Redesigning Dense Linear Algebra Software for ManyCore and Beyond

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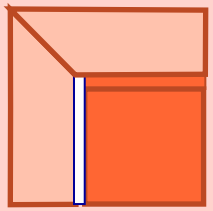
Major Changes to Software

- Must rethink the design of our software
  - Another disruptive technology
    - Similar to what happened with cluster computing and message passing
  - Rethink and rewrite the applications, algorithms, and software
- Numerical libraries for example will change
  - For example, both LAPACK and ScaLAPACK will undergo major changes to accommodate this

A New Generation of Software:

Software/Algorithms follow hardware evolution in time		
LINPACK (70's) (Vector operations)		Rely on - Level-1 BLAS operations

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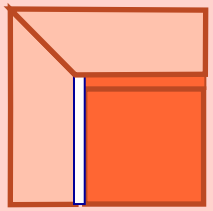
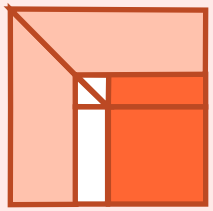
LINPACK (70's) (Vector operations)		Rely on - Level-1 BLAS operations
LAPACK (80's) (Blocking, cache friendly)		Rely on - Level-3 BLAS operations

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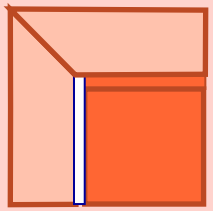
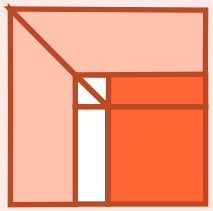
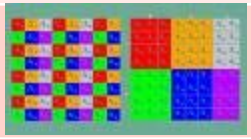
LINPACK (70's) (Vector operations)		Rely on - Level-1 BLAS operations
LAPACK (80's) (Blocking, cache friendly)		Rely on - Level-3 BLAS operations
ScaLAPACK (90's) (Distributed Memory)		Rely on - PBLAS Mess Passing

A New Generation of Software:

Parallel Linear Algebra Software for Multicore Architectures (PLASMA)

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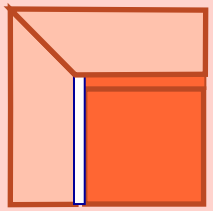
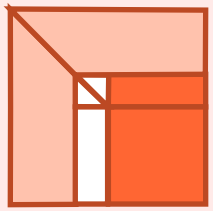
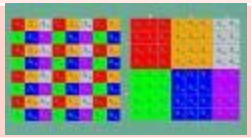
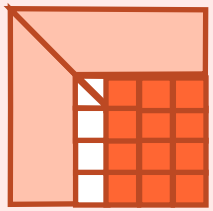
LINPACK (70's) (Vector operations)		Rely on - Level-1 BLAS operations
LAPACK (80's) (Blocking, cache friendly)		Rely on - Level-3 BLAS operations
ScaLAPACK (90's) (Distributed Memory)		Rely on - PBLAS Mess Passing
PLASMA (00's) New Algorithms (many-core friendly)		Rely on - a DAG/scheduler - block data layout - some extra kernels

Those new algorithms
- have a very low granularity, they scale very well (multicore, petascale computing, …)
- removes a lots of dependencies among the tasks, (multicore, distributed computing)
- avoid latency (distributed computing, out-of-core)
- rely on fast kernels

Those new algorithms need new kernels and rely on efficient scheduling algorithms.

