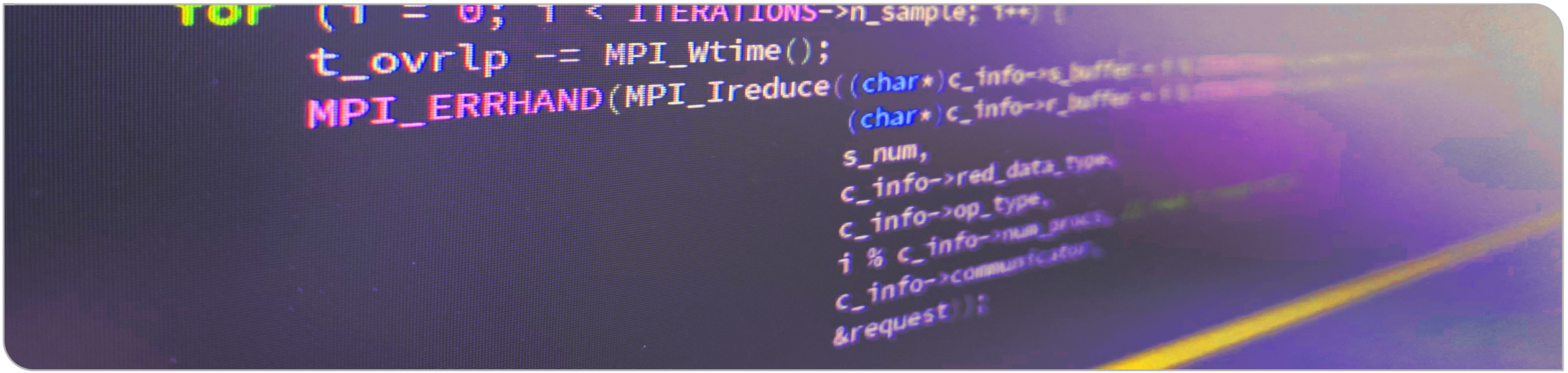
Karlsruhe Institute of Technology

Scalable Discrete Algorithms for the Basic Toolbox

HLRS Results and Review Workshop · 2024-10-10

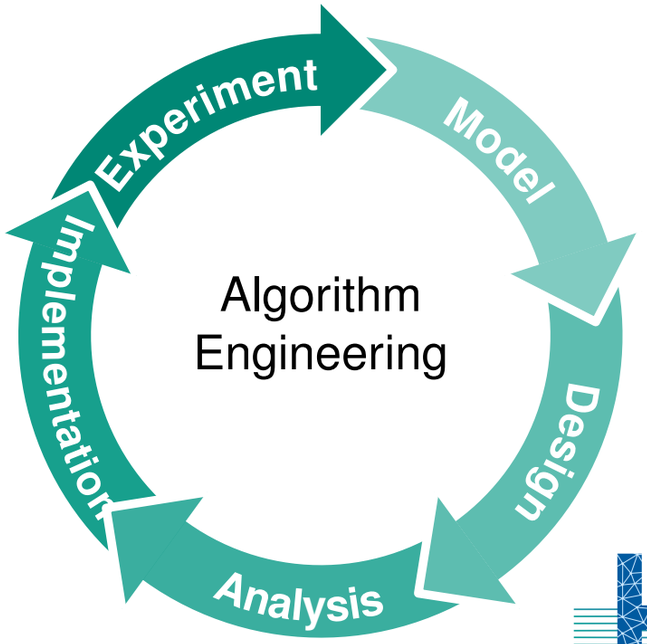
Lukas Hübner, Florian Kurpicz, Peter Sanders, Matthias Schimek,
Dominik Schreiber, Daniel Seemaier, **Tim Niklas Uhl**

Institute of Theoretical Informatics (ITI), Algorithm Engineering



Project Overview

Design **scalable algorithms** for essential building blocks in **massively parallel computing**, with a focus on non-numerical algorithms for **Big Data** applications



HoreKa

Basic Toolbox

Automated SATisfiability
- SAT Solving
- malleable job scheduling

Graph Algorithms
- Minimum Spanning Tree
- Connected Components
- Triangle Counting
- Graph Partitioning

Text Indexing
- String Sorting

Fault Tolerance

Communication Primitives
- MPI C++ bindings

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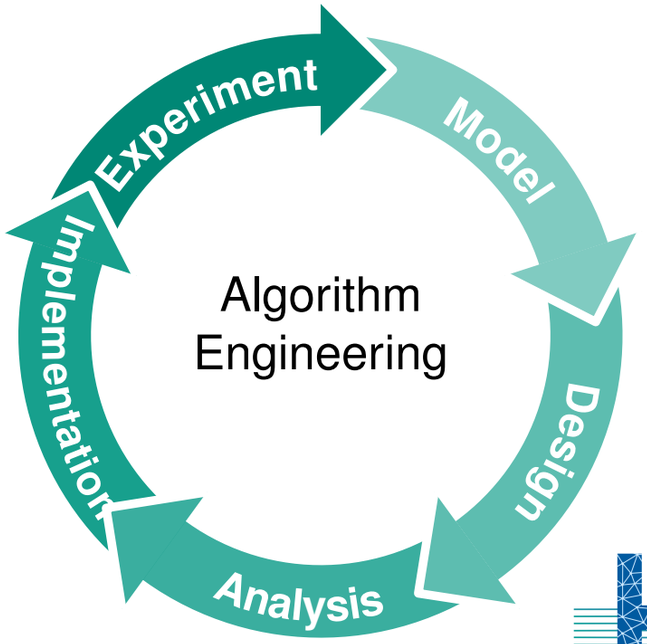

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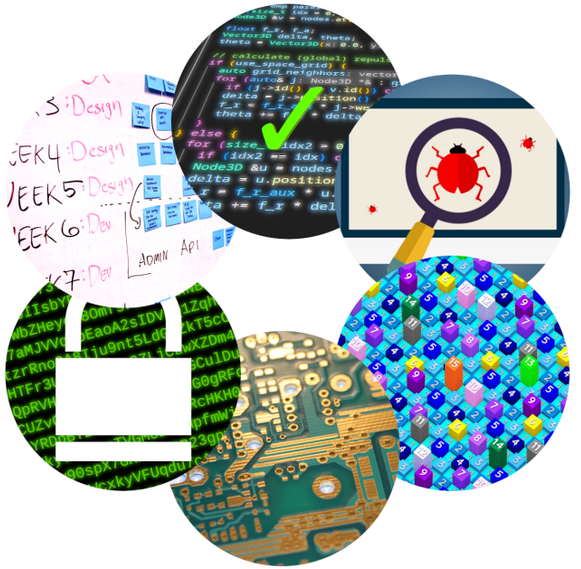
SAT Solving and Malleable Job Scheduling

Sanders, Schreiber [SAT'20–24, Euro-Par'23, JAIR, SPAA'24, HOPC'24]

The $\mathcal{NP}$-complete SAT problem [Cook 1971]

Find a **satisfying variable assignment** for **propositional formula**

$F := \bigwedge_{c \in C} (\bigvee_{\ell \in c} \ell)$



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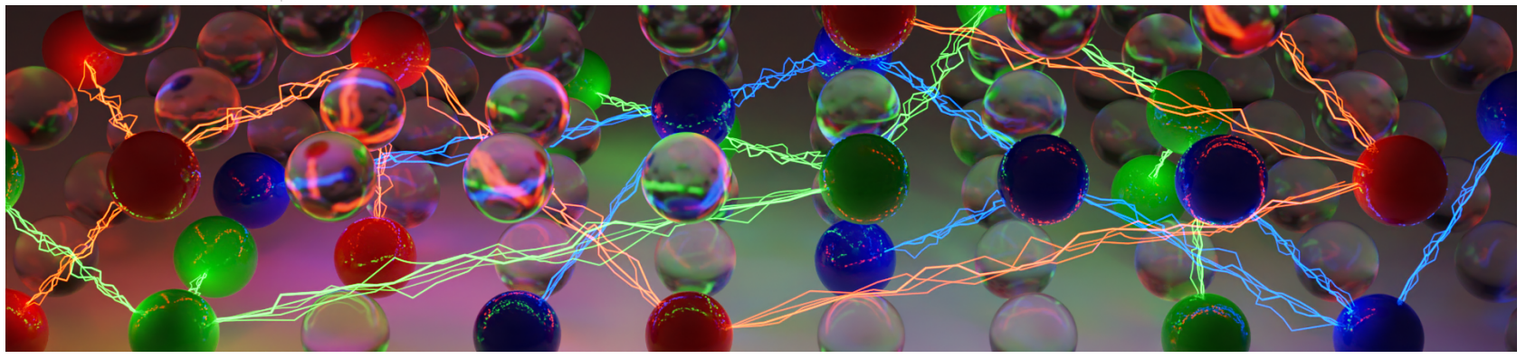
The mAllob system

schedule · balance · solve · prove



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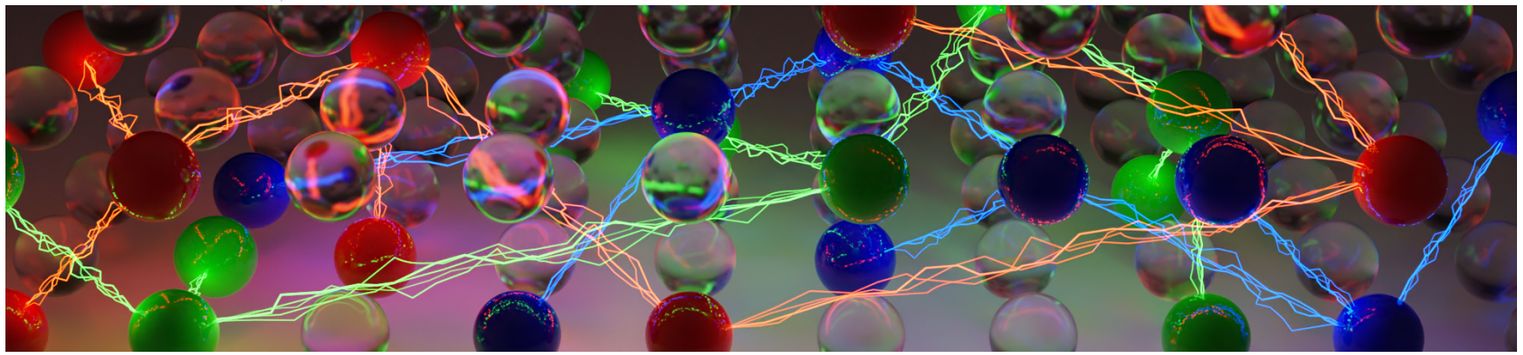

