Composition of Algorithmic Building Blocks in Template Task Graphs

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Task Graphs and their Composition

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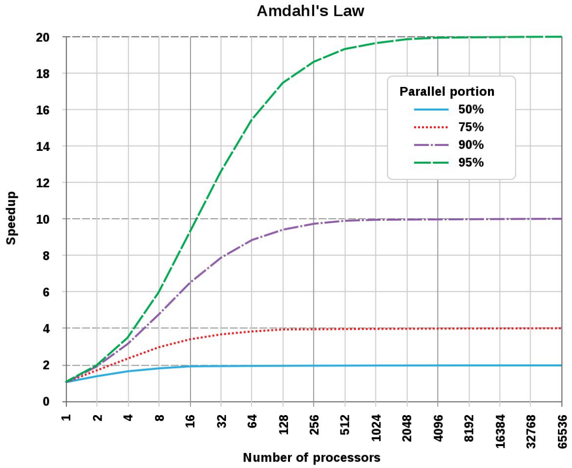
Do we know how to compose task graphs?

Why Task Graph Composition

- Assume N consecutive functions implemented using the same task programming model
  - N forks and joins without composition
  - Write-back to data structures instead of direct flow
  - Gene Amdahl says that's bad

https://upload.wikimedia.org/wikipedia/commons/1/1a/Gene_Amdahl_on_a_classic_grey_Ferguson_tractor_at_Amdahl.JPG



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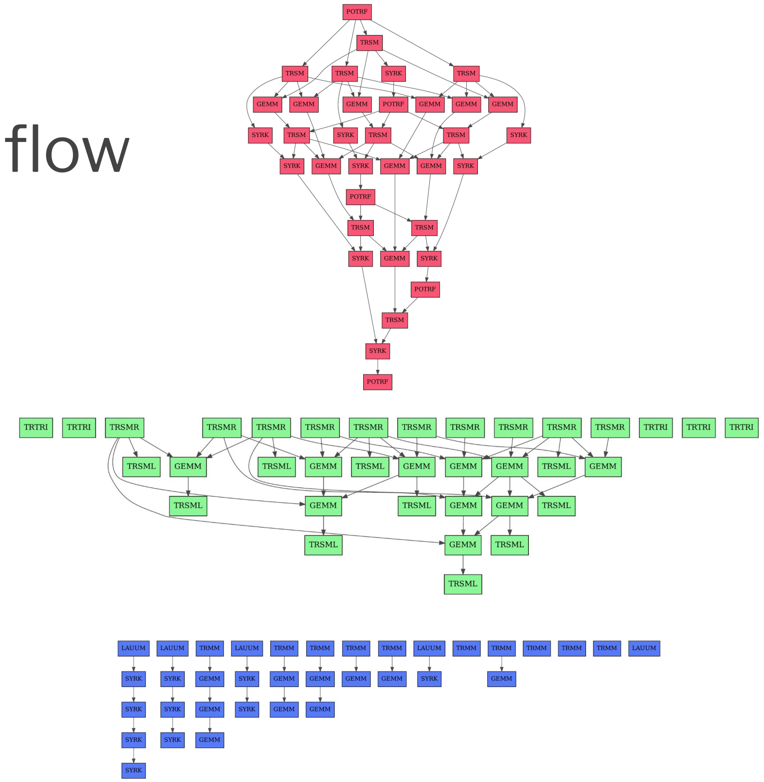
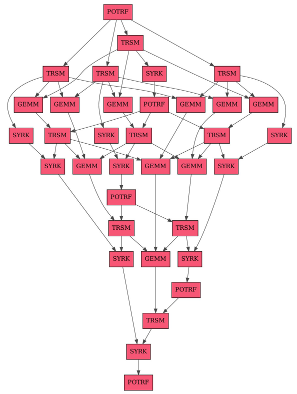
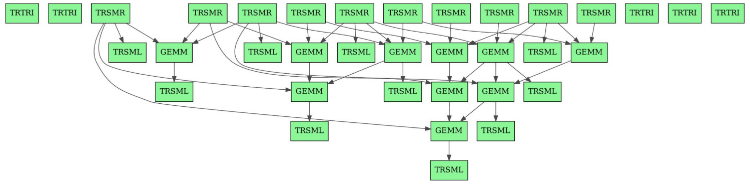


Example: Cholesky Matrix Inversion

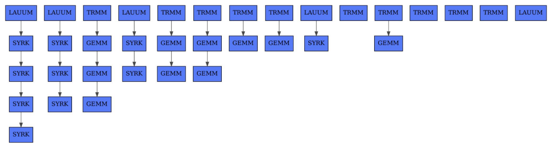
- Cholesky Factorization (POTRF) followed by matrix inversion
    - Given A, compute A^{-1}
    - A: Hermitian positive-definite matrix