Steps in the LAPACK LU

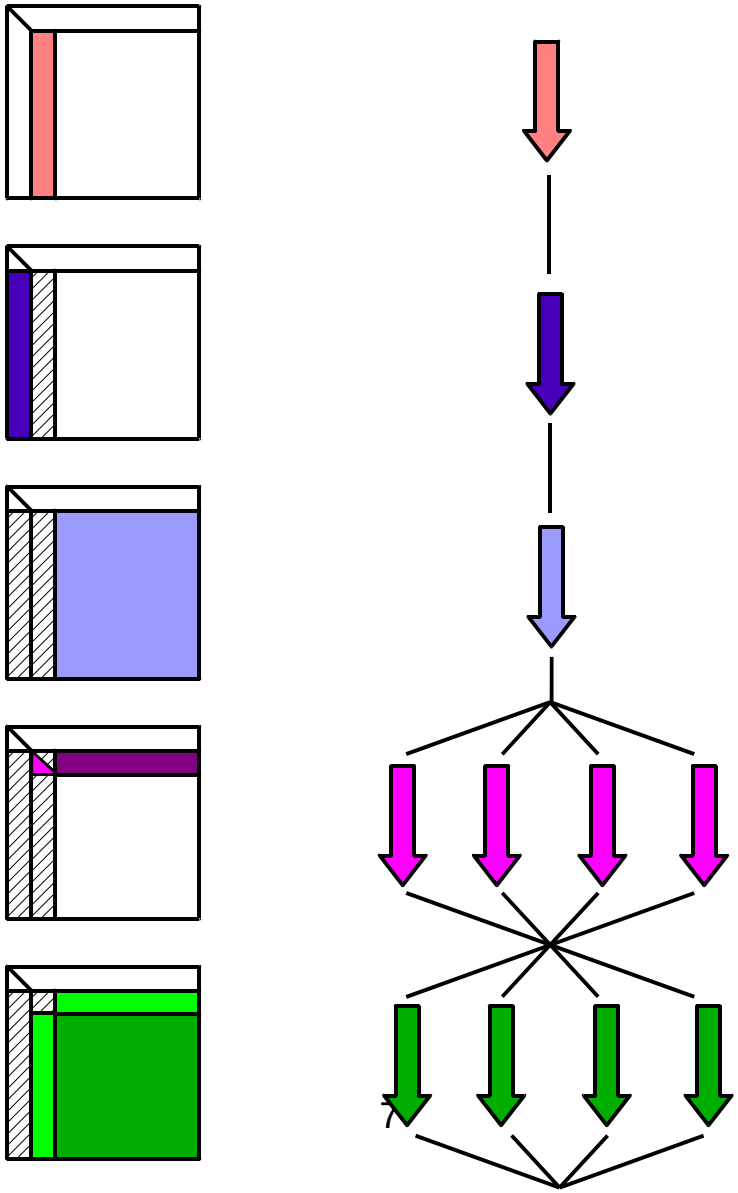
DGETF2
(Factor a panel)

DLSWP
(Backward swap)

DLSWP
(Forward swap)

DTRSM
(Triangular solve)

DGEMM
(Matrix multiply)