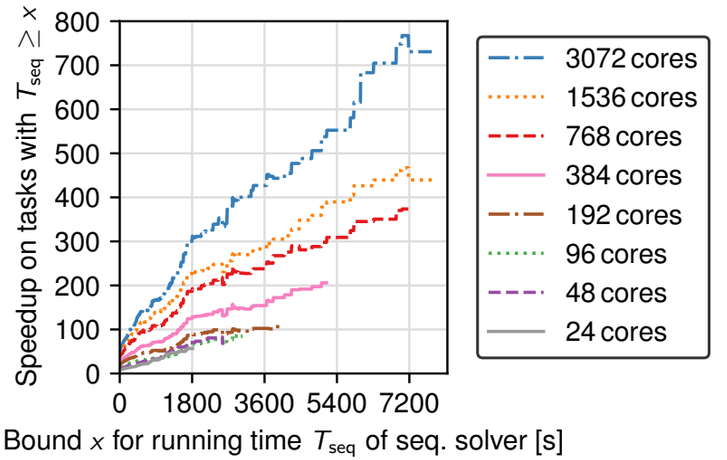

400 SAT instances

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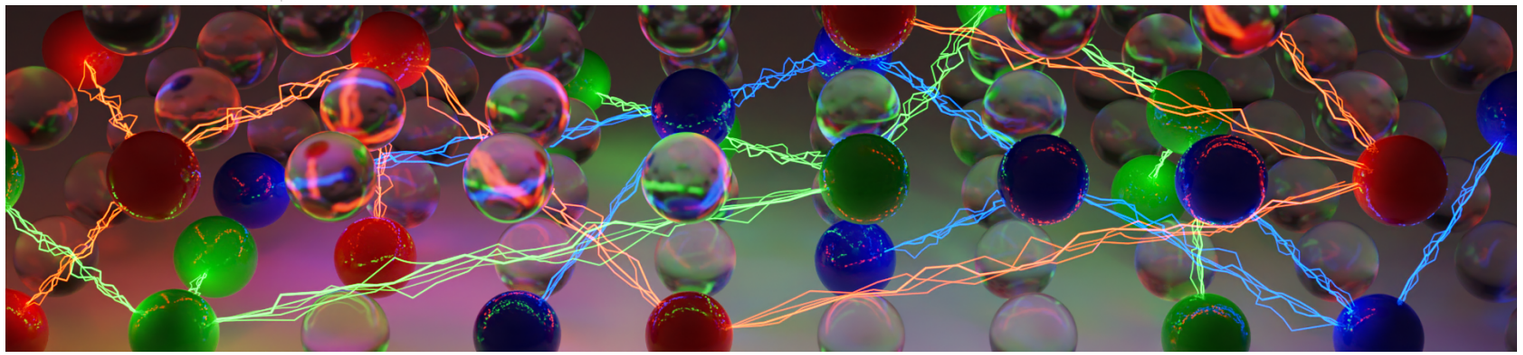

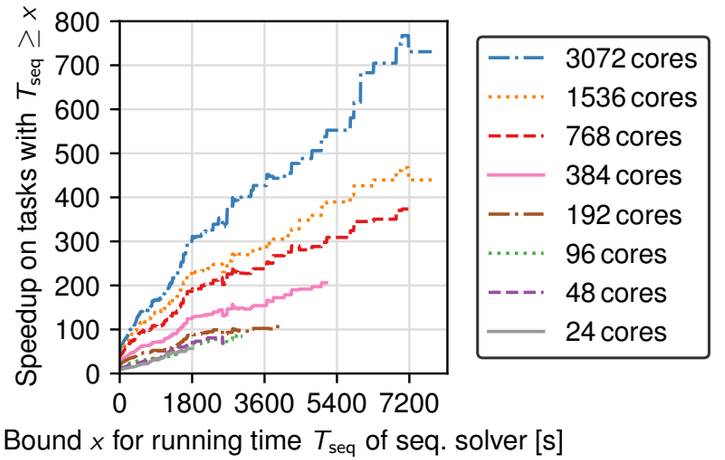

400 SAT instances

- Latest research: **Produce and validate proofs** that a result is correct
  $\Rightarrow$ Enables use of distributed SAT solving for **critical applications**, e.g., **software verification**

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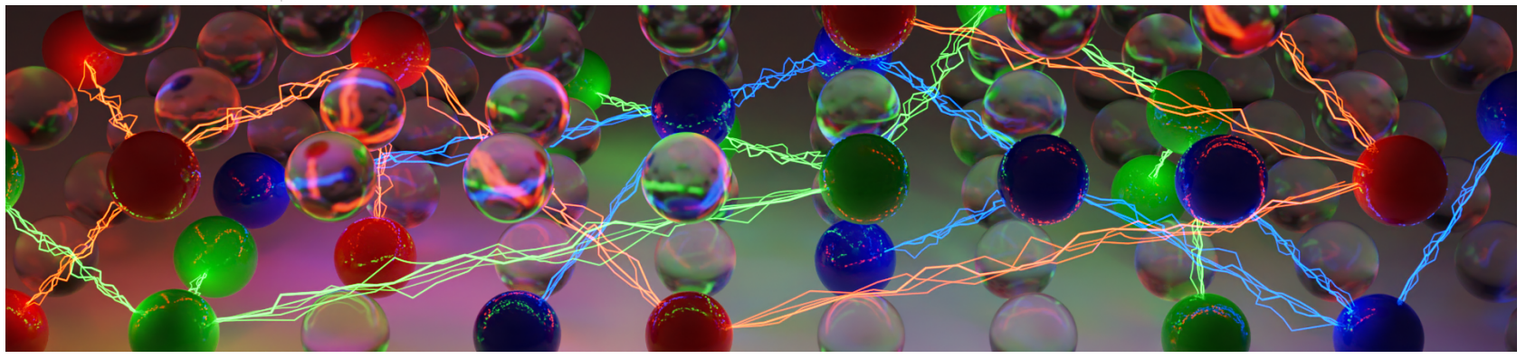

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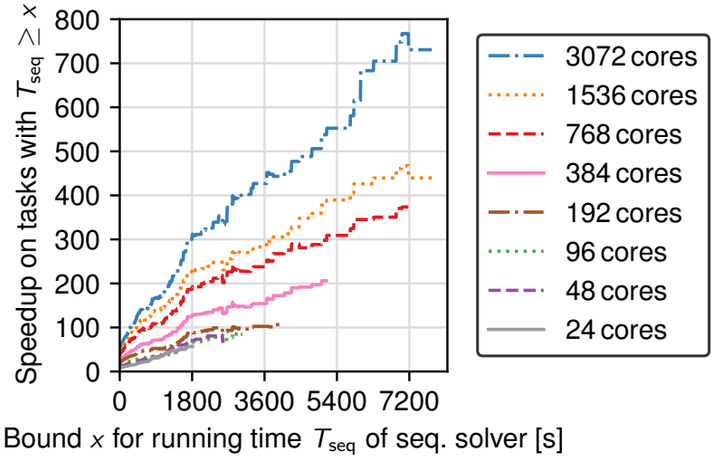
*"Mallob-mono is now, by a **wide** margin, the most powerful SAT solver on the planet."* —Byron Cook, Amazon Science, 2021

Best cloud solver @ SAT'20–24

Dissertation Award **Fahiem Bacchus Award**

github.com/domschrei/mallob



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Scalable Distributed Graph Partitioning

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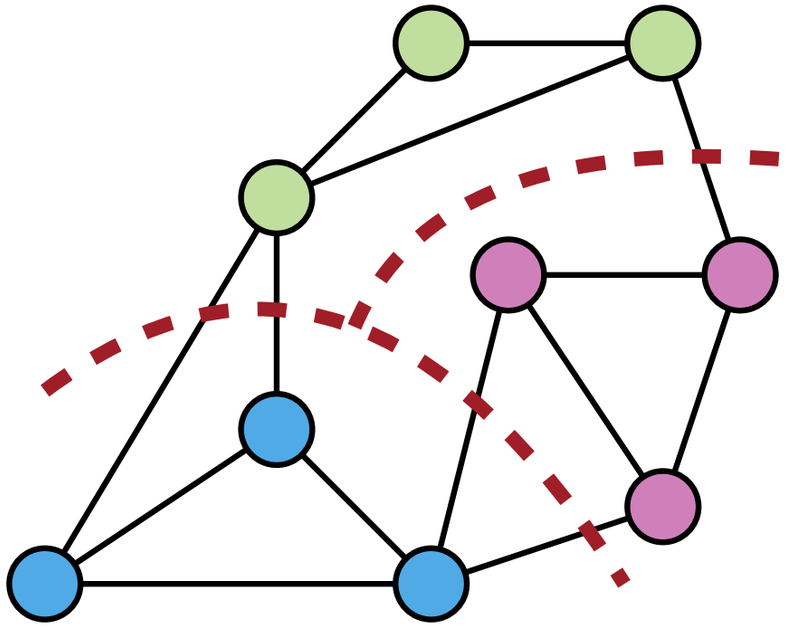

Given a graph $G = (V, E, c, \omega)$, partition V into k disjoint blocks such that:

- blocks have roughly the same weight:
  $c(V_i) \leq L_{\max} := (1 + \varepsilon)\frac{c(V)}{k}$
- while minimizing some objective, e.g., edge cut:
  $\sum_{i \neq j} \omega(E_{ij})$

Nearest Neighbor Search

Distributed Databases

Circuit Placement

Load Balancing

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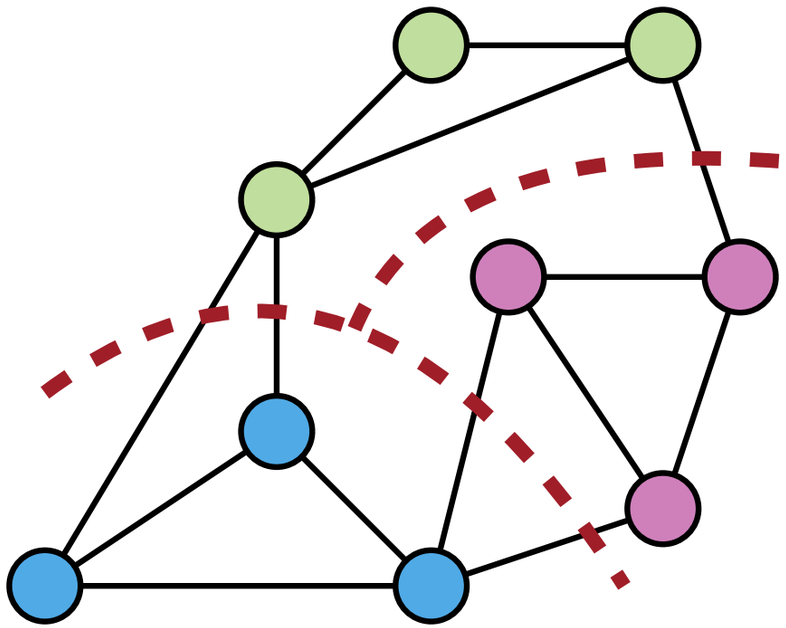

