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Scalable and Portable LU Factorization with Partial Pivoting on top of Runtime Systems

Alycia Lisito, Mathieu Faverge, David Goudin, Matthieu Kuhn, Pierre Ramet

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Context

We explore solutions to implement efficient **LU factorization with partial pivoting** using the **sequential task flow programming model**. Due to the pivoting strategy, the algorithm generates a **large number of very small tasks**, which usually overload the runtime system and make it inefficient. We propose two solutions to improve the efficiency and reduce the number of tasks. First, we apply well-known **blocking strategies** in the context of task-based algorithms. Secondly, we explore **batching** techniques to reduce the number of tasks submitted to the runtime system. Moreover, in distributed architectures, partial pivoting generates **many reductions on the critical path** throughout the factorization which needs to be carefully handled to reach high performance. Two task-based reduction algorithms are proposed to express these operations and improve the runtime reactivity on the critical path. These proposals have been implemented in the dense linear algebra library **CHAMELEON** on top of the **STARPU** runtime system.

Objective

- Implement an LU factorization for large heterogeneous architectures with performance portability
- Being able to schedule efficiently large and fine grains computations

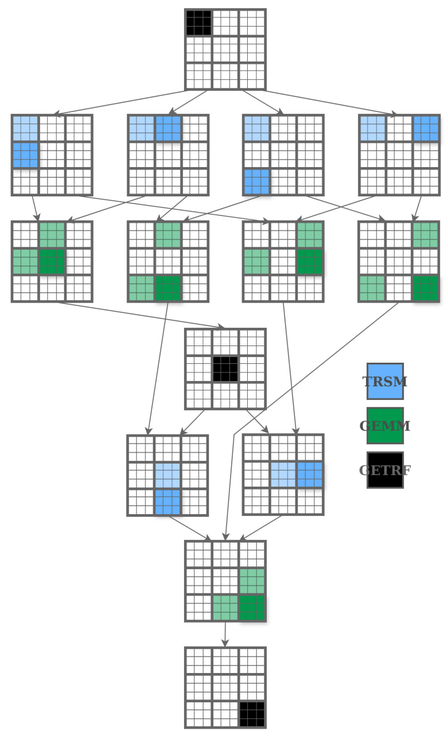
Proposed solution

- Use task-based programming models
  → STARPU runtime system
- Extend existing task-based dense linear algebra library
  → CHAMELEON

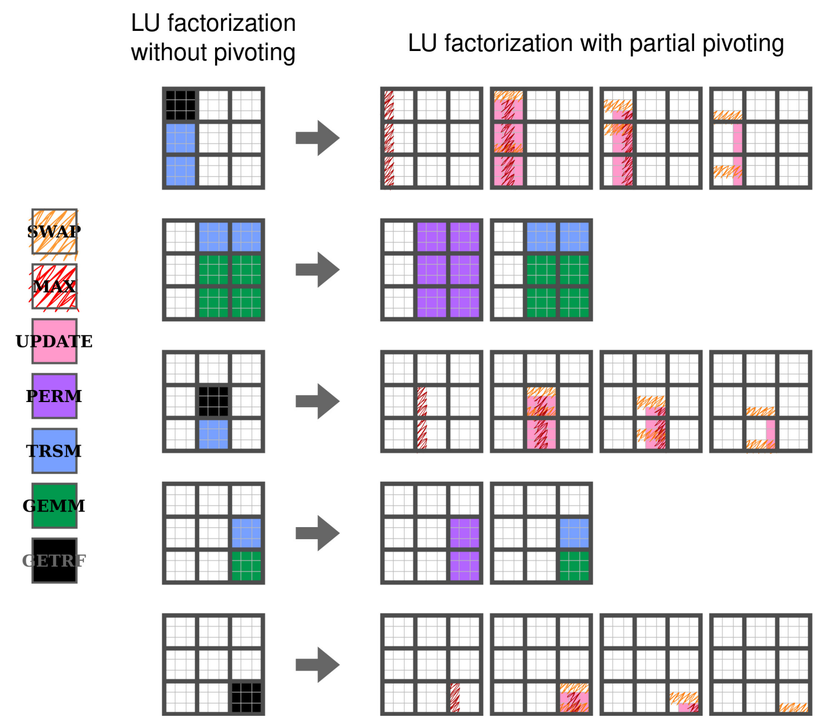
Problems

- Need to look for the maximum value at each column
  - Many small grain reduction tasks
  - Add synchronizations and communications
- Need to apply efficiently the permutation
  - Require to collect data from many tiles of the matrix, on different devices
  - Another set of reduction/broadcast operations that need to be implmented efficiently on heterogeneous distribued context
- Due to the last two points, the set of tasks to manage becomes extremely larger that w/o pivoting

