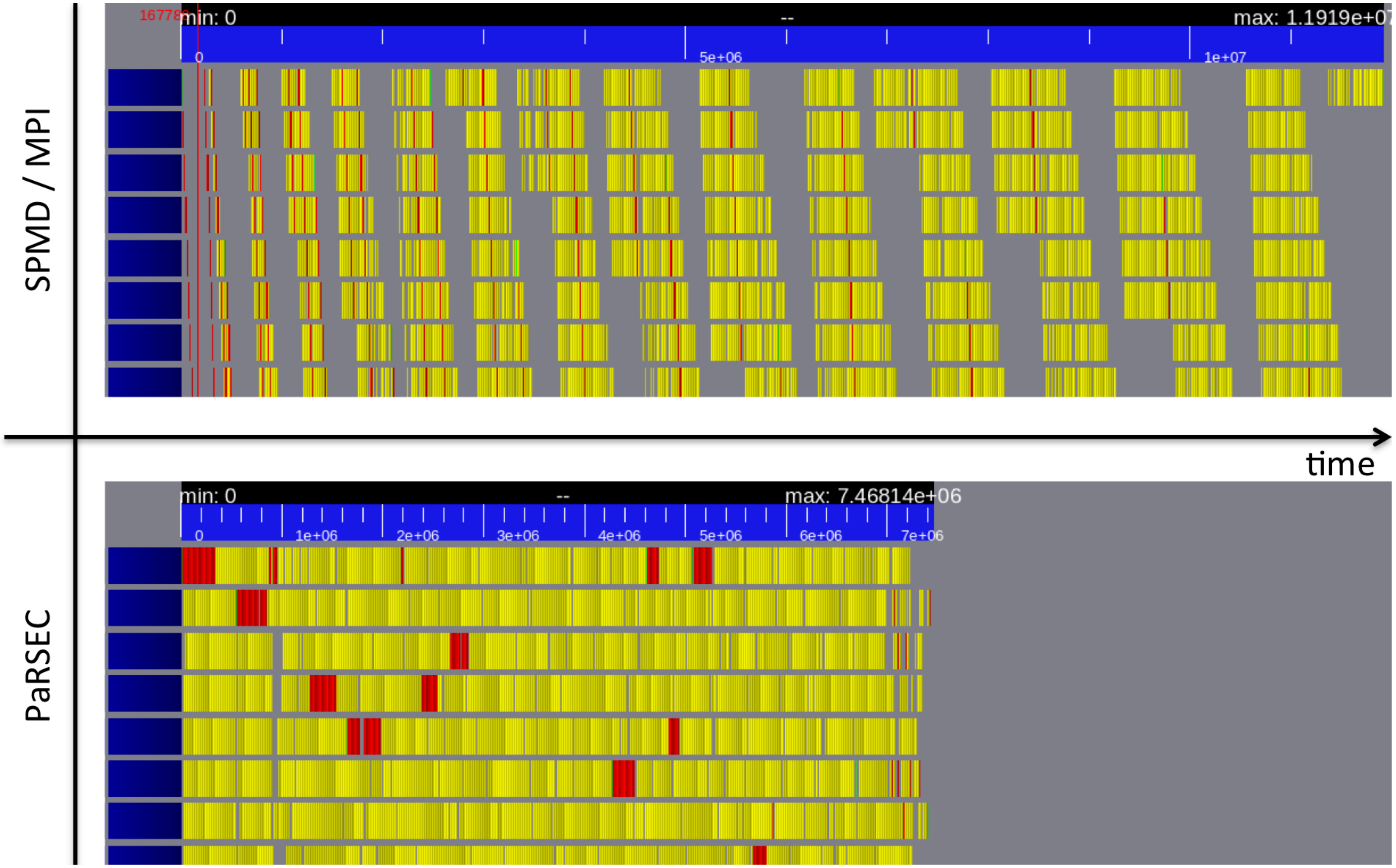
$$S_{DTG} = cW + (W-1)(c-1)W$$

$$S_{PTG} = \frac{cW^2}{P}$$

$$Speedup = \frac{S_{DTG}}{S_{PTG}} = P\left(1 - \frac{1}{c} + \frac{1}{cW}\right) = O(P)$$