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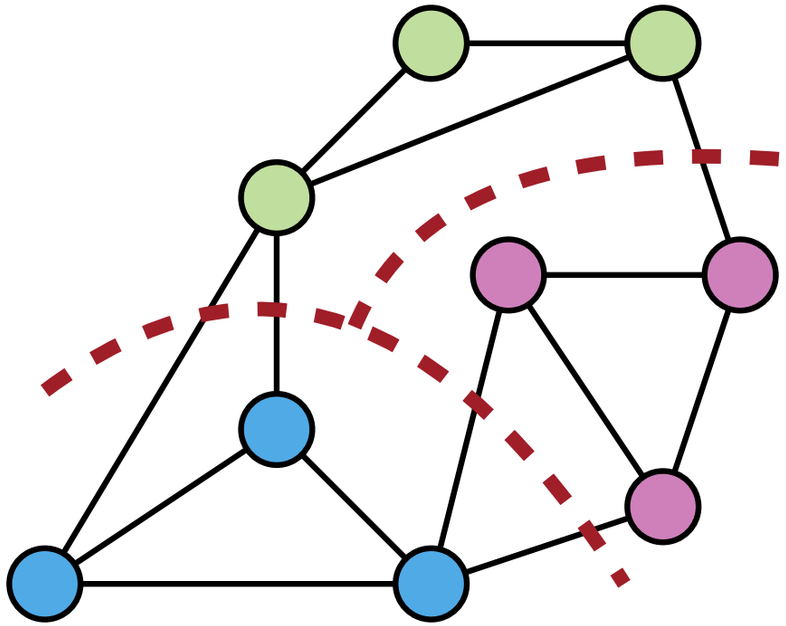

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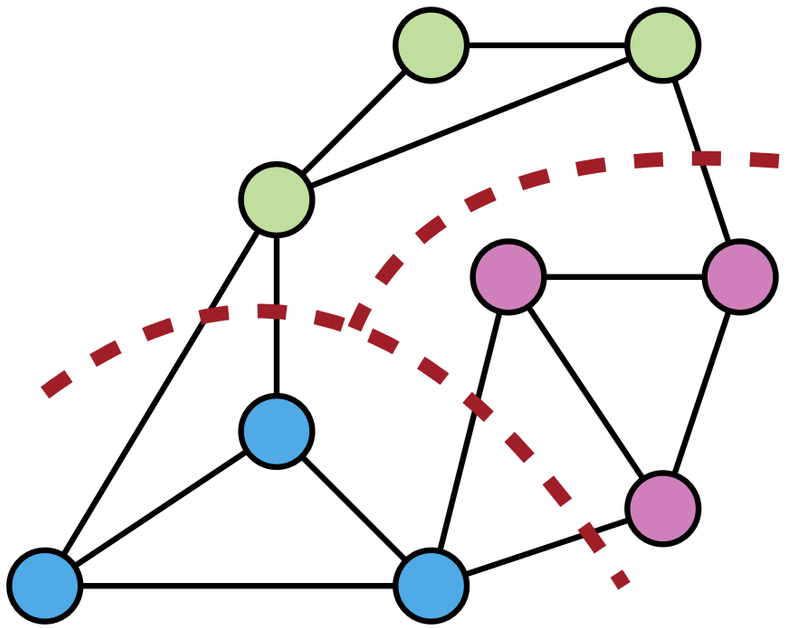

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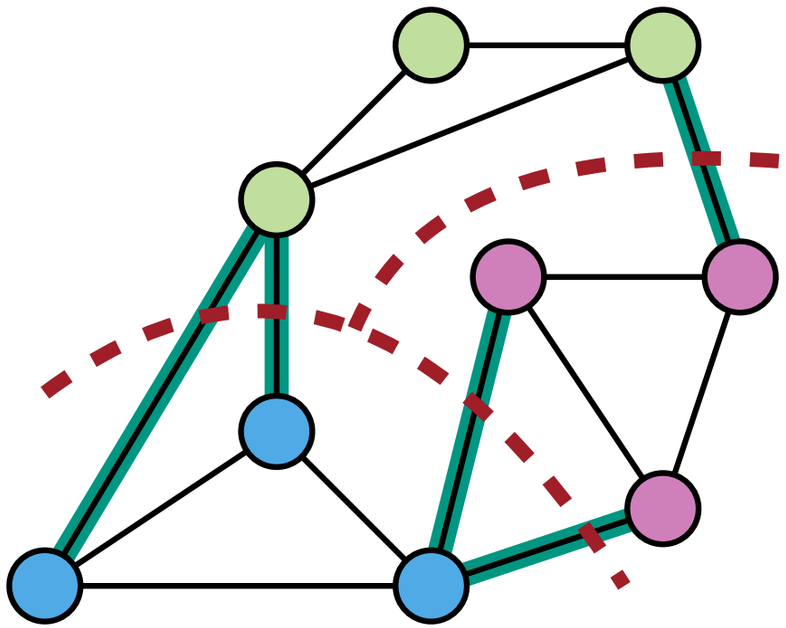

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$$\sum_{i \neq j} \omega(E_{ij}) = 5$$

edges between blocks i and j

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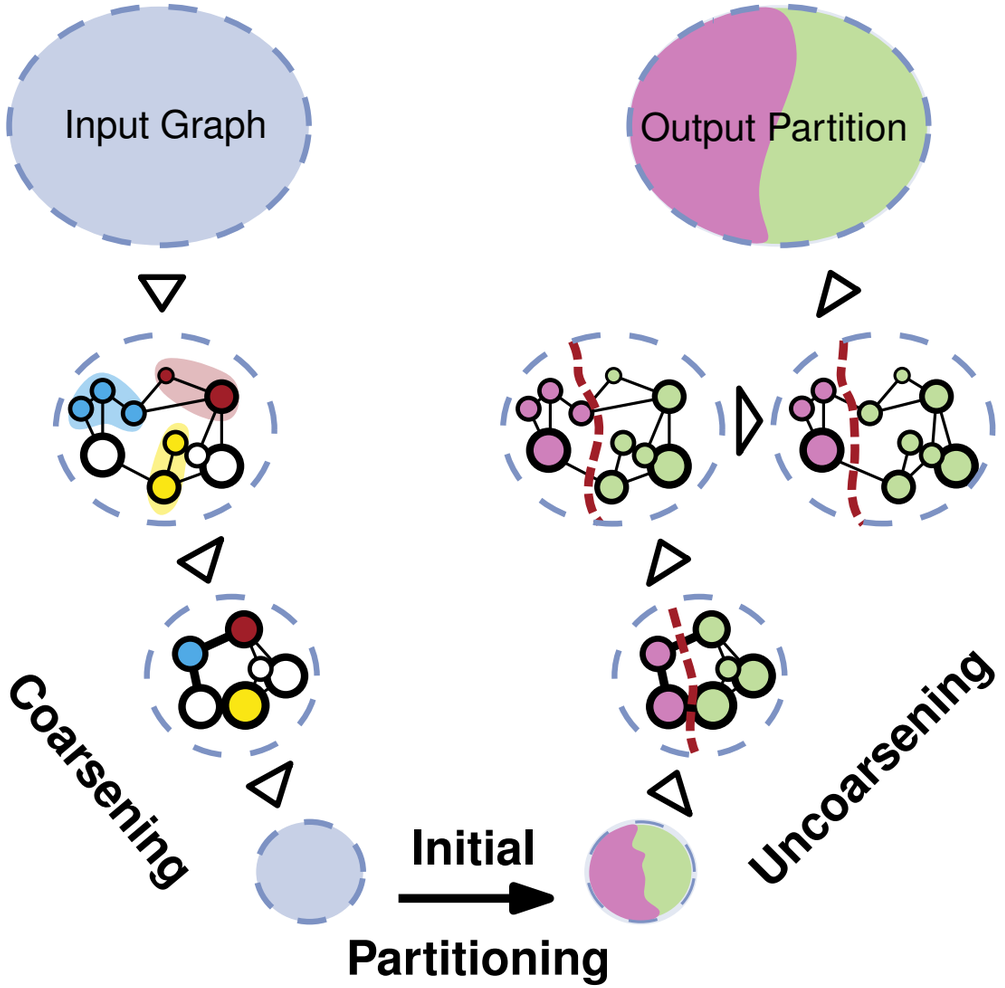

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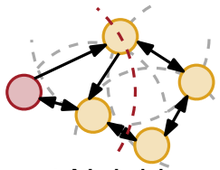
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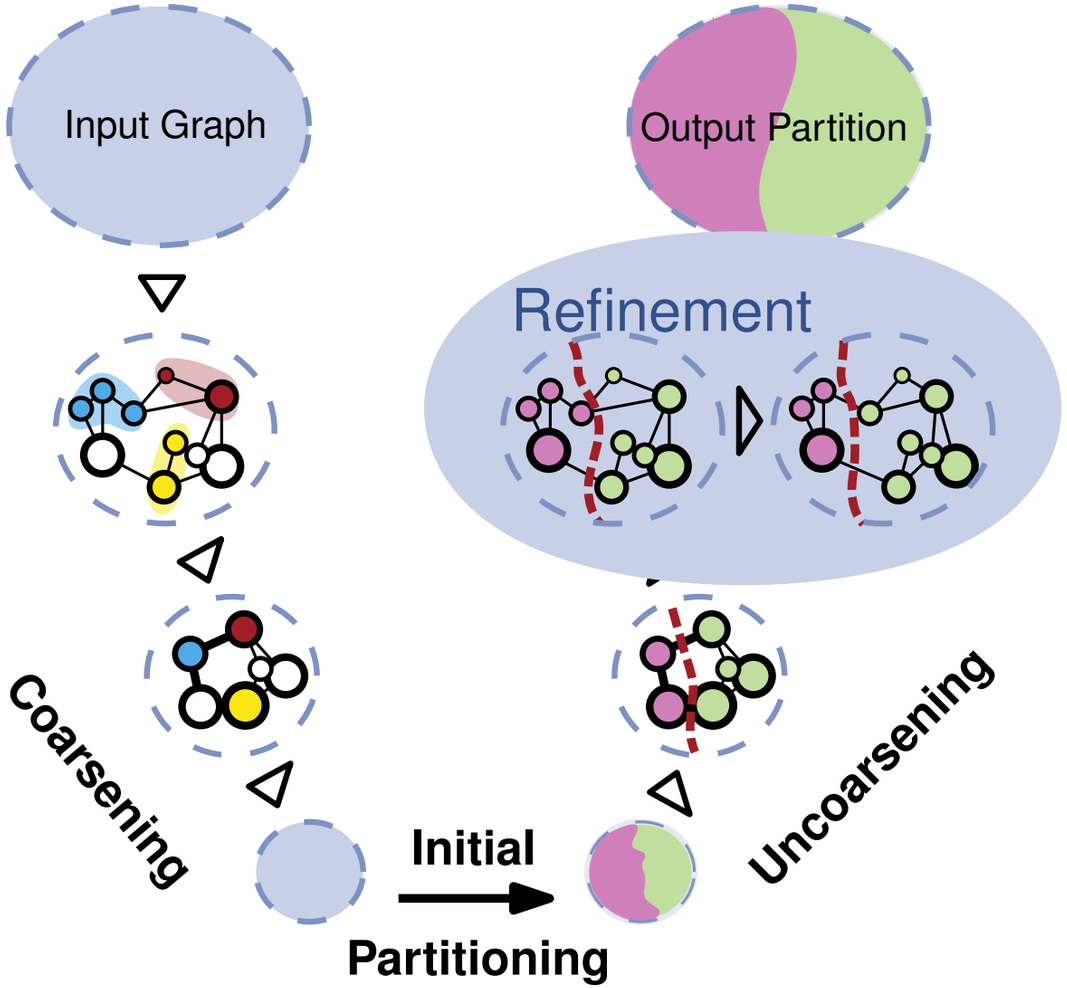