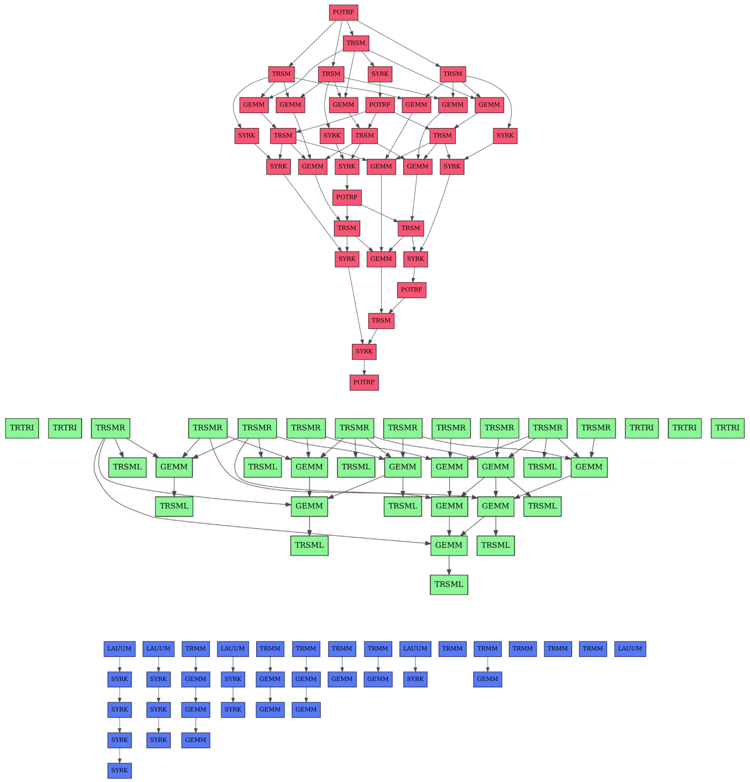
- Inversion: Given L from POTRF
    - Compute L^{-1} from L (TRTRI)
    - Compute $A^{-1} = (L^{-1})^T L^{-1}$ (LAUUM)
    - POTRI = TRTRI ⊕ LAUUM

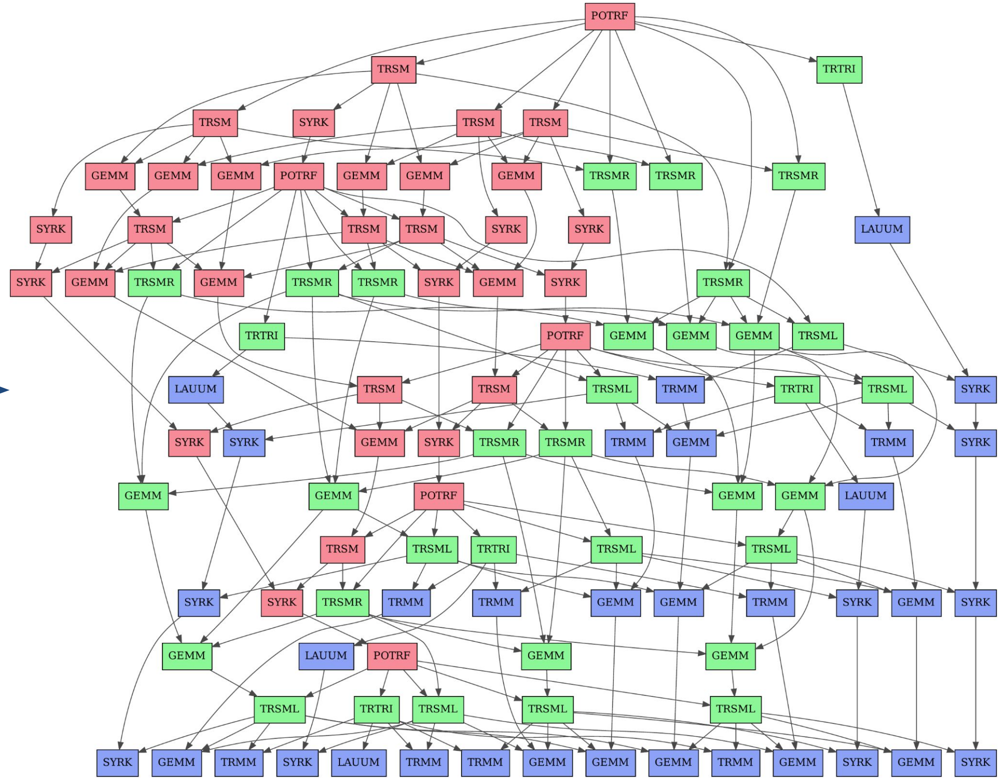


- POINV = POTRF ⊕ POTRI
  = POTRF ⊕ TRTRI ⊕ LAUUM



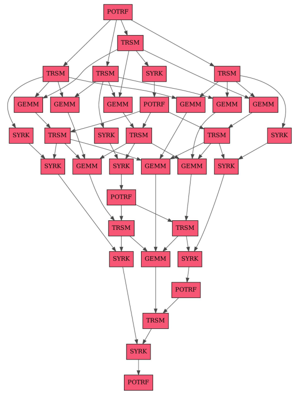
Task Graph Composition at Work

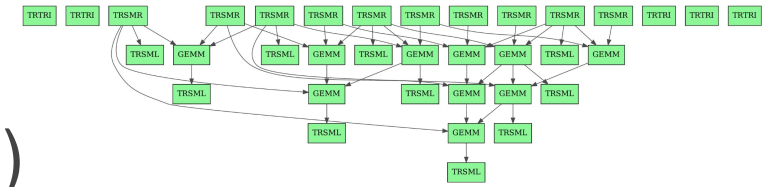


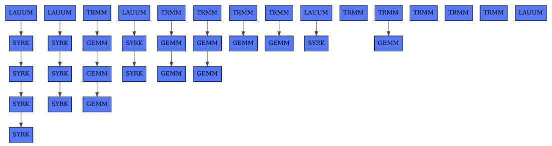


Existing Approaches to Task Graph Composition

- **Dependency**-based approaches
  - OpenMP, OmpSs, StarPU, PaRSEC DTD, ...
  - Sequential discovery of tasks and their dependencies
  - Limited discovery windows
  - Limited scalability
- **Handle**-based approaches (HPX)
  - Composition through future passing
  - One future per element
  - Significant efforts for LA required
- **Parameterized Task Graphs** (PaRSEC PTG)
  - Flow within a graph
  - Operates exclusively on data collections
  - Missing: external interfaces