PTG vs CGP

- Doesn’t deal well (or at all) with varying parallelism
- Idle time: bulk synchronous and load imbalance / noise
- Communication/computation overlapping
- Memory-hierarchy-awareness loses portability
- Multiple models for compute heterogeneity: MPI + X



PTG vs CGP

QR factorization

Task Affinity and Scheduling

Task Affinity and Scheduling

- Task scheduling is a well-studied problem: NP-complete, efficient heuristics and approximations usually used
- Tasks scheduled on nodes with task affinity hints
- Within a node, several strategies are used:
  - Memory locality
  - Starvation minimization
  - User-defined priorities

Task Affinity and Scheduling

- Memory locality:
  - Hierarchy of ready task queues mapped to memory hierarchy: one per core/socket/node
  - Since child tasks are put into same queues as parent, this guarantees some level of memory locality

Task Affinity and Scheduling

- Starvation minimization:
  - Shared task queue ensures compute resources aren’t starved of tasks (and thus idle)
  - Antithetical to memory locality

Task Affinity and Scheduling

- Hybrid scheduling:
  - Short local queues improve locality of ready tasks
  - Excess ready tasks are placed on a shared queue, reducing starvation
- User-provided priorities are versatile and can be used instead for regular algorithms that are well-understood

Performance

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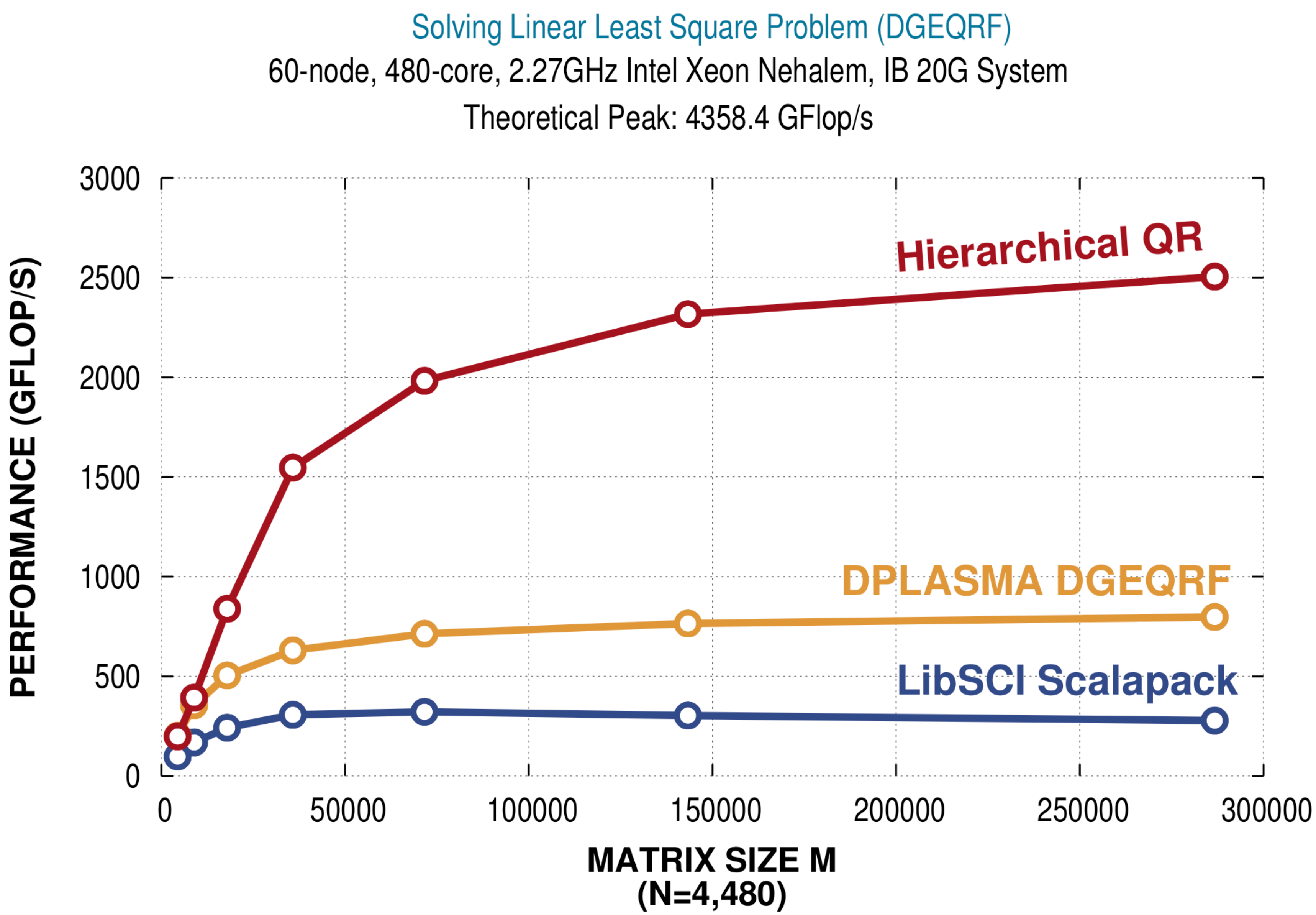
- Comparison with applications/libraries using MPI
- Several libraries:
    - LibSCI: vendor ScaLAPACK tuned for Cray
    - DPLASMA: dense linear algebra on top of PaRSEC