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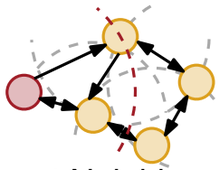
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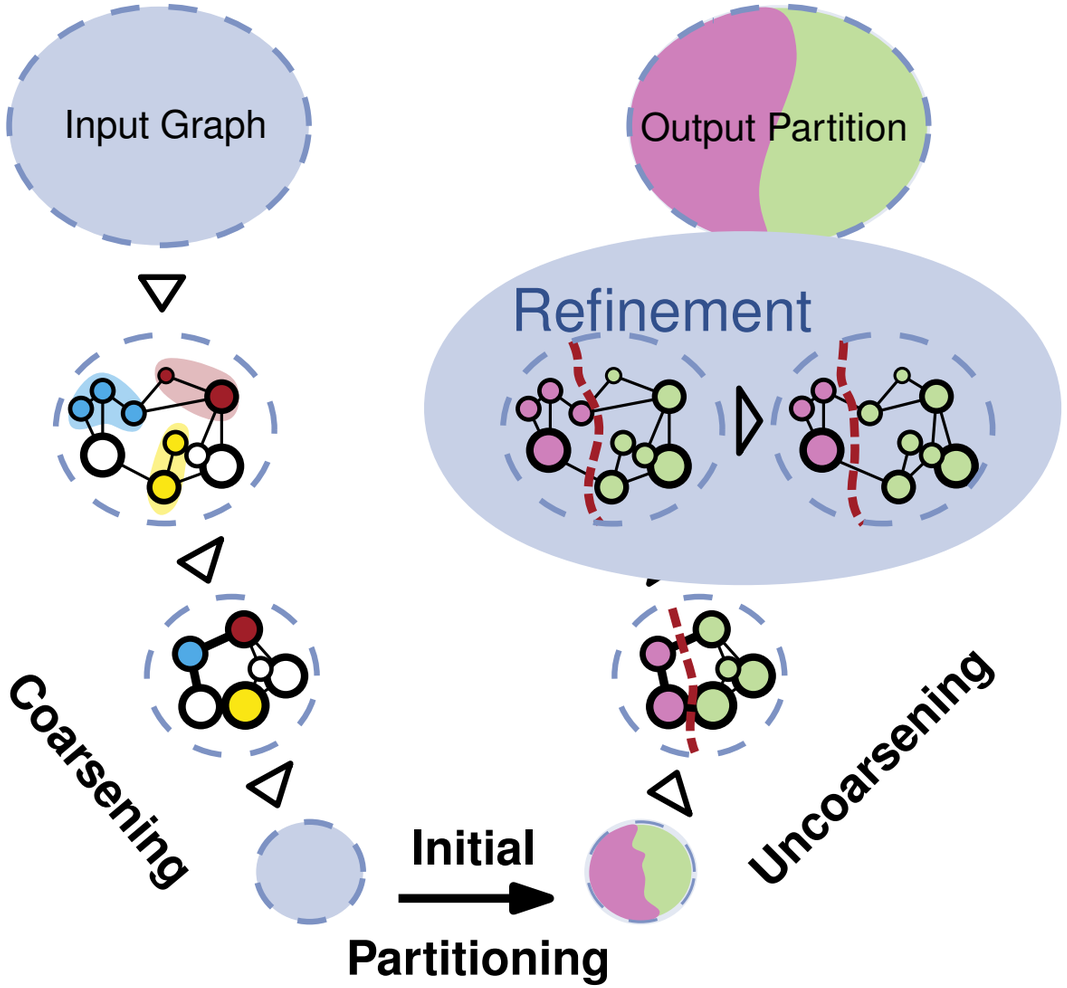