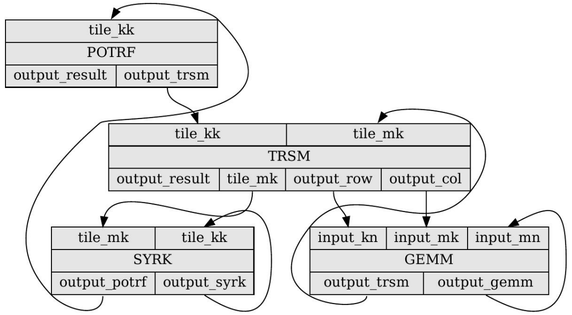


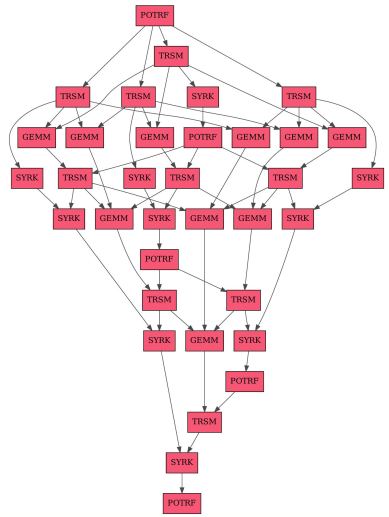




Introducing: Template Task Graphs

- Algorithms expressed as **abstract graphs**
  - All possible edges in task graph declared *a priori*
  - Template Tasks (TT) with input and output terminals
  - **Tasks are instances** of TTs identified by IDs
  - **Edges** represent **sets of values** flowing between tasks
  - Data movement through the graph handled by TTG
- Template Task Graph unrolled during execution
  - Fully distributed graph discovery



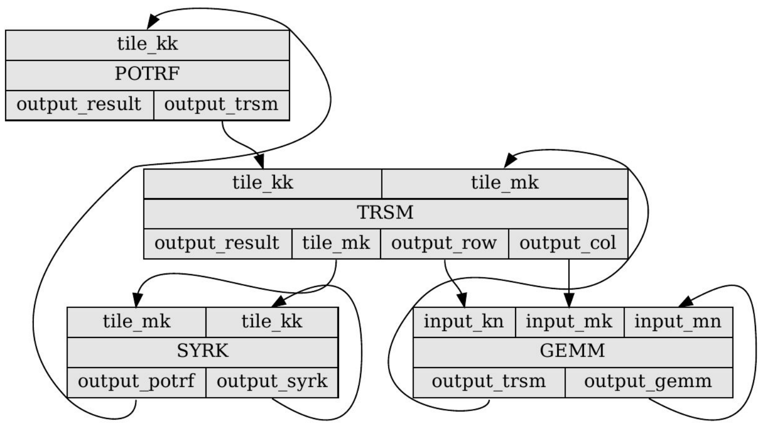


G. Bosilca, R. J. Harrison, T. Herault, M. M. Javanmard, P. Nookala and E. F. Valeev, "The Template Task Graph (TTG) - an emerging practical dataflow programming paradigm for scientific simulation at extreme scale," *2020 IEEE/ACM Fifth International Workshop on Extreme Scale Programming Models and Middleware (ESPM2)*, 2020.

Edges in Template Task Graphs

- **Edges** connect template tasks through **terminals**
- Tasks decide on which output terminal(s) to send data

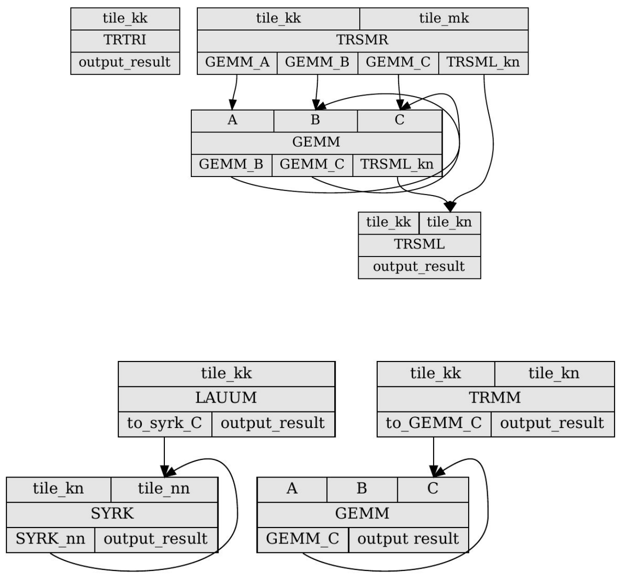
- Edges connect
  - A single output terminal (its input)
  - Multiple input terminals (its output)