Performance



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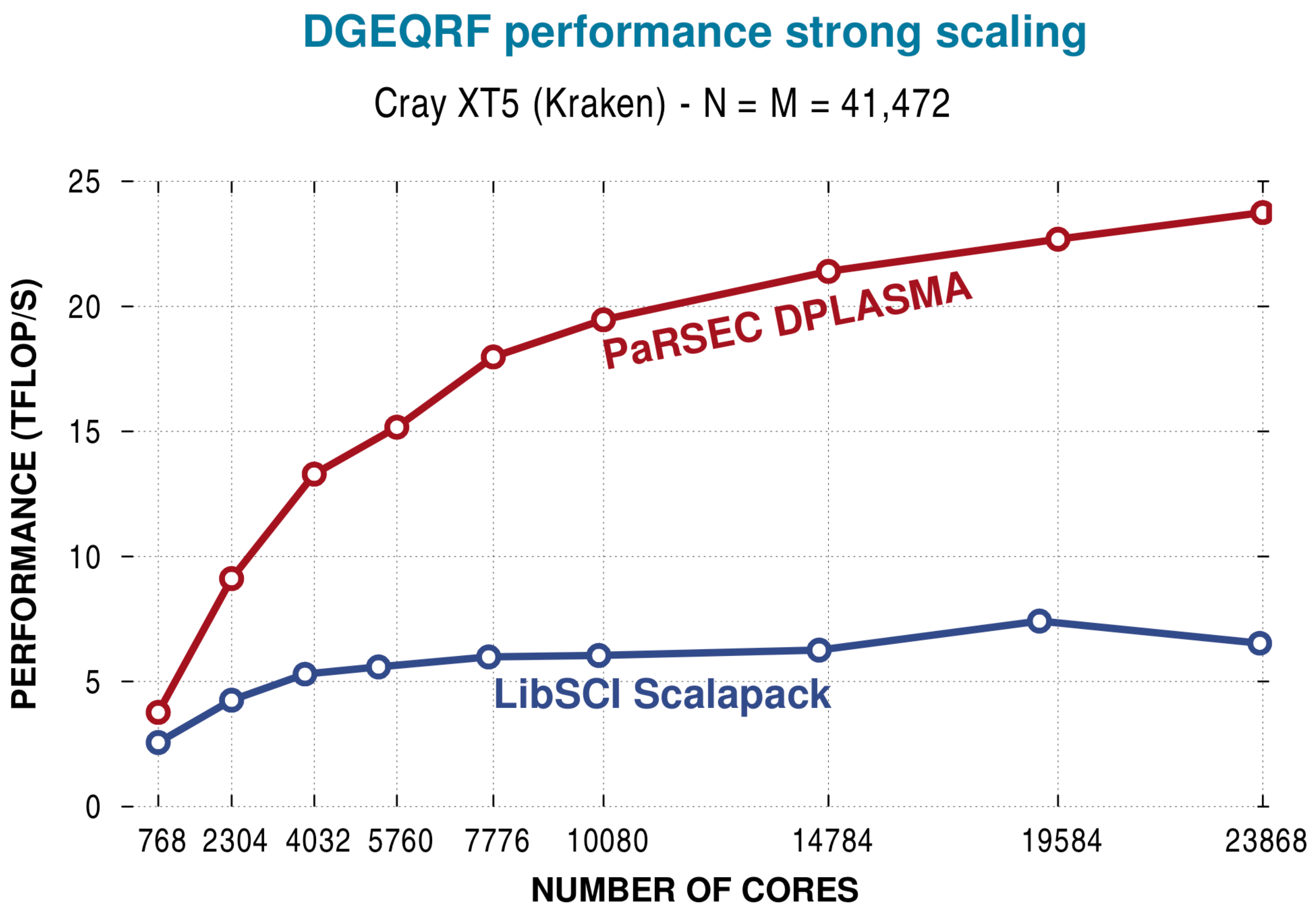