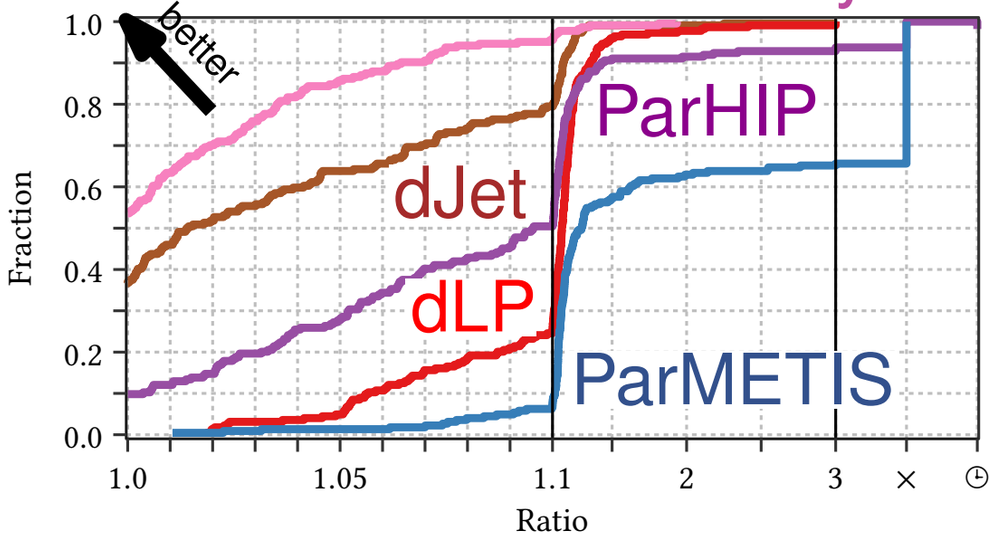

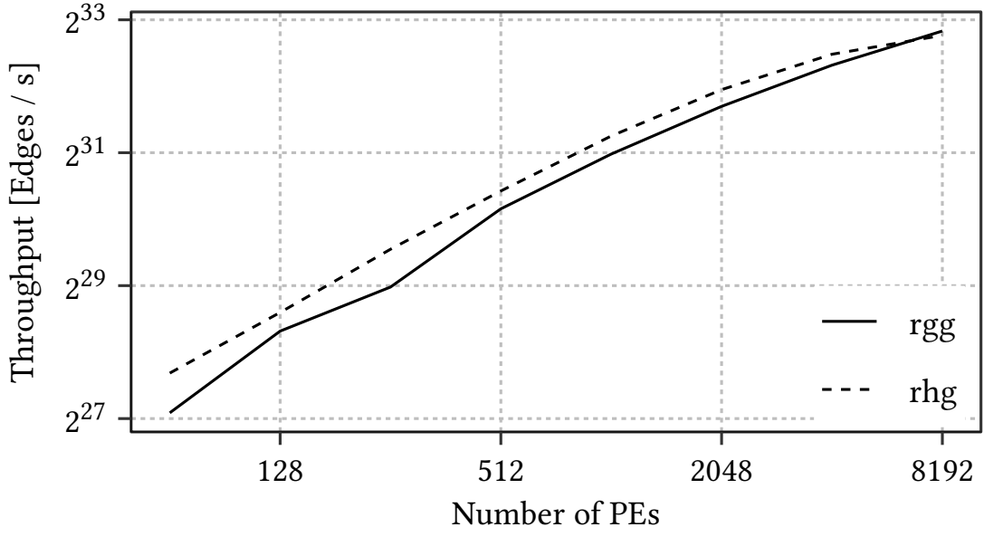

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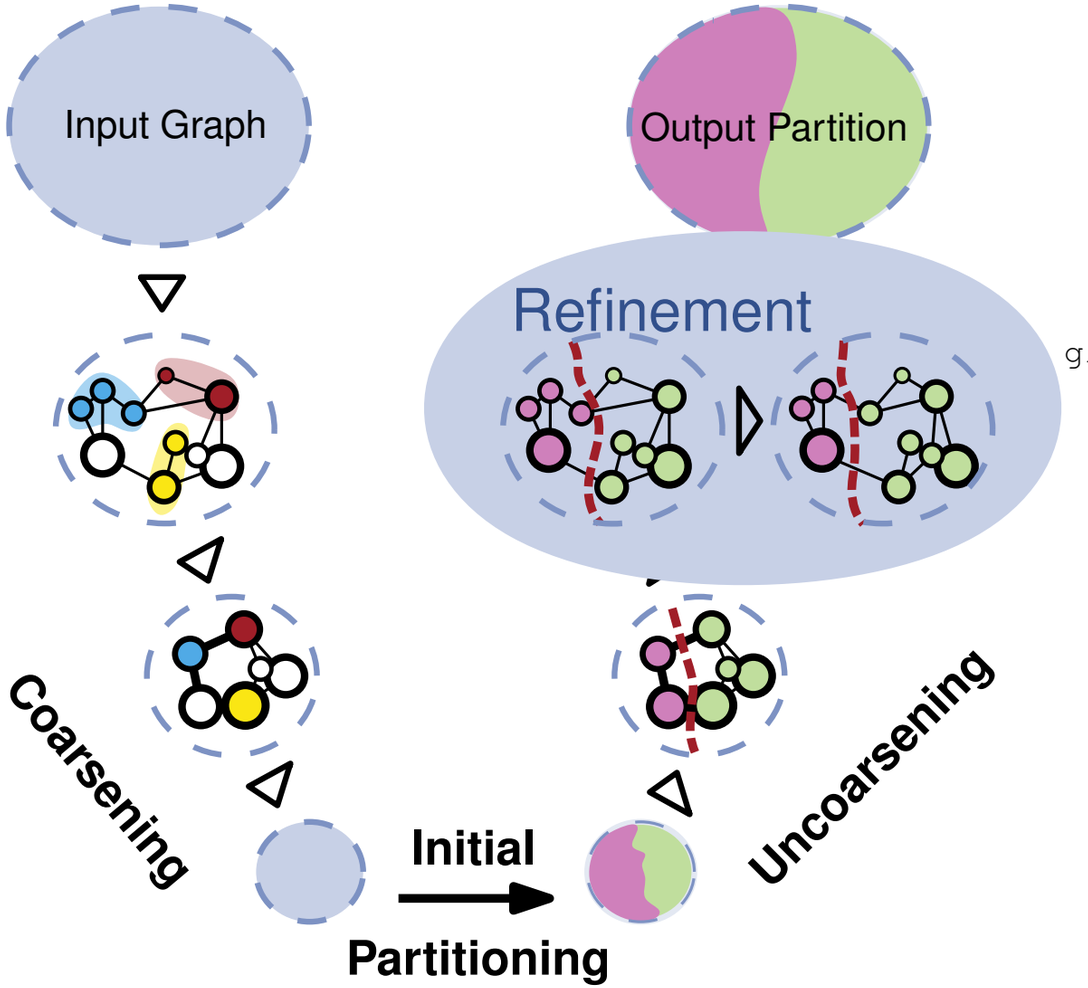
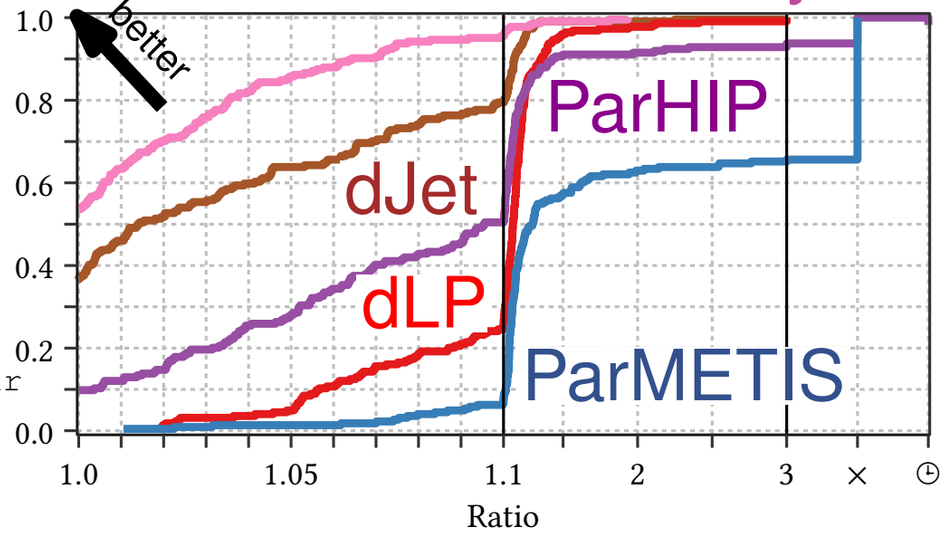
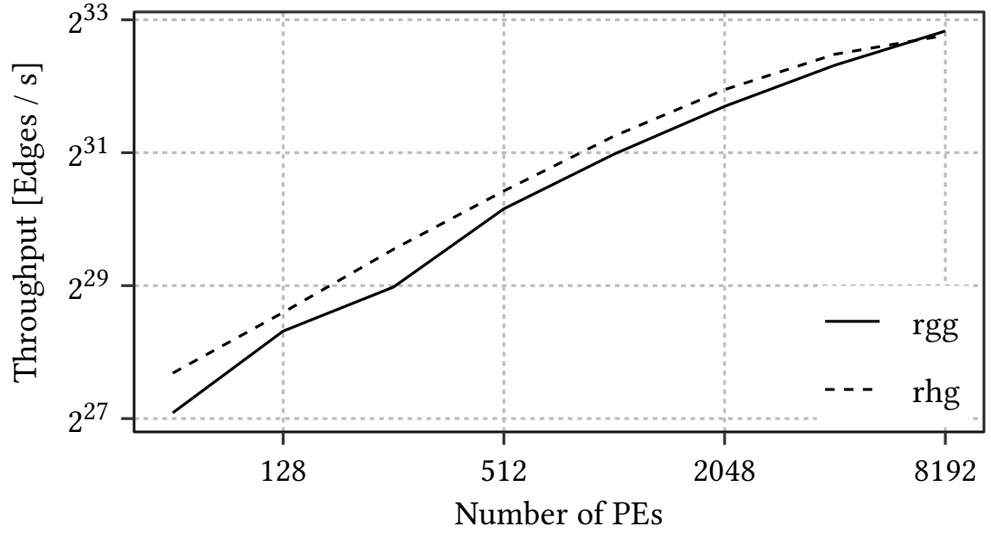


github.com/KaHIP/KaMinPar



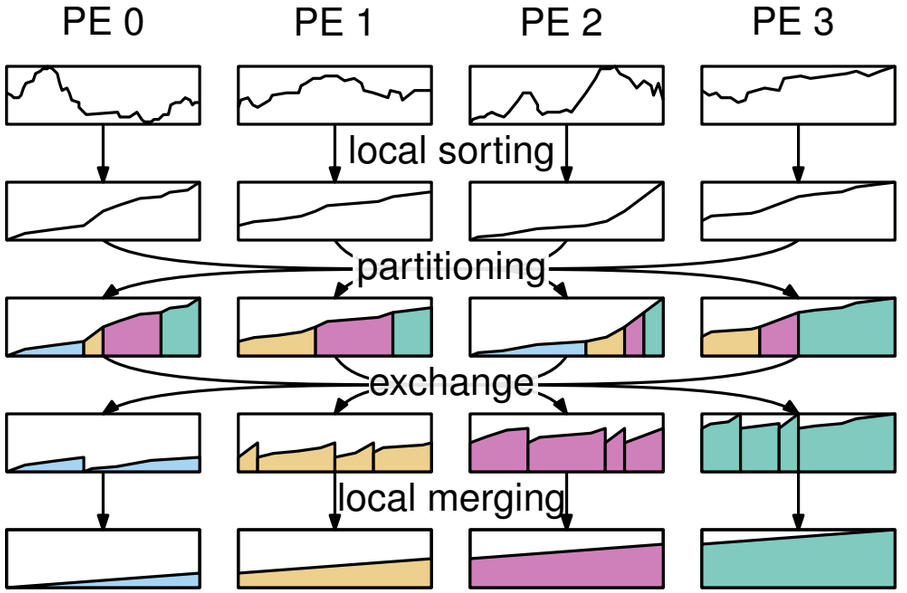


Scalable Distributed String Sorting

Kurpicz, Mehnert, Sanders, Schimek [SPAA'24, ESA'24]

- sorting strings is **multidimensional** problem
- different from classical **atomic** sorting
- algorithm: distributed merge string sort

$\Rightarrow$ low comm. volume **but high latency**



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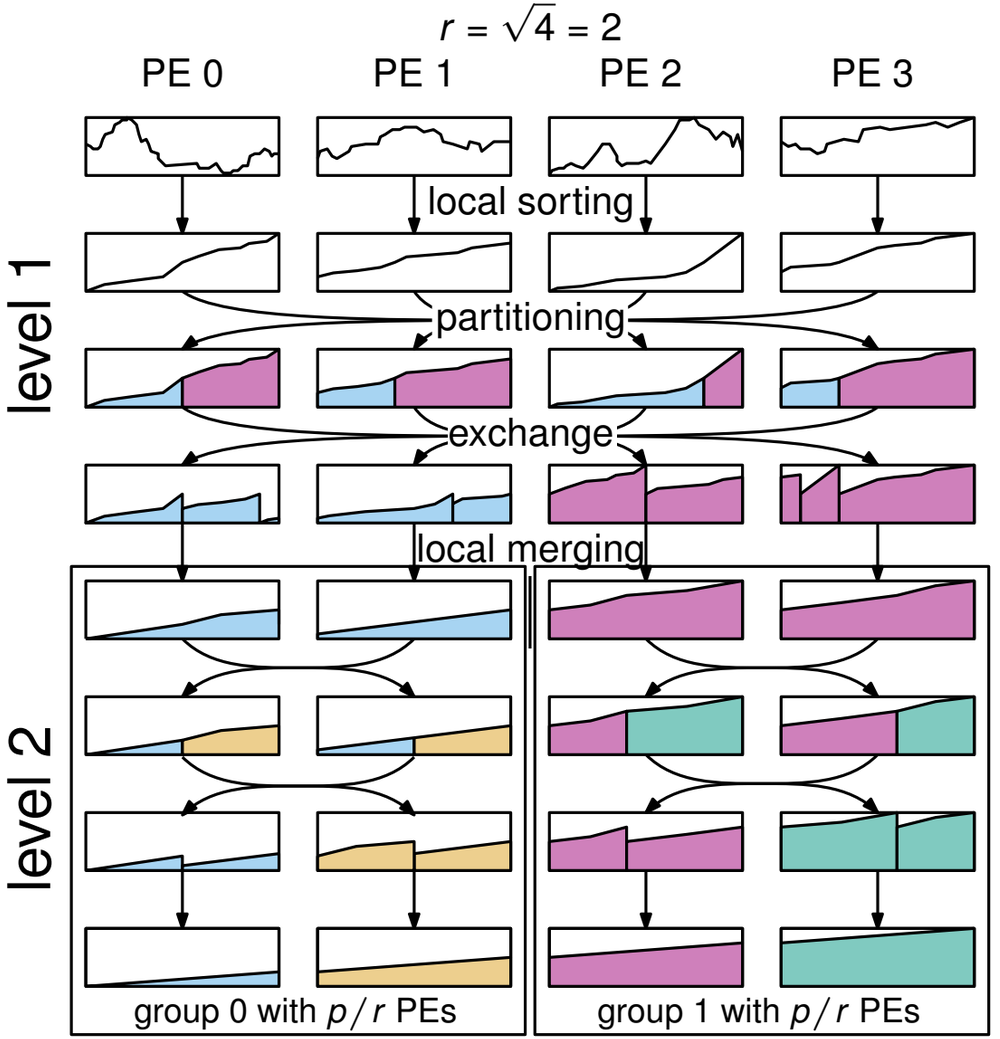

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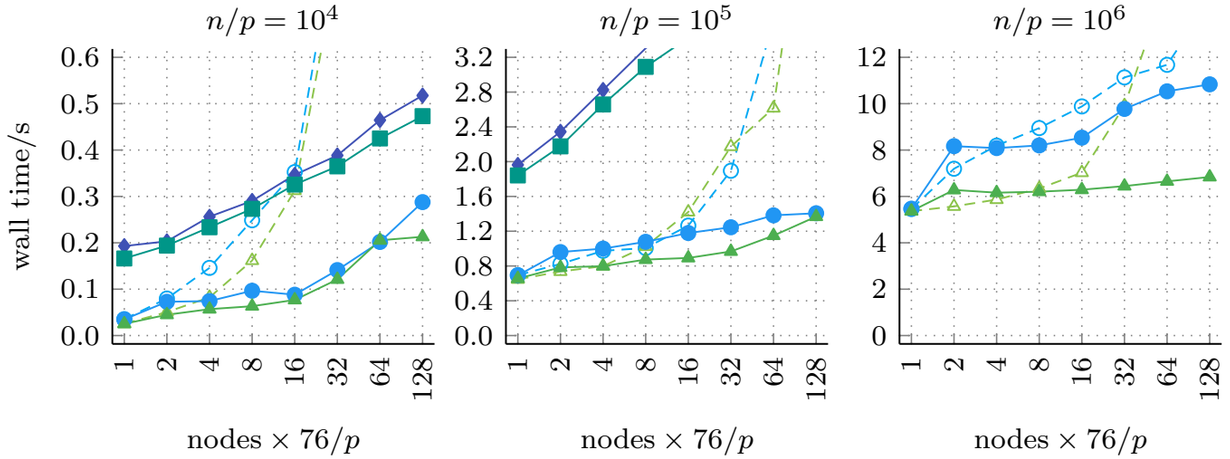