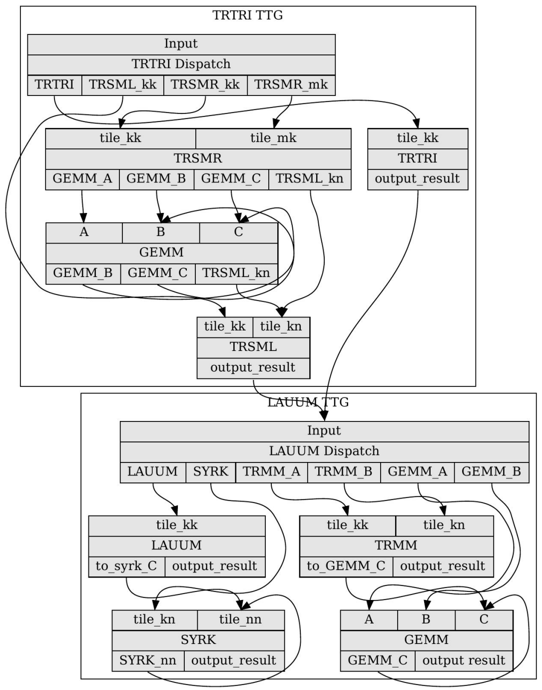
- Can we use Edges to connect Task Graphs?*

Connecting Graphs: Edges as Composition Devices

- Introduce **Dispatch Tasks** to Task Graphs
  - Dispatch incoming data to internal tasks
  - Internal edges and tasks not visible to outside
  - Single output edge, to connect to successors



Composition



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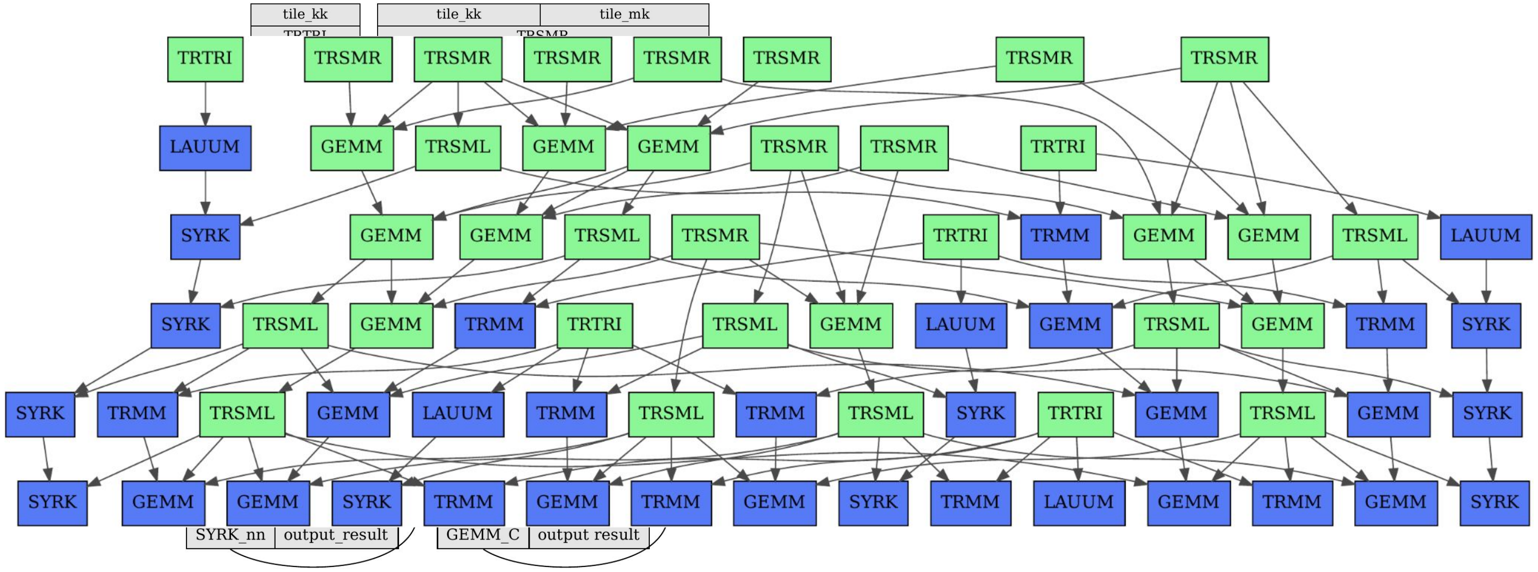
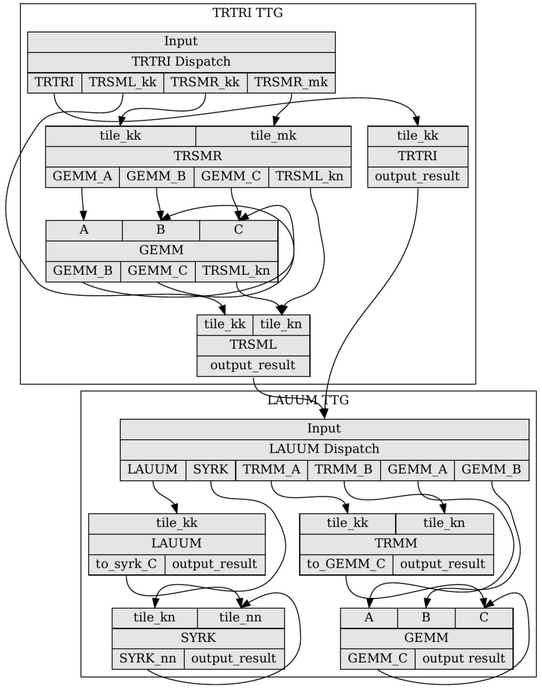