Task-based LU factorization w/o partial pivoting

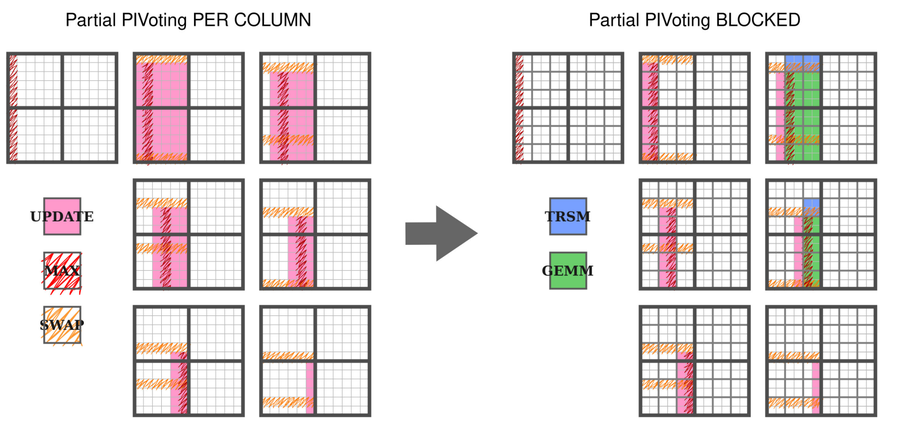


Extension to LU w/ partial pivoting

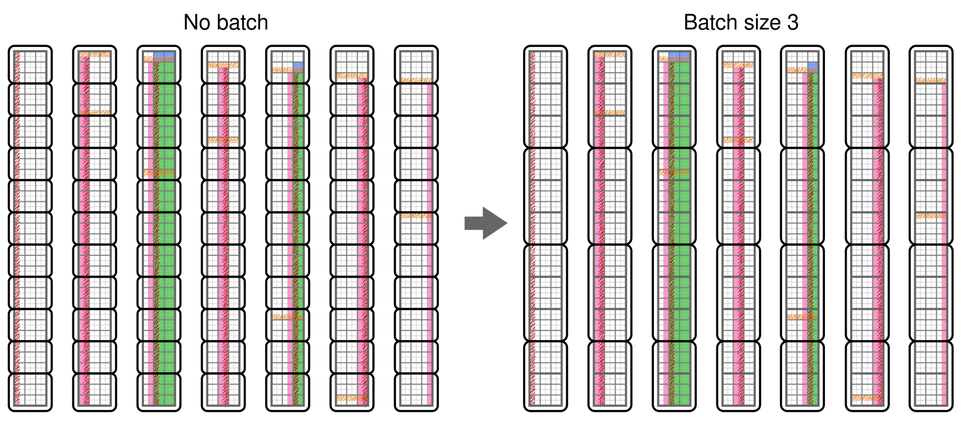


Task number optimizations

Inner blocking



Task batching



Inner blocking

- Increases tasks granularity
- Exploits runtime local reduction

Task batching

- Reduces the runtime overhead
- Reduces the number of tasks
- Increases tasks size

Reduction optimizations

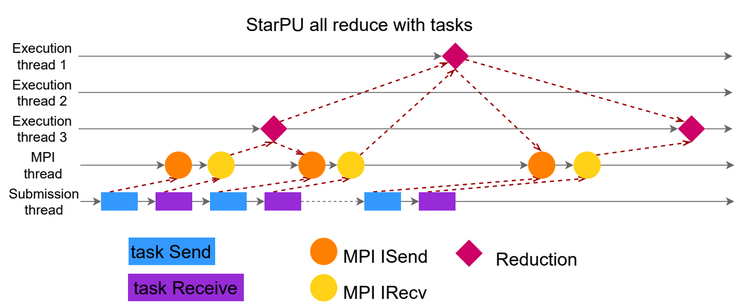
All reduce using the STARPU tasks

- STARPU handles the communications
- Different workers involved in the reduction
- Does not block the workers while waiting for the communications
- Generates many small tasks