LAPACK

LAPACK

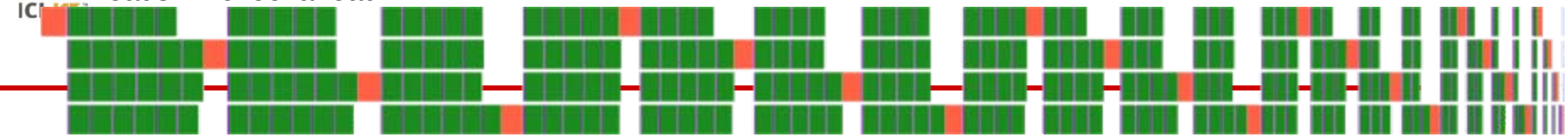
LAPACK

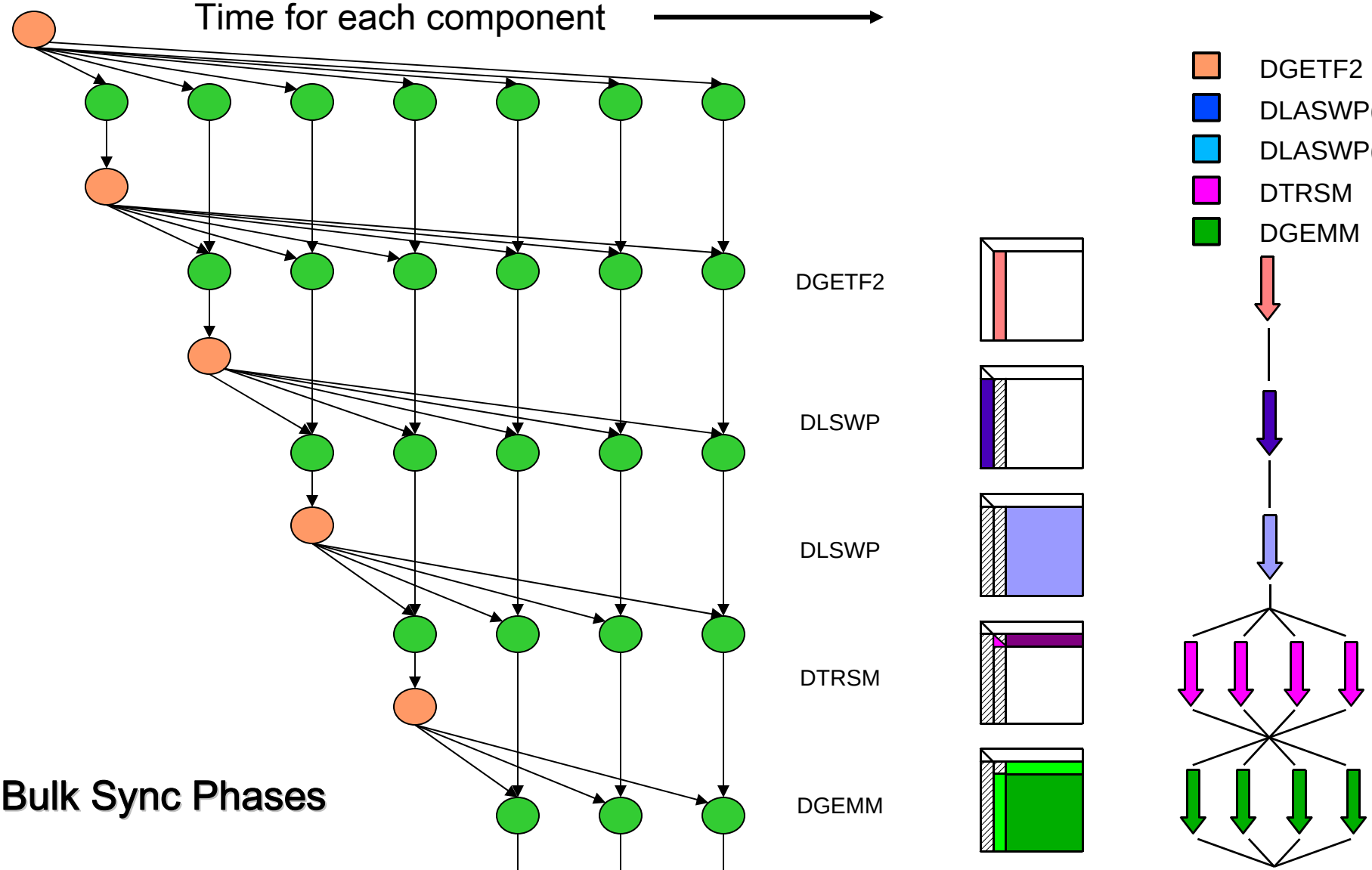
BLAS

BLAS

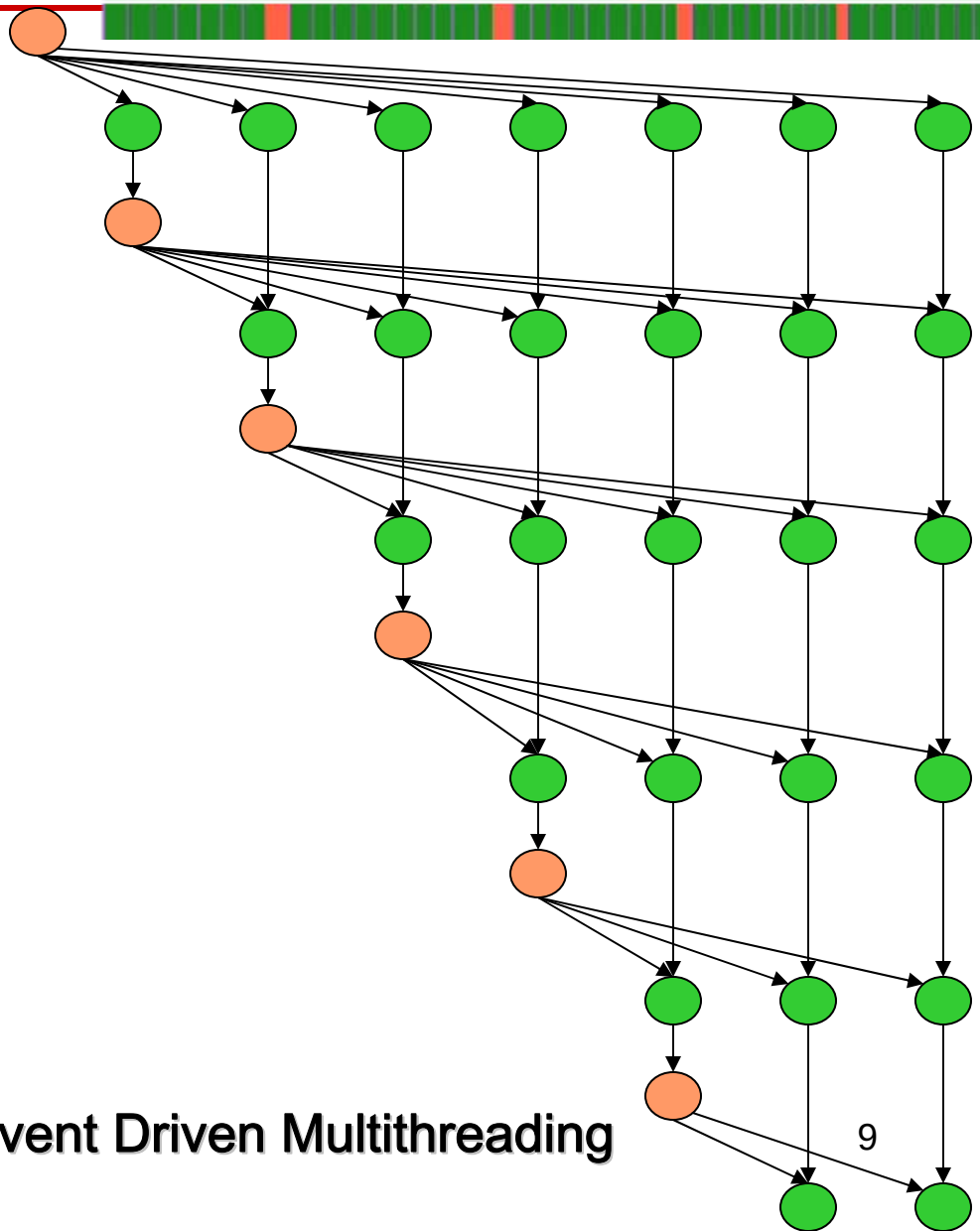
LU Timing Profile (4 processor system)

Threads – no lookahead





Adaptive Lookahead - Dynamic



```
while(1)
    fetch_task();
    switch(task.type) {
        case PANEL:
            dgetf2();
            update_progress();
        case COLUMN:
            dlaswp();
            dtrsm();
            dgemm();
            update_progress();
        case END:
