Impact of Data Distribution and Schedulers for the LU Factorization on Multi-Core Clusters Impact of Data Distribution and Schedulers for the LU Factorization on Multi-Core Clusters

Otho José Sirtoli Marcondes, Lucas Mello Schnorr, Phillipe Olivier Alexandre Navaux
Instituto de Informática, UFRGS

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Context

- HPC is the backbone for groundbreaking research and innovation across numerous scientific and engineering disciplines.
- Modern clusters have thousands of multi-core nodes.
- Dense linear algebra (e.g., LU factorization) is a core workload.

Introduction and Motivation

Load balancing across nodes is a critical challenge.

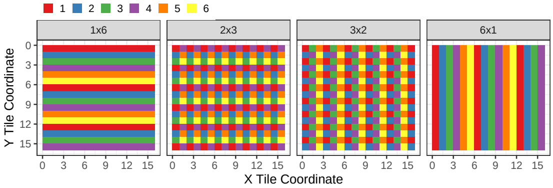
- Static data distribution: excellent data locality but lacks adaptability.
- Dynamic scheduling: great adaptability but incurs overhead.
- Hybrid strategies aim to combine both efficiently (StarPU-MPI and CHAMELEON).

Objective

- Analyze how data distribution and scheduling heuristics affect LU factorization performance.

Static Data Distribution

- Block-Cyclic (BC) used in ScaLAPACK, HPL benchmark.
- Balances computation and communication via P×Q grid.
- Limitations with prime node counts or heterogeneous resources.



Task-Based Runtime Systems

- Frameworks: StarPU, PaRSEC, OmpSs.
- Express computations as task DAGs.
- Adaptability and performance portability.
- Schedulers dynamically assign tasks.

Hardware Environment

Resource	Specification
Cluster	PCAD @ INF/UFRGS
Nodes	6
Cores per node	24 (2$\times$12 Xeon Silver 4116)
Memory per node	96 GB DDR4
Network	10G Ethernet (X540-AT2)

Software Environment

- CHAMELEON 1.3.0 for dense linear algebra.
- StarPU-MPI 1.4.7 runtime system.
- OpenMPI 4 transport layer.
- GNU Guix for reproducible package management.
- Data analysis in R suing StarVZ framework.

Application: LU Factorization

- Decomposes matrix A into L (lower) and U (upper).
- Kernels used:
  - DGEMM – matrix multiplication
  - DTRSM – triangular solve
  - DGETRF_NOPIV – LU without pivoting
- Hybrid execution:
  - Static inter-node block distribution
  - Dynamic intra-node scheduling via StarPU

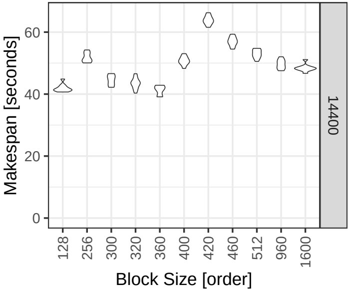
Experimental Design

Square matrix size of 14.4K (double precision).

1. Phase 1: Tile size tuning (128–1600)
2. Phase 2: Full factorial 4×4 experiment
   - Schedulers: lws, random, dmda, dmdas
   - Distributions: 1×6, 2×3, 3×2, 6×1
3. Phase 3: Detailed trace analysis with StarVZ
   - Fixed `lws` scheduler
   - Varying PxQ (BC) parameters.

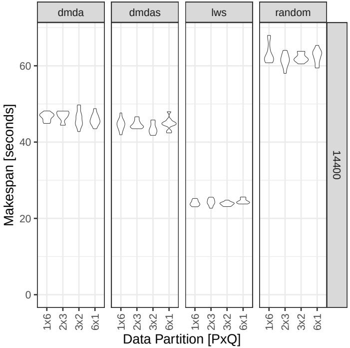
Preliminary Study

- Tested 10 tile sizes with `lws` scheduler.
- Best performance at 360×360 blocks.



Overview of the Comparison

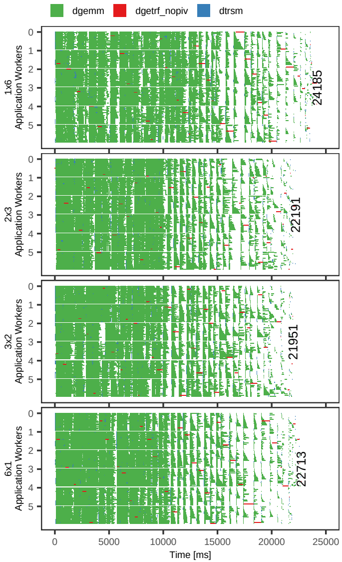
- Varying data distribution and schedulers.
- 1×6 and 6×1: $\approx$3900 MPI operations.
- 2×3 and 3×2: $\approx$2300 MPI operations.
- Similar makespans across different data distributions and schedulers.



OpenMPI Delays

- Fixed `lws` scheduler, varying data distributions.
- More dense behavior of `dgemm` tasks until 10s.
  - 1×6 (worst): mean idle $\approx$1500 ms
  - 2×3 (best): mean idle 800 ms
- Bottleneck from network latency, not algorithmic imbalance.

OpenMPI Delays



Schedulers Comparison

- Fixed 3×2 distribution, `lws` and `dmdas` schedulers.
- Per-node optimistic makespan (ABE):
  - ≈14605 ms for `lws`
  - ≈15045 ms for `dmdas`
- LWS temporal gaps between tasks ≈7841 ms; `dmdas` ≈9154 ms.
- 200 more outlier tasks in `dmdas` explain longer runtime.

Data distribution similarities

- Makespan difference <3%.
- ABE difference between nodes 1 and 2:
  - 3×2: ≈2249 ms
  - 6×1: ≈2194 ms
- Similar load imbalance between the two.

Conclusion and Future Work

- Impact of data distribution and scheduler heuristics.
- `dmda` and `dmdas` presented similar performances.
- `lws` best performing scheduler.
- Data partition (P) had minimal impact on performance.
- Scale experiments using SimGrid simulation.
- Study repetitive network delays in StarPU-MPI.

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Contact

Thank you for your attention!

Otho José Sirtoli Marcondes <otho.marcondes@inf.ufrgs.br>
Lucas Mello Schnorr <schnorr@inf.ufrgs.br>
Phillipe Olivier Alexandre Navaux <navaux@inf.ufrgs.br>