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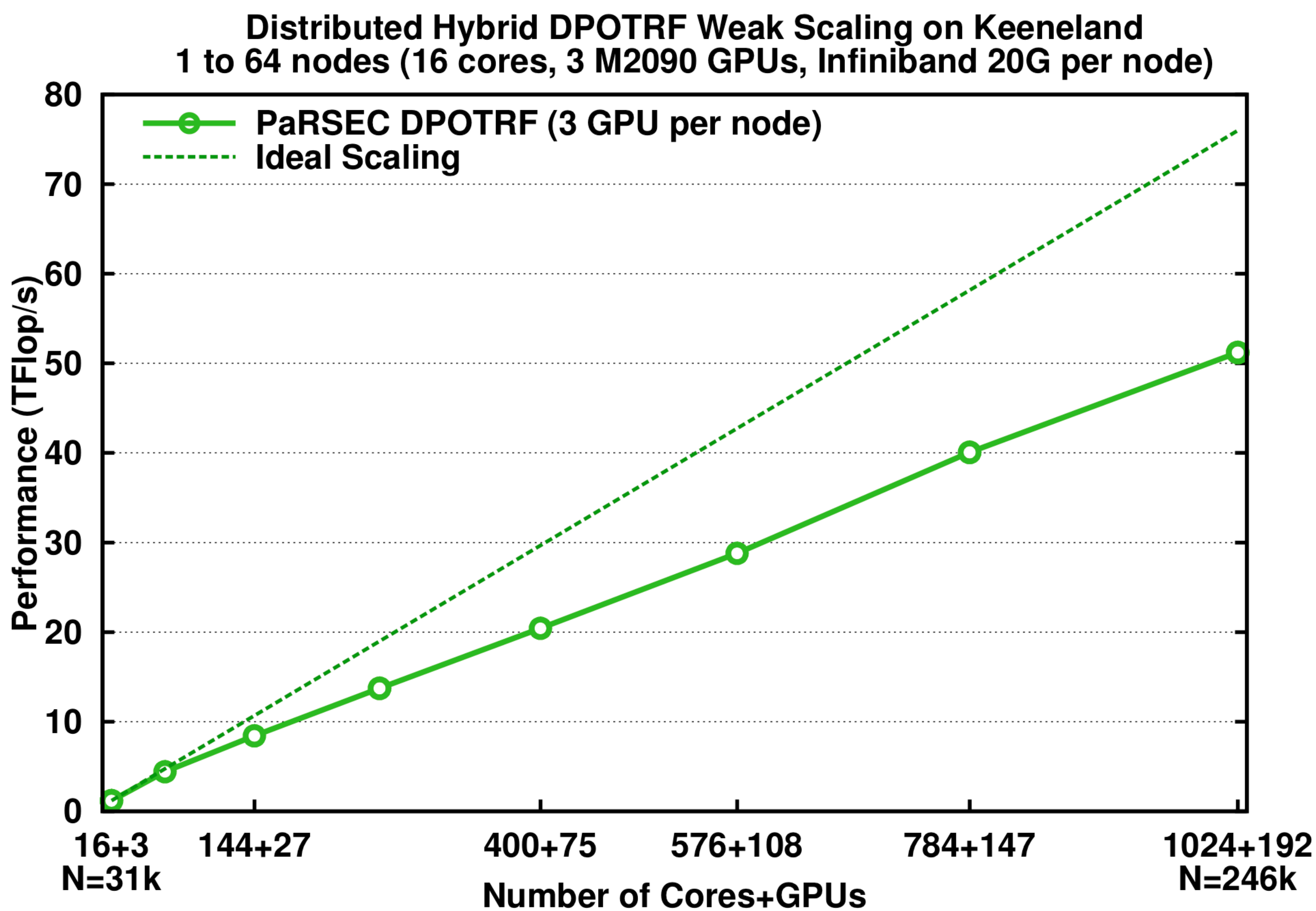