            for()
                dlaswp();
            return;
    }
}
```

Reorganizing algorithms to use this approach

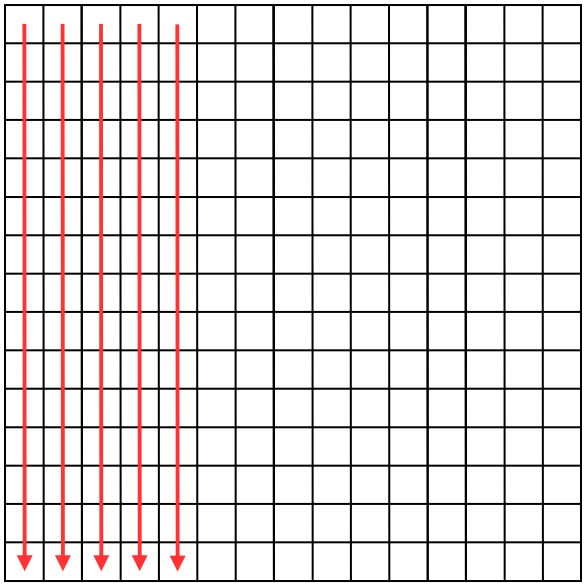
Redesign

- Asychronicity
  - Avoid fork-join (Bulk sync design)
- Dynamic Scheduling
  - Out of order execution
- Fine Granularity
  - Independent block operations
- Locality of Reference
  - Data storage – Block Data Layout

Achieving Fine Granularity

Fine granularity may require novel data formats to overcome the limitations of BLAS on small chunks of data.