Task Graphs as Black Box Functions

- **Edges**: well-defined interface between graphs
- Internal structure of a task-graph irrelevant to caller

- Composing TRTRI & LAUUM into POTRI

```cpp
using namespace std;
auto make_potri_ttg(ttg::Edge<Key2, MatrixTile>&input,
                    ttg::Edge<Key2, MatrixTile>&output)
{
  ttg::Edge<Key2, MatrixTile>
                    trtri_to_lauum("trtri_to_lauum");

  auto ttg_trtri = make_trtri_ttg(input, trtri_to_lauum);
  auto ttg_lauum = make_lauum_ttg(trtri_to_lauum, output);

  auto ins  = make_tuple(ttg_trtri->template in<0>());
  auto outs = make_tuple(ttg_lauum->template out<0>());
  vector<unique_ptr<ttg::TTBase>> ops(2);
  ops[0] = std::move(ttg_trtri);
  ops[1] = std::move(ttg_lauum);

  return ttg::make_ttg(std::move(ops),
                       ins, outs, "POTRI TTG");
}
```

Input Edge

Output Edge

Internal Edge

Internal Subgraphs

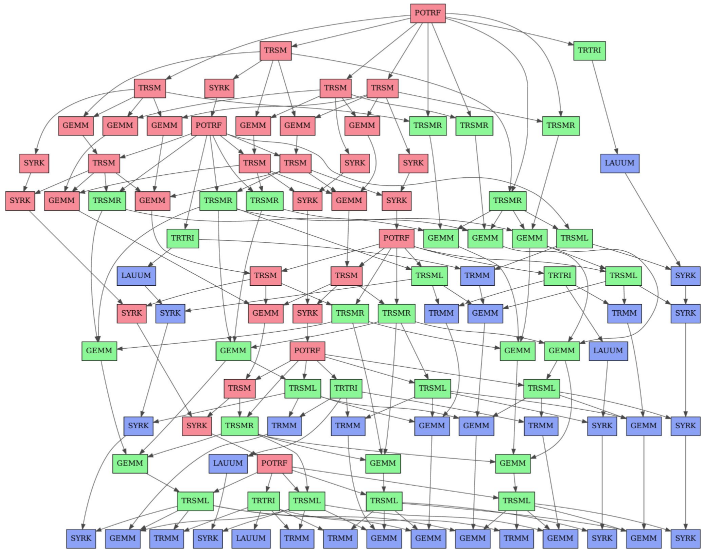
New Template Task Graph

Benefits of Task Graph Composition

- Minimized serial application parts

- Application-level **depth-first execution** (memory reuse)
  - Cache reuse
  - Device data transfer minimization (for out-of-core computation)

- **Flexibility**: reusing intermediate results becomes trivial
  - Example: tiles of a Cholesky factorized matrix
    - As input for POTRI
    - Used together with POTRI results
  - TTG will manage tile copies

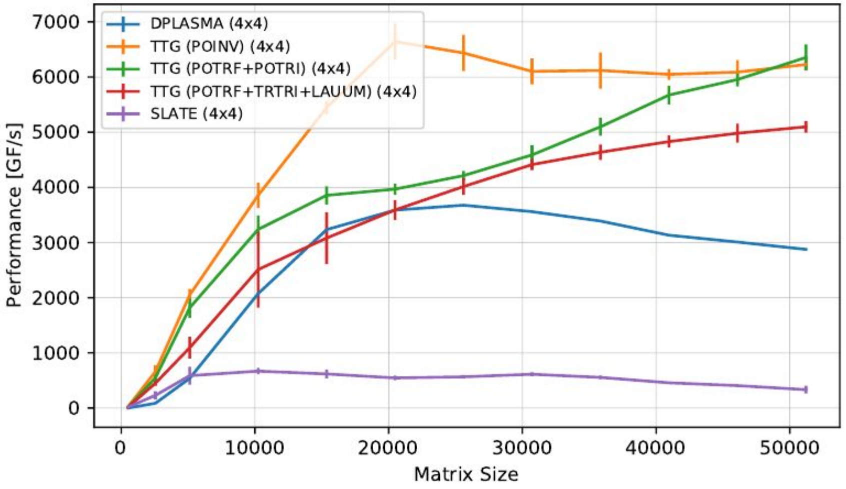


Experimental Evaluation: Test System Setup

- All experiments executed on Hawk
  - Installed at HLRS in Stuttgart, Germany
  - 2x64core AMD EPYC nodes, 2.2 GHz
  - Mellanox ConnectX-6
- Open MPI 4.1.0
- GCC 10.2.0

POINV Composition

- 16 nodes on Hawk, 64 threads each
- Full composition beneficial for small tile sizes
  - Fine-grain composition helps hide communication latency
  - Beats both DPLASMA (based on PaRSEC PTG) and SLATE



(a) Tile size 128.