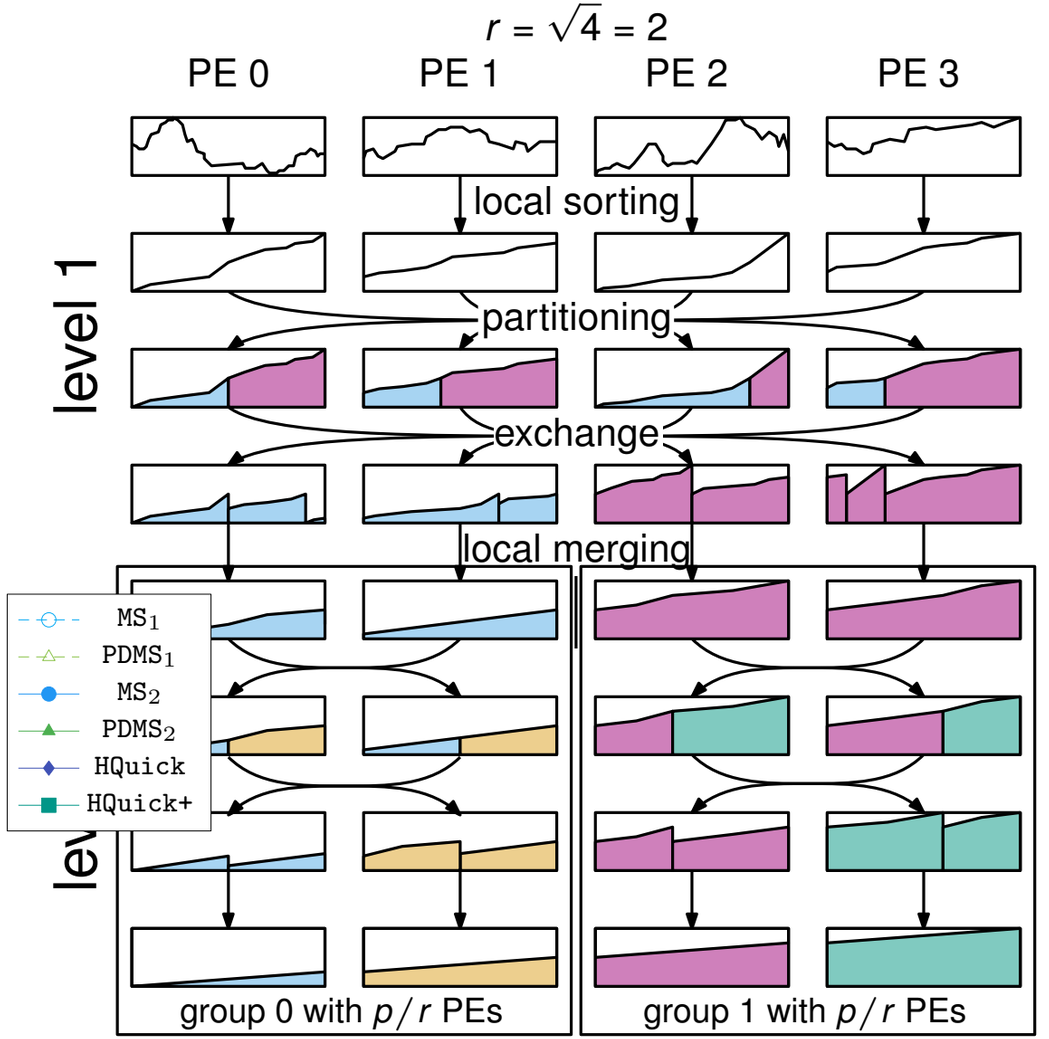

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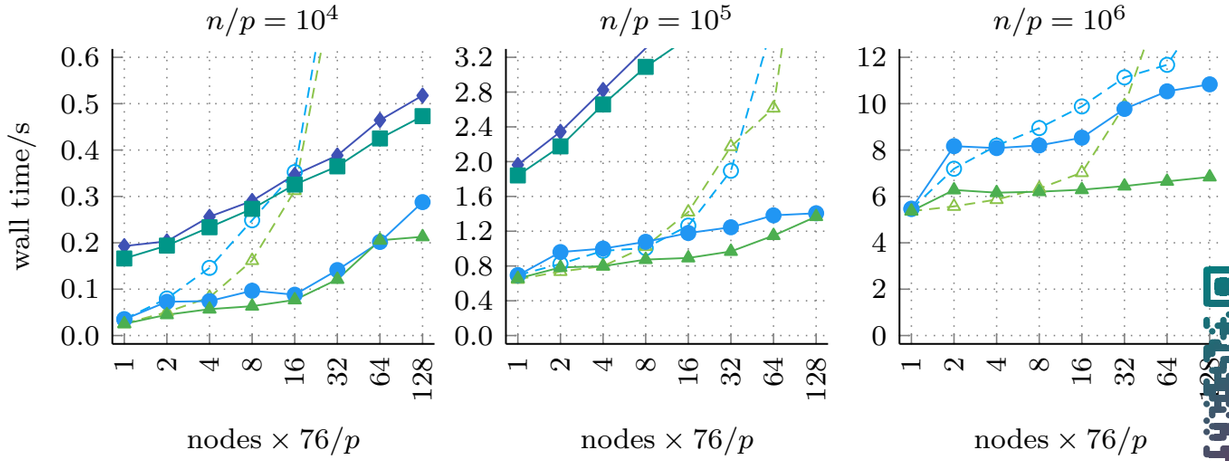
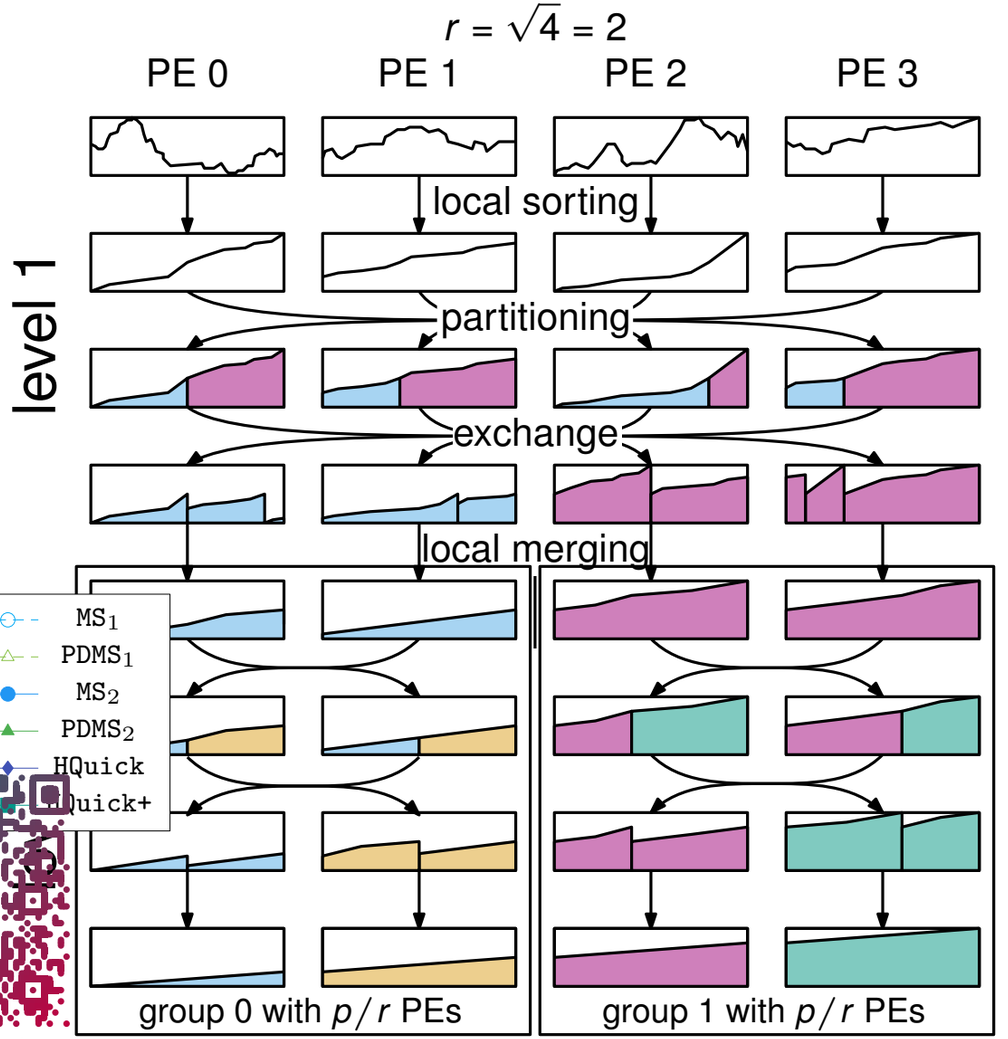
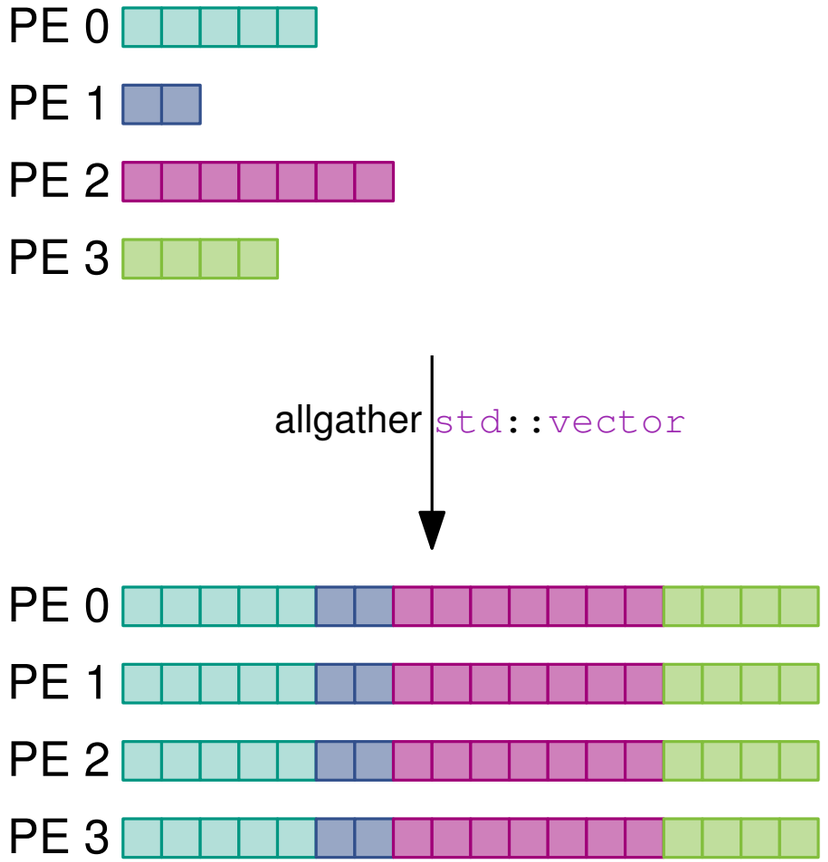




github.com/mschimek/scalable-distributed-string-sorting

Flexible (Near) Zero-Overhead C++ MPI Bindings

Uhl, Schimek, Hübner, Kurpicz, Hespe, Seemaier, Sanders [SPAA'24, SC'24]