Column-Major



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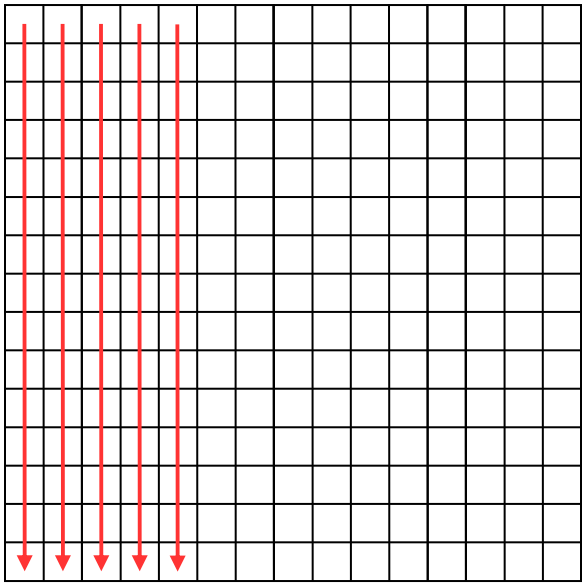
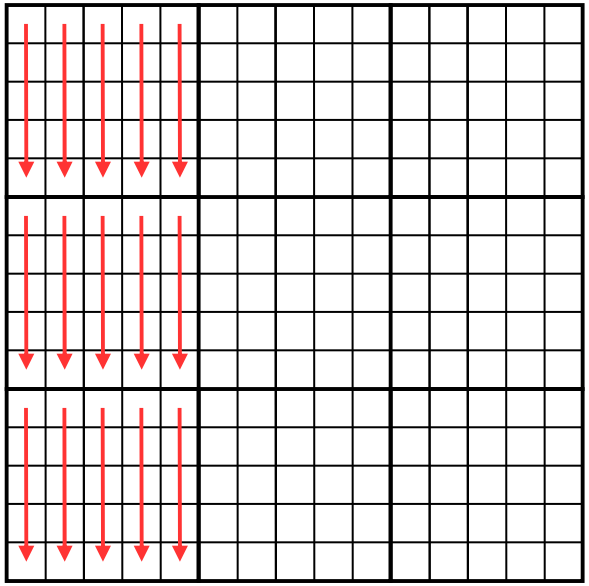
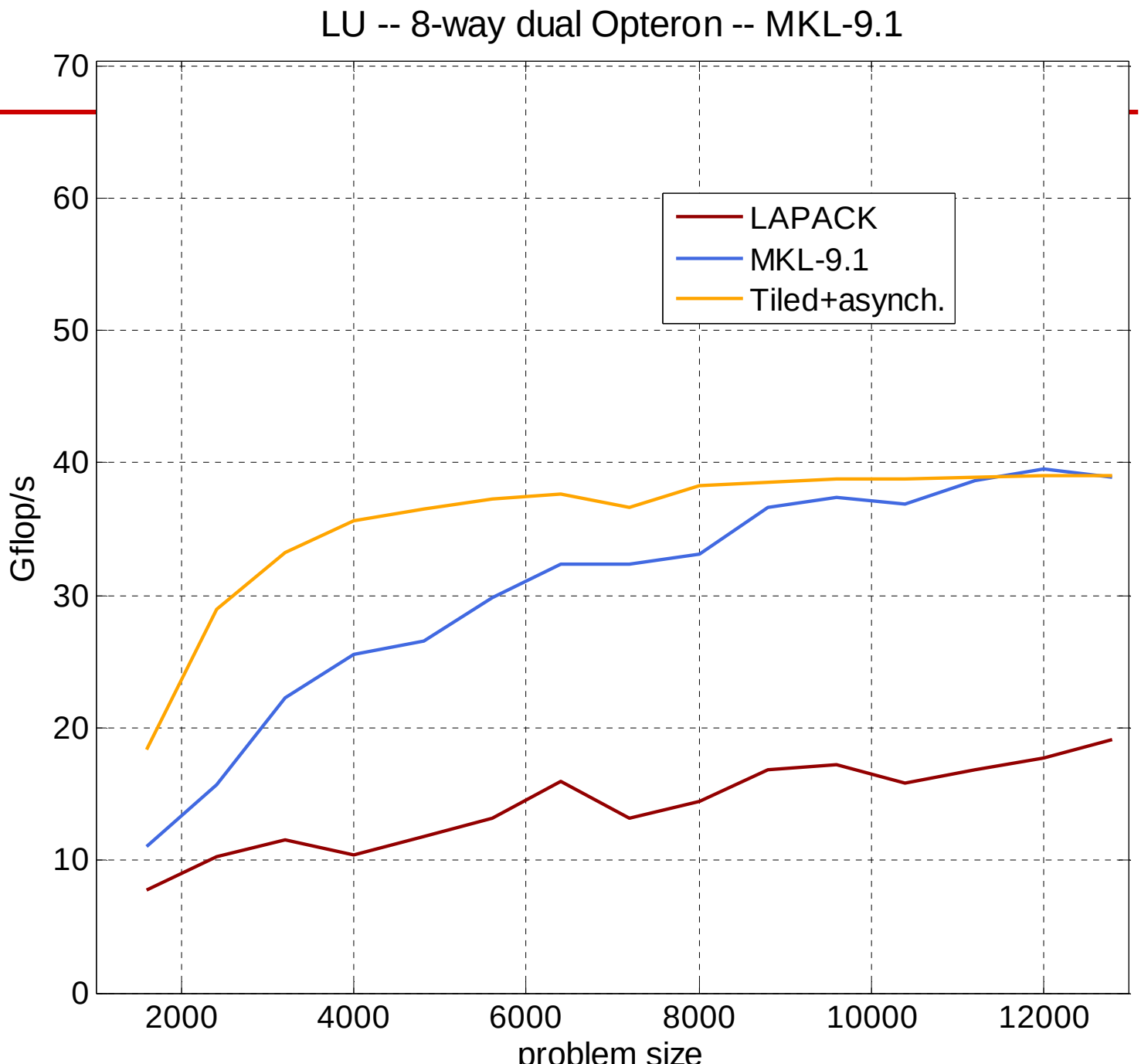
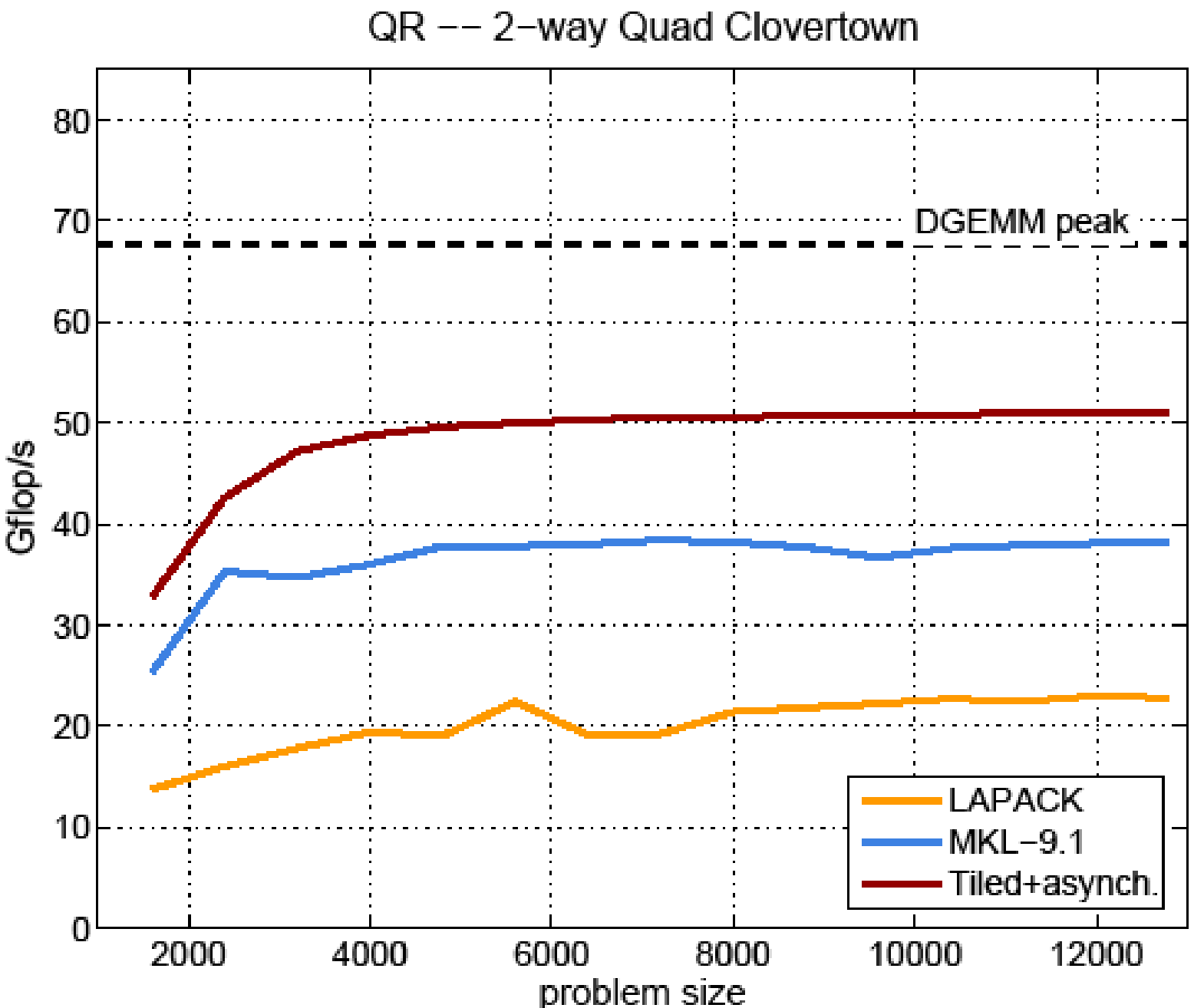