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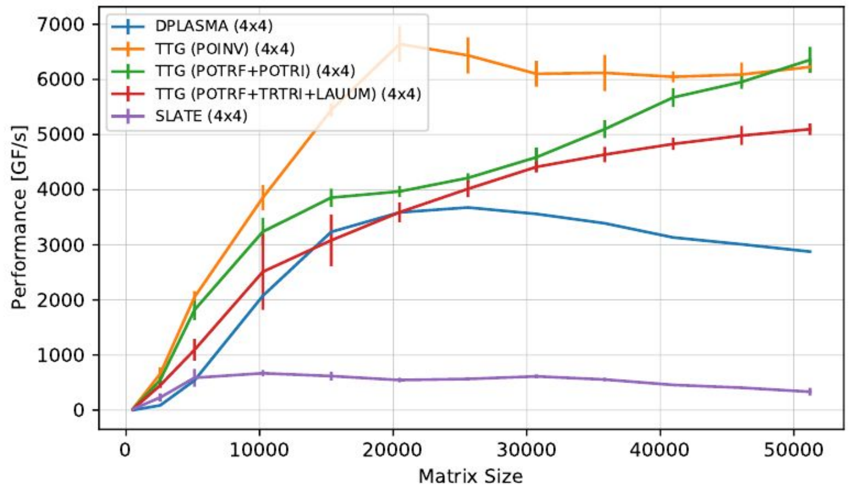

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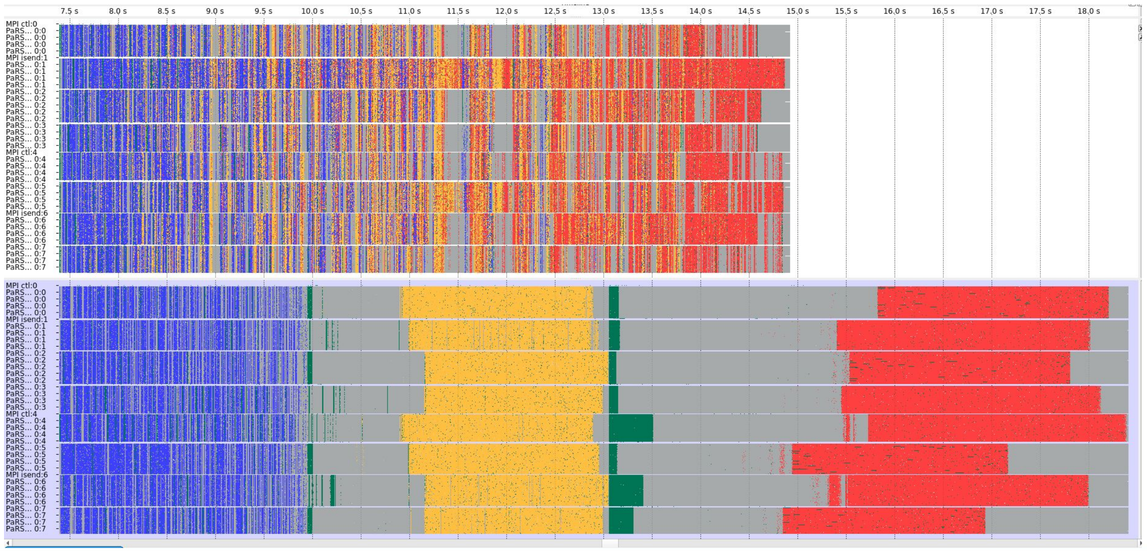

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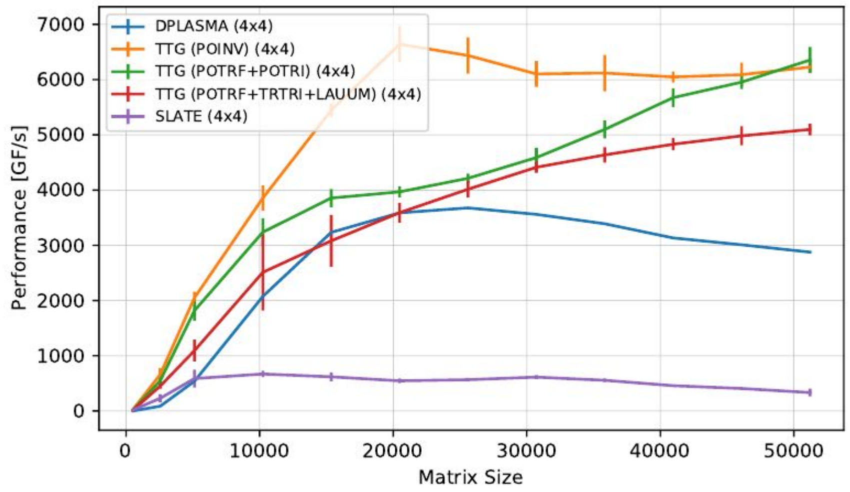