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```cpp
std::vector<double> get_whole_vector(std::vector<double> const& v_local, MPI_Comm comm) {
  int size;
  int rank;
  MPI_Comm_size(comm, &size);
  MPI_Comm_rank(comm, &rank);
  std::vector<int> rc(size), rd(size);
  rc[rank] = v_local.size();
  MPI_Allgather(MPI_IN_PLACE, 0, MPI_DATATYPE_NULL, rc.data(), 1, MPI_INT, comm);
  std::exclusive_scan(rc.begin(), rc.end(), rd.begin(), 0);
  std::vector<double> v_global(rd.back() + rc.back());
  MPI_Allgatherv(v_local.data(), v_local.size(), MPI_DOUBLE,
                 v_global.data(), rc.data(), rd.data(),
                 MPI_DOUBLE, comm);
  return v_global;
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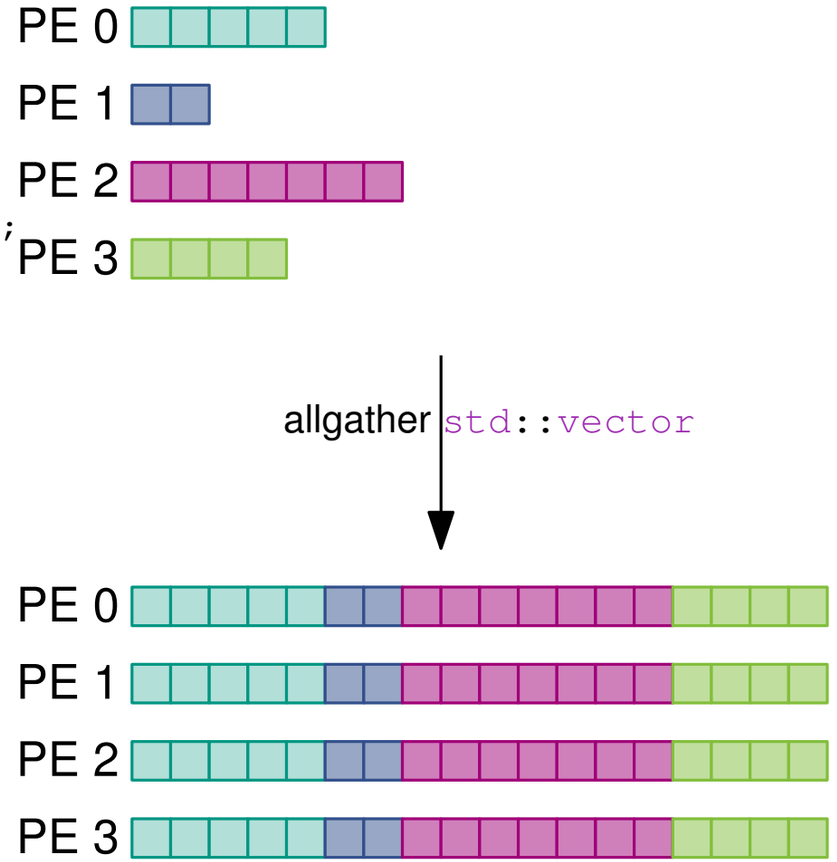

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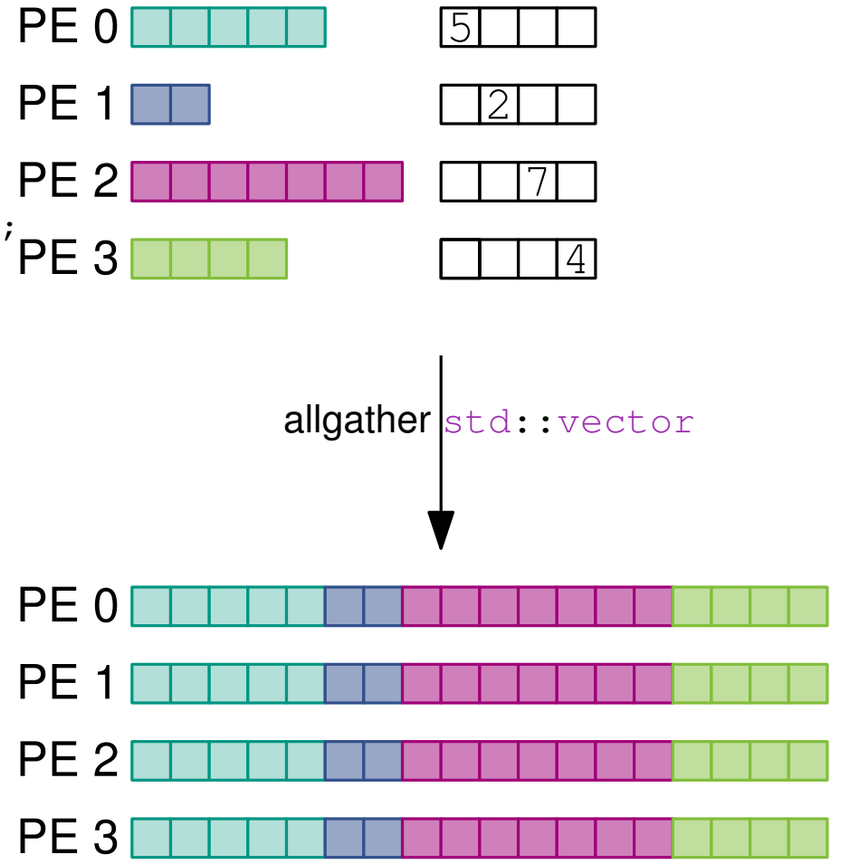

Flexible (Near) Zero-Overhead C++ MPI Bindings

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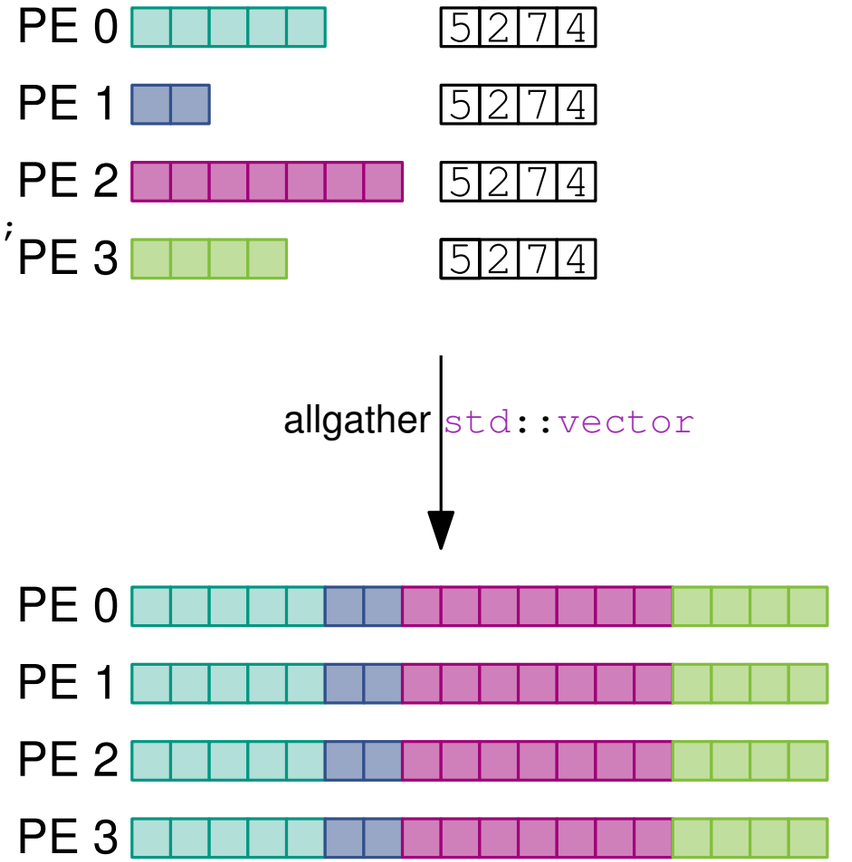

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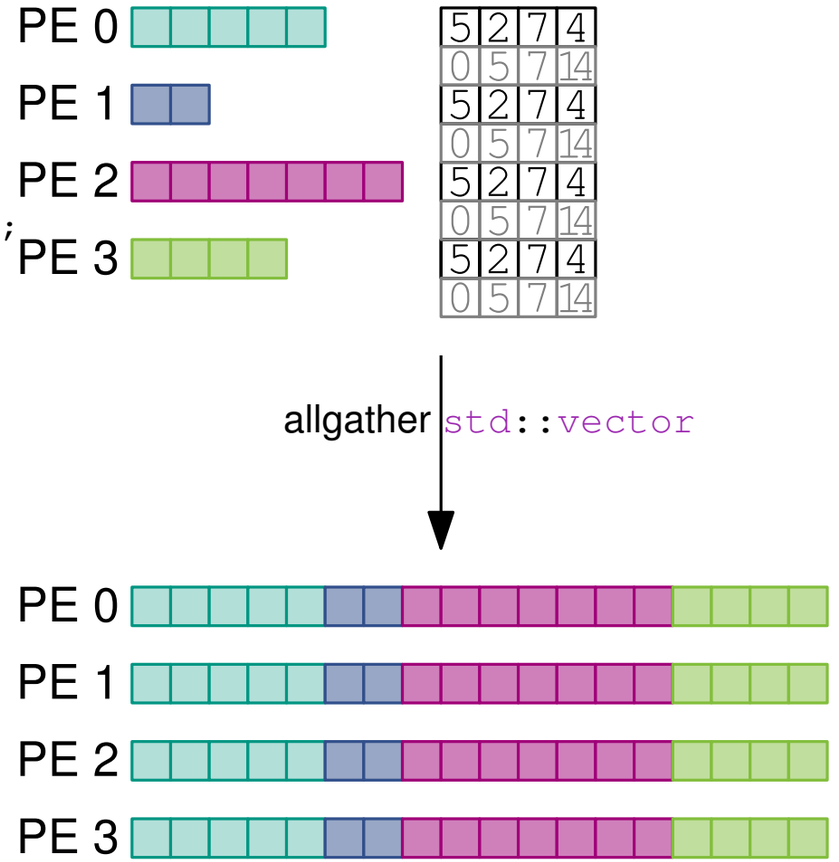

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C-ish API

all other parameters can be inferred

parameter order?