Block data layout




LU -- 8-way dual Opteron -- MKL-9.1
Gflop/s
problem size
0
10
20
30
40
50
60
70
2000
4000
6000
8000
10000
12000
LAPACK
MKL-9.1
Tiled+asynch.


QR -- 2-way Quad Clovertown
Gflop/s
problem size
DGEMM peak
LAPACK
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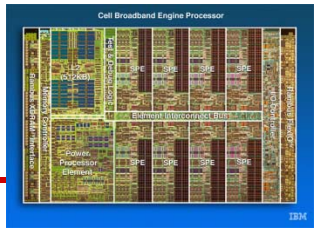
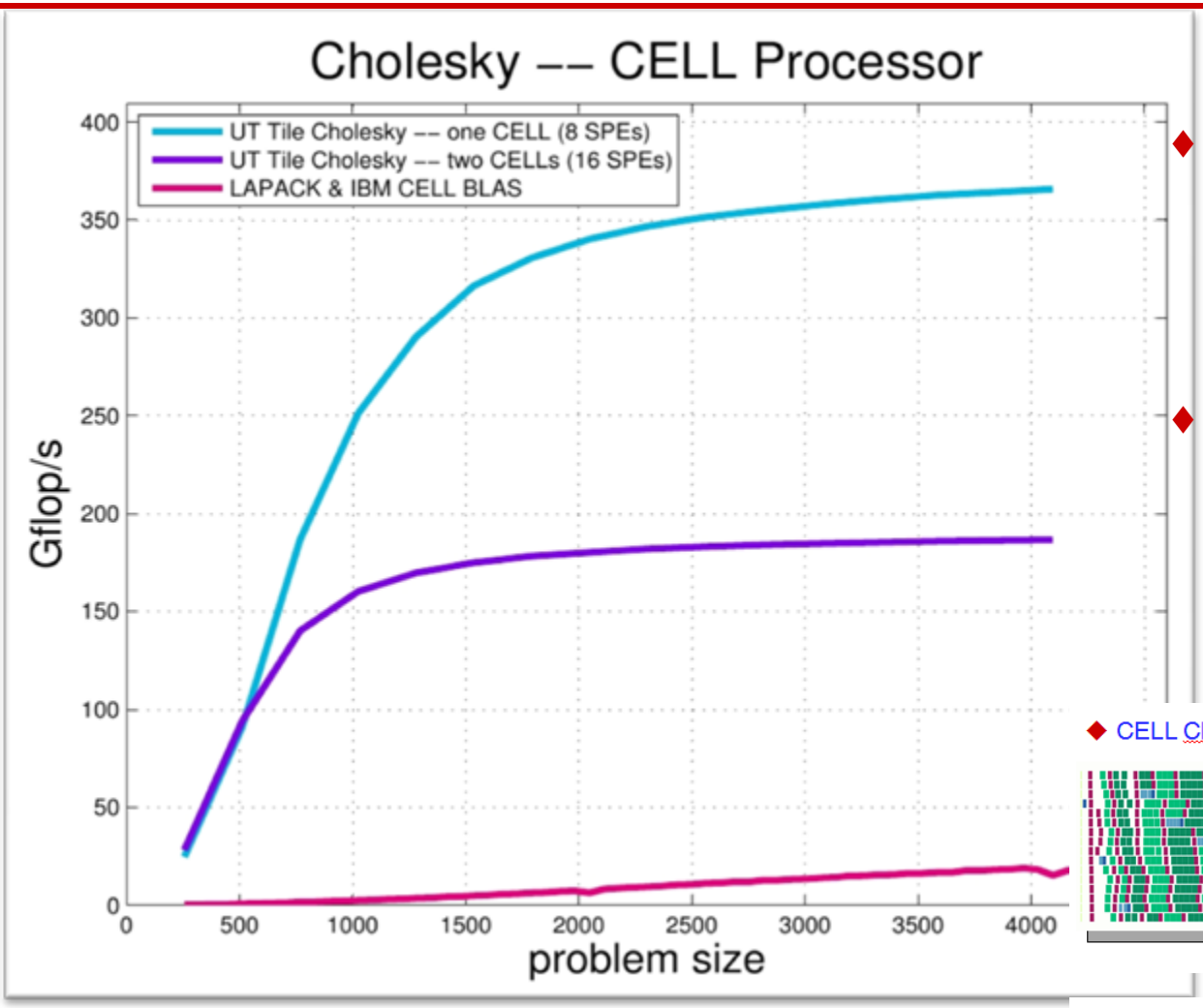
0
10
20
30
40
50
60
70
80
2000
4000
6000
8000
10000
12000

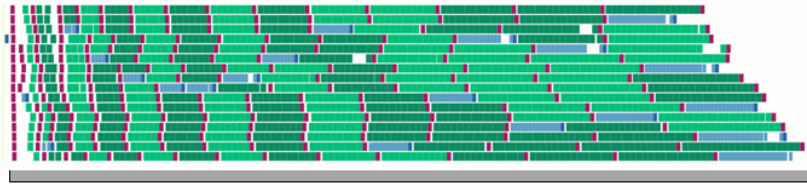
Cholesky on the CELL



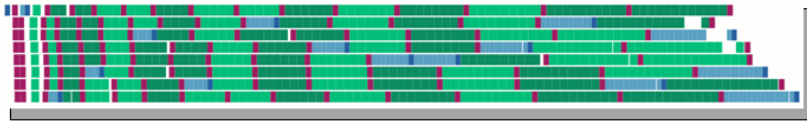


- 1 CELL (8 SPEs)
  - 186 Gflop/s
  - 91 % peak
  - 97 % SGEMM peak
- 2 CELLs (16 SPEs)
  - 365 Gflop/s
  - 89 % peak
  - 95 % SGEMM peak

- CELL Cholesky – 16 cores



- CELL Cholesky – 8 cores



Single precision results on the Cell

Next Steps

- Looking at implementations of the algorithms using:
  - Cilk, SMP SuperScalar, Intel Threading Building Blocks, UPC,…
- Distributed memory implementations will follow

Collaborators / Support

- U Tennessee, Knoxville
  - Julien Langou, Julie Langou, Piotr Luszczek, Jakub Kurzak, Stan Tomov, Remi Delmas, Peng Du
- UC Berkeley:
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Microsoft

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U.S. DEPARTMENT OF ENERGY

The MathWorks