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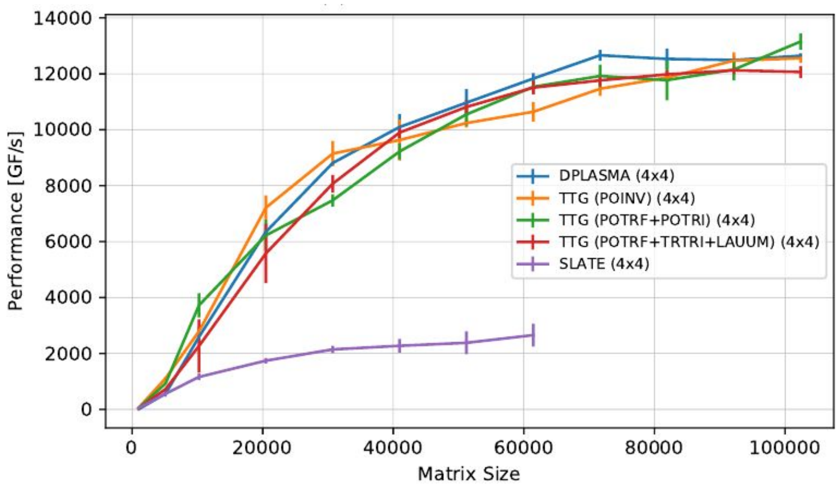
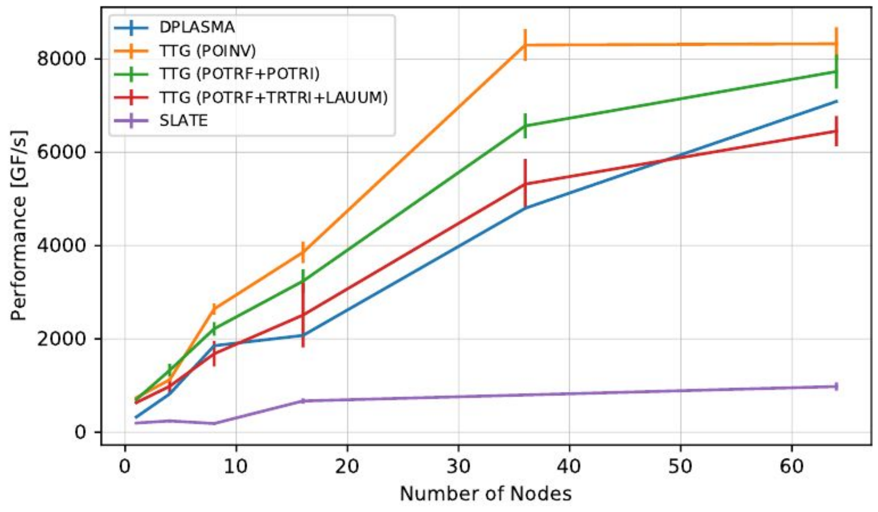


(b) Tile size 256.

POINV Composition

- Scaling from 1-64 nodes on Hawk
  - Full composition beneficial for smaller tasks



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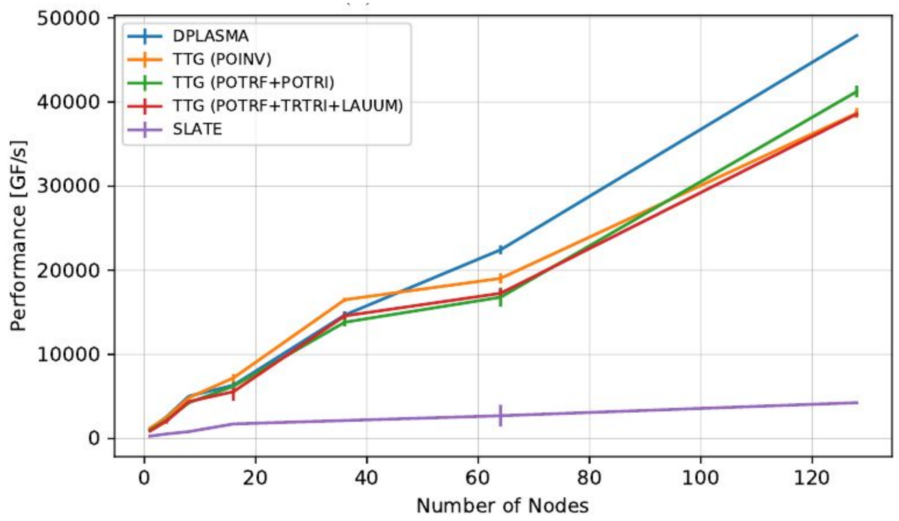

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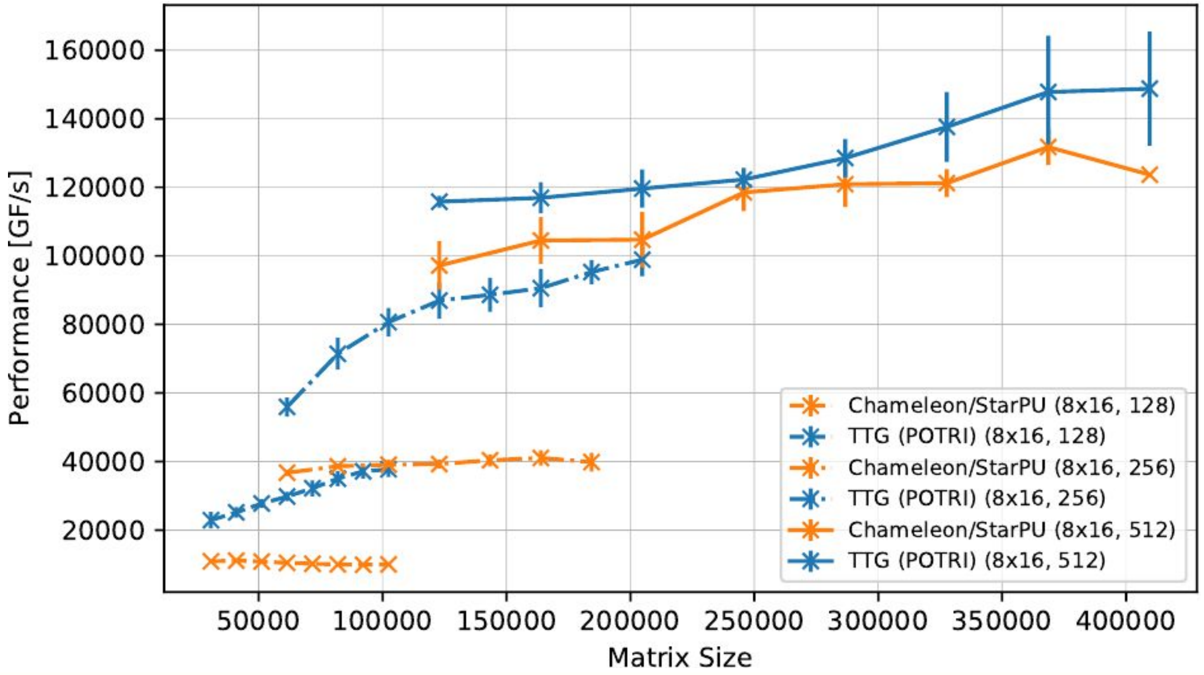
POTRI: Comparison with Chameleon