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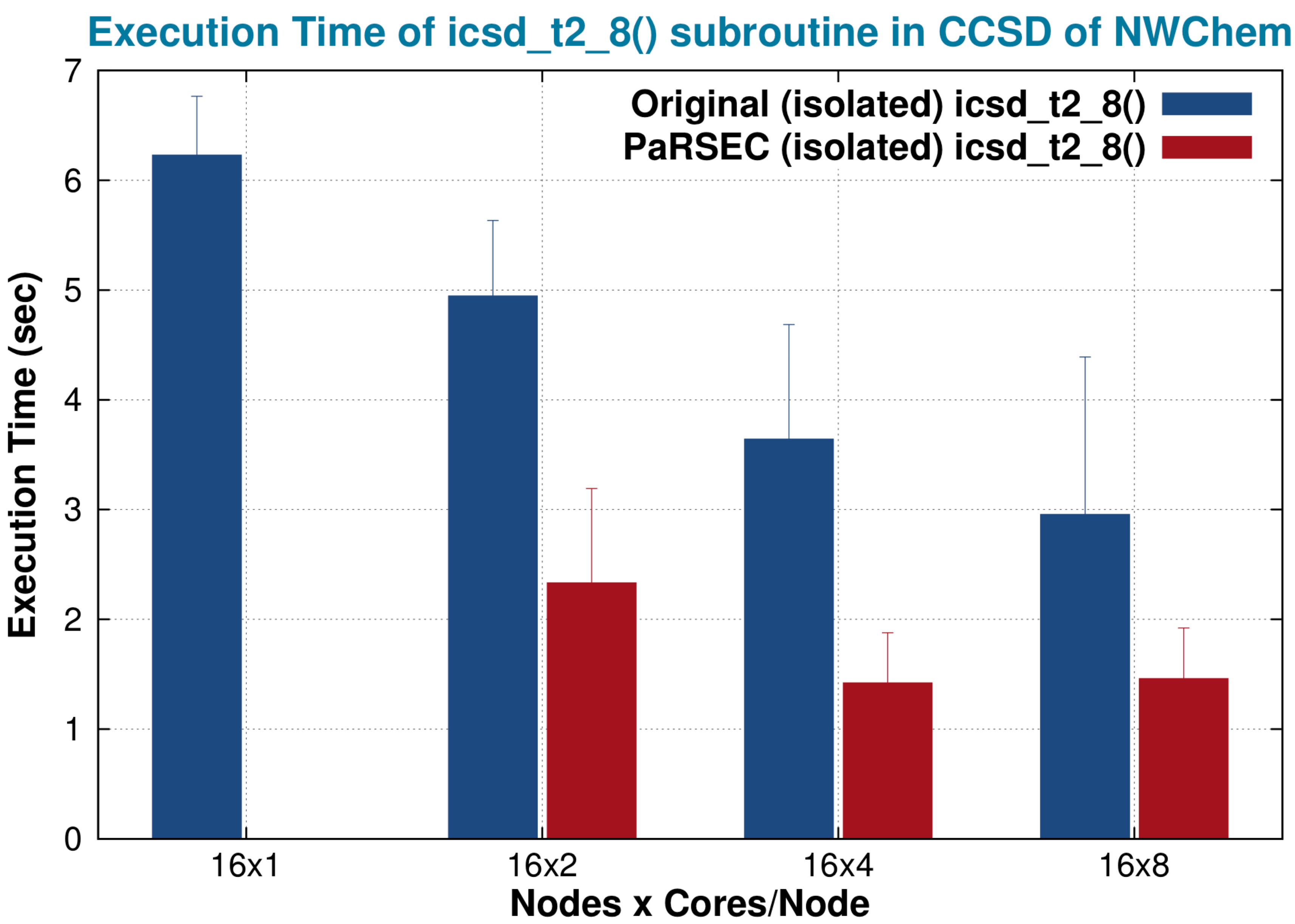

Conclusion

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- Current and upcoming HPC systems will require a new abstraction to take full advantage of.
- PTG is proposed as the solution:
  - More flexible
  - Exposes more parallelism
  - Lower overheads than DTG

Questions?