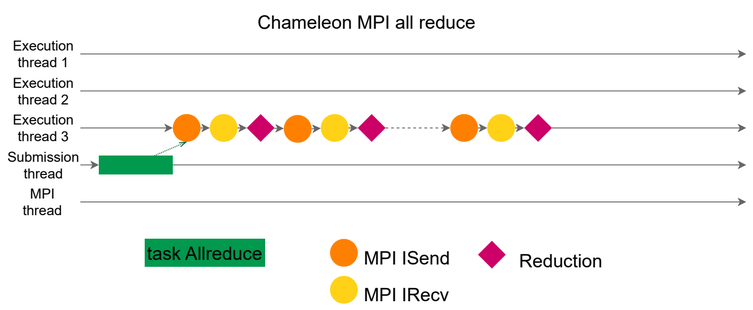
All reduce with MPI communication in one STARPU task

- One worker per reduction
- Blocks the worker while waiting for the communications
- Reduces the runtime overhead
- Reduces the number of tasks

All reduce with STARPU tasks

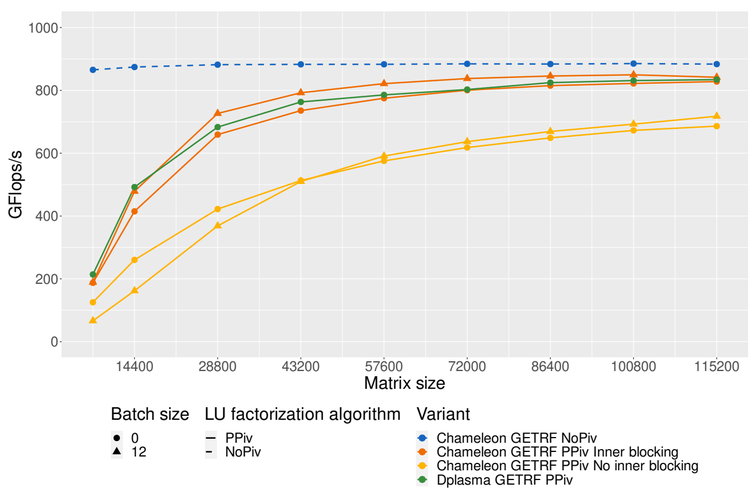


All reduce in one STARPU task

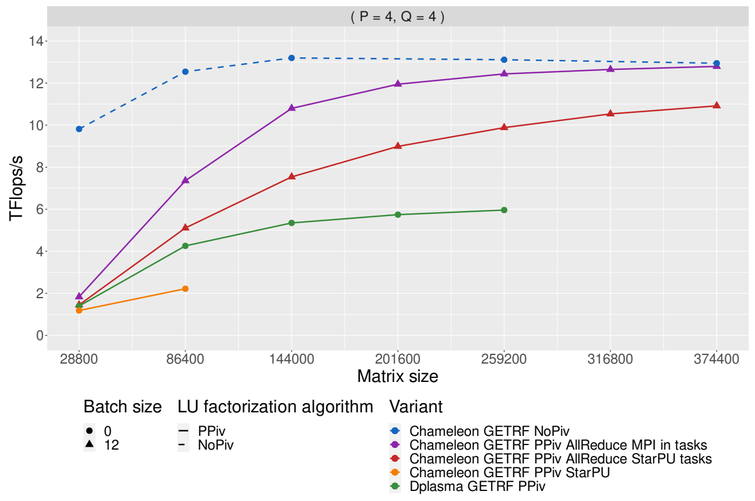


Experiments

Results in shared memory



Results on distributed architecture



Results

- Inner bocking with tasks batching solution reaches 95% of the NoPiv performance in shared memory for matrices larger than 70k
- On distributed architecture, the best solution reaches the NoPiv performance (13TFlops/s)
- Both solutions outperform the OpenSource task-based existing solution from DPLASMA
- The scalability of the best solution reaches 97% on 16 nodes

Future work

- Use of hierchical tasks to filter the permutation
- Choose the batching size dynamically

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