- 128 nodes on Hawk
- Chameleon (v1.1.0, using StarPU 1.3.9)
- POTRI : TRTRI ⊕ LAUUM
- TTG performance benefits
  - Depth-first execution
  - Parallel distributed task discovery



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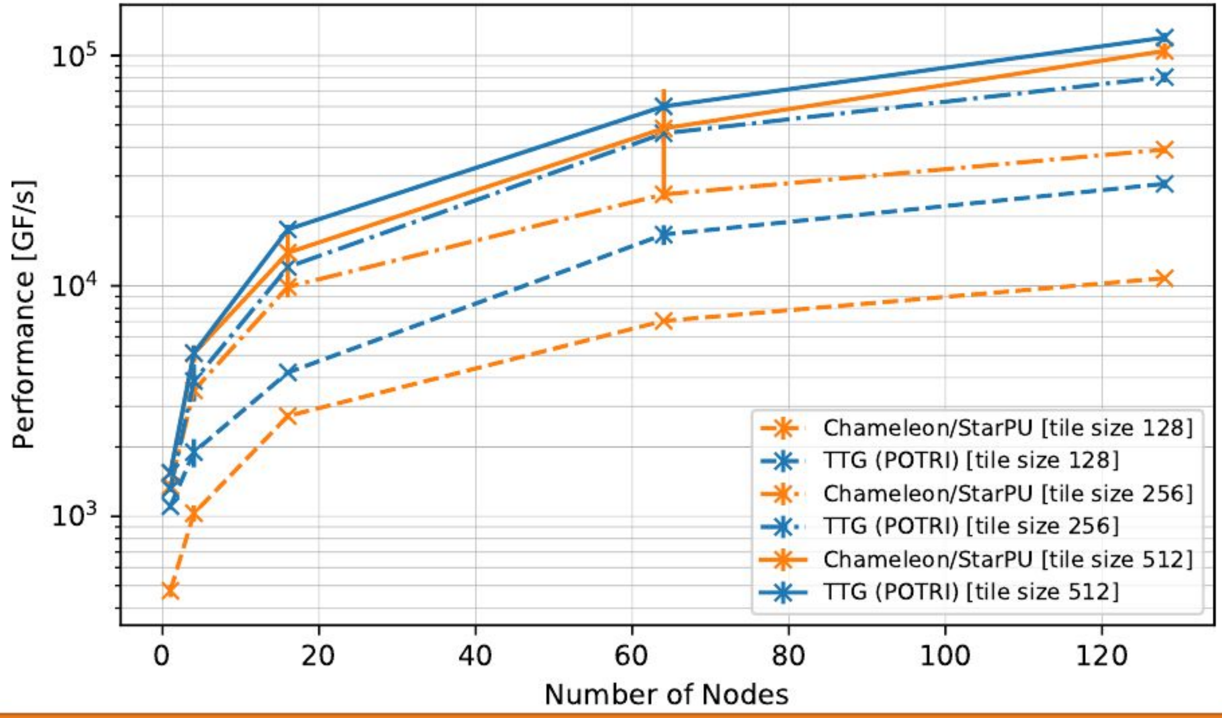
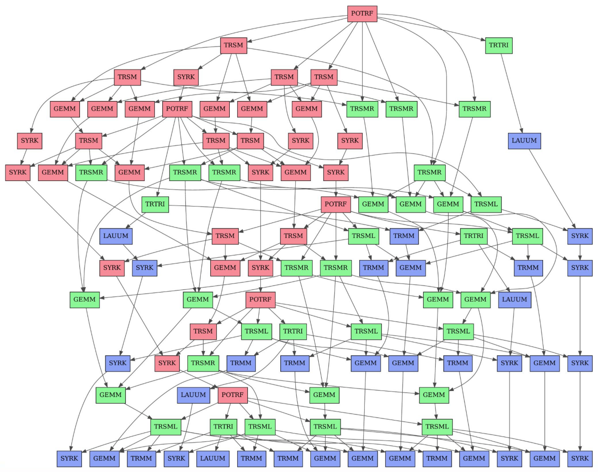


Conclusions

- Task graph composition helps hide communication latencies

- **Edges represent sets of future values**
  - Distribute values to multiple subscribers (input terminals)
  - Provide a clean interface to encapsulate black-box functionality
  - Coupling of graphs through single input, single output Edge

- Full-scale application composition without breaking abstraction barriers



Future Work

- GPU support (beyond Unified Memory, 2023)
- Inverse data flow: pulling data from the bottom of the task graph
- Coupling of different task-based programming models
  - Example: TiledArray & TTG

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Questions?

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Check us out on Github:
github.com/TESSEorg/ttg/

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