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arbitrary parameter order!

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manual allocation

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common idiom: boilerplate!

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return by reference

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return by reference
or by value

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```

```cpp
// avoid implicit allocation
comm.allgatherv(send_buf(v_local),
                recv_counts_out<no_resize>(some_buf));

// pass buffer ownership to calls
rc = comm.allgatherv(send_buf(v_local), recv_buf(v_global),
                     recv_counts_out<resize_to_fit>(std::move(rc)));

// retrieve auxiliary data
auto [recvbuf, counts] = comm.allgatherv(send_buf(v_local),
                                         recv_counts_out());
```

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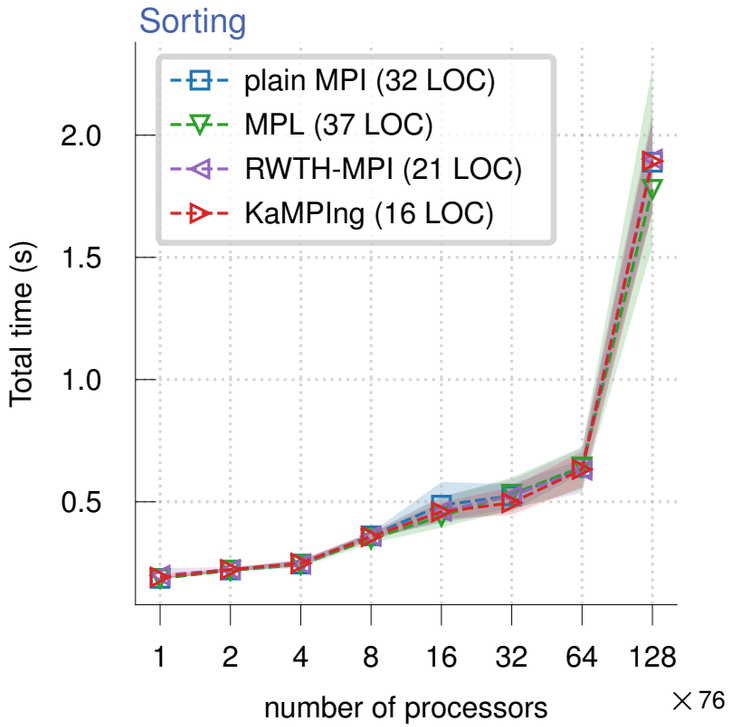

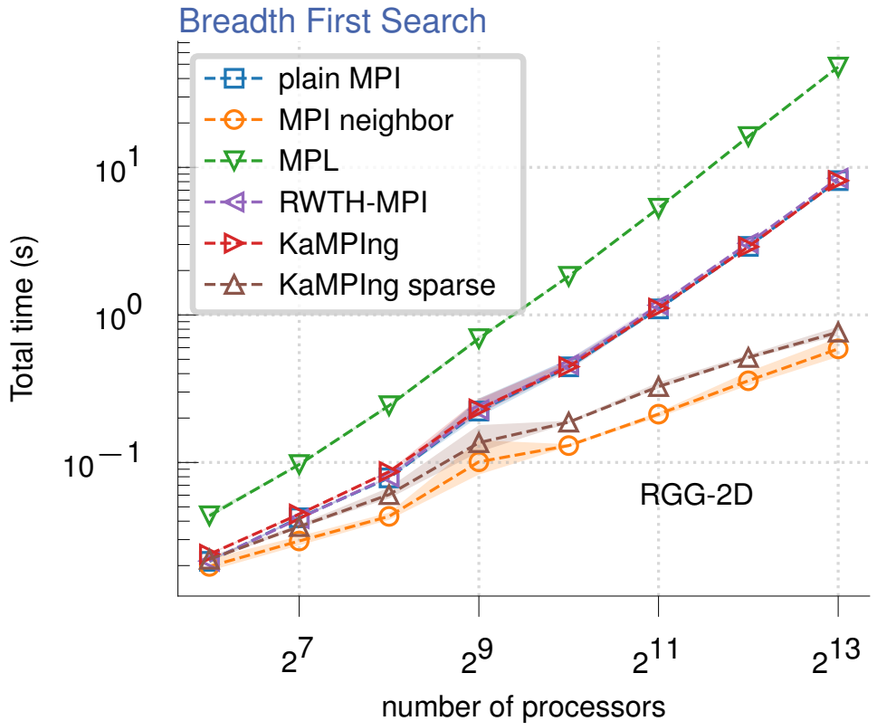

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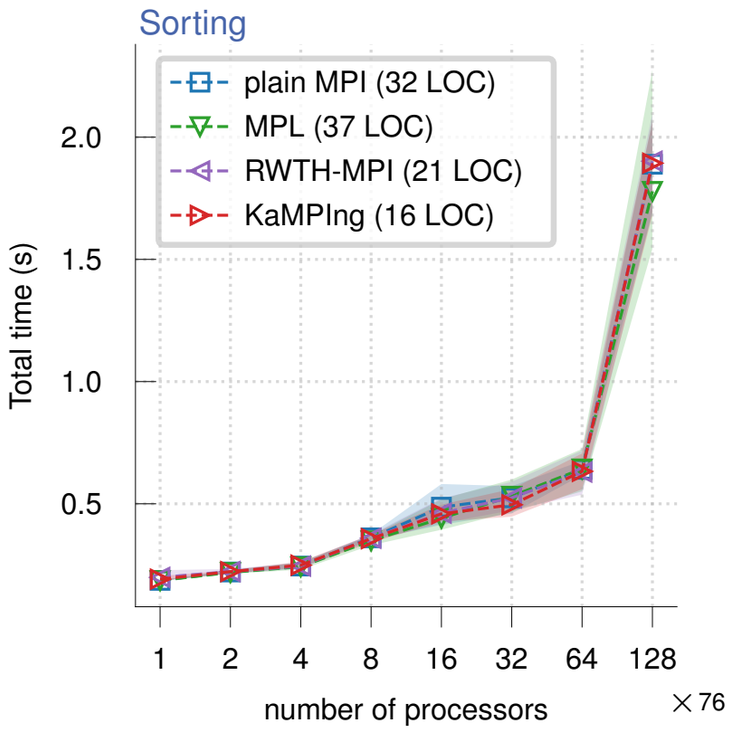

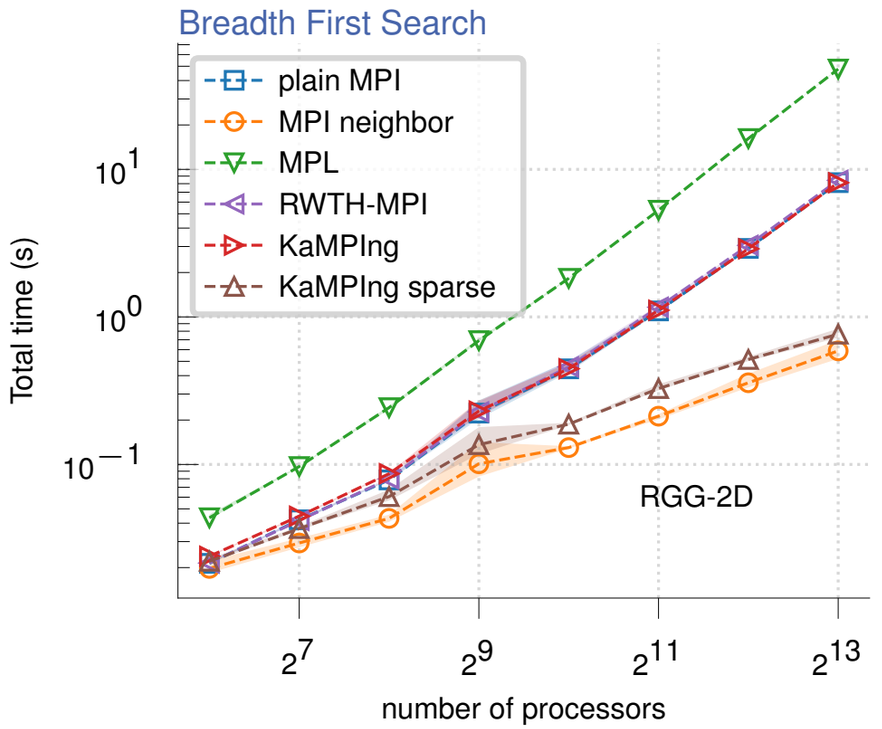

github.com/kamping-site/kamping

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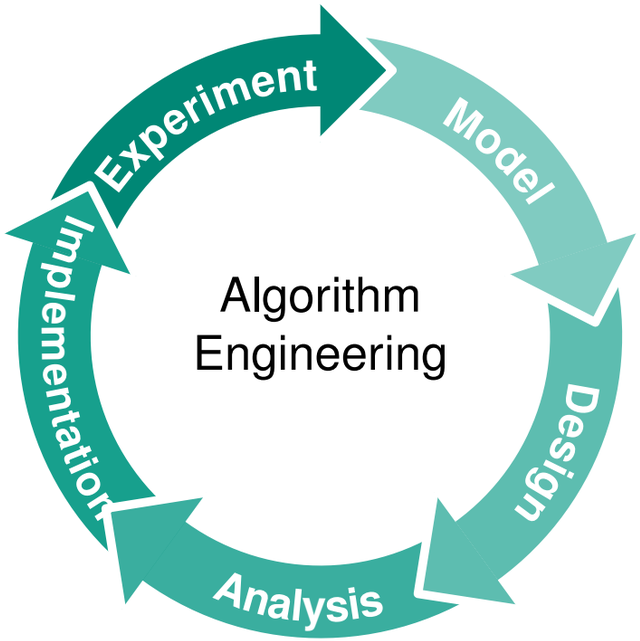
Conclusion

Our resource usage

- ≈ **3 million Core-h** used, currently CPU-only
- jobs differ from common HPC workloads
  - **irregular/skewed** communication patterns
  - short jobs at **large scale**
  - many parameter combinations
  - many iterative runs due to **algorithm engineering**

Our results

- state-of-the-art distributed **SAT solving system system**
- state-of-the-art distributed **graph partitioner**
- state-of-the-art distributed **string sorting**
- a new **C++ MPI library** for writing perfomant MPI code fast



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