Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Optimization Principles for Collective Neighborhood Communications

Torsten Hoefler, Timo Schneider
ETH Zürich
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Parallel Application Classes

- We distinguish five classes of applications with regards to their communication patterns:

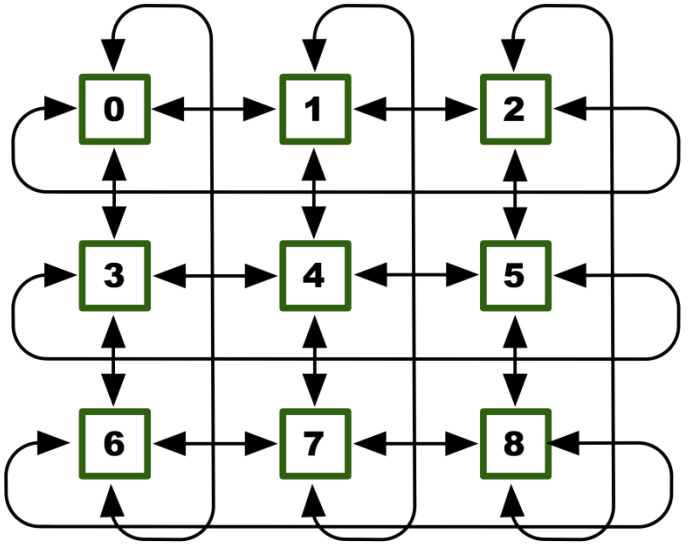
1. Compile-time static (fixed at compile time)
2. Run-time static (fixed after problem input)
3. Run-time flexible (changes slowly during runtime)
4. Dynamic (completely unstructured)
5. “Embarrassingly” parallel (insignificant)

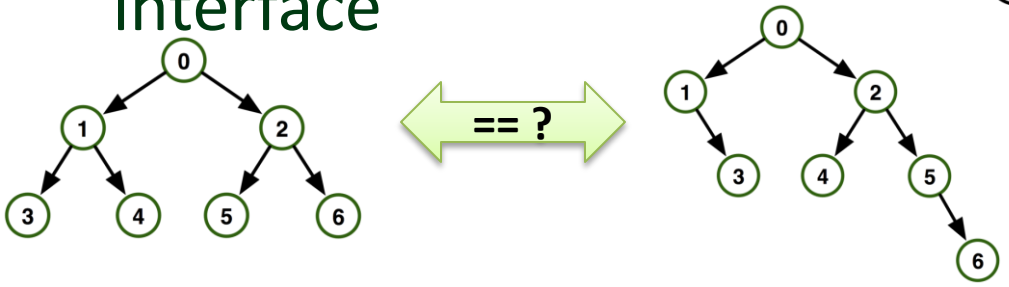
MPI-3.0 IS HERE!

- Ratified in September!
  - MPICH 3.0 released Nov. 13
- Many new features, e.g.:
  - MPIT (Tools) interface
  - New one sided operations
  - Shared memory windows (cf. EuroMPI'12)
  - Noncollective comm. Creation (cf. EuroMPI'11)
  - Nonblocking collectives (cf. SC07)
  - Neighborhood collectives (this work)
  - … and many more features!

MPI 3.0's Neighborhood Collectives

- Idea: "build your own collective"
  - MPI library optimizes it during runtime
  - Interesting challenges and opportunities
  - Utilizes process topology interface

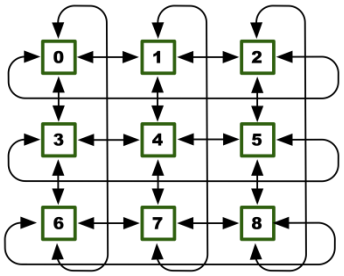


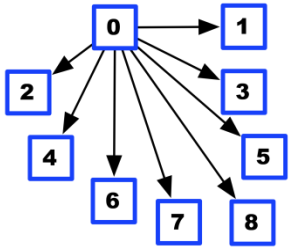


Hoefler et al.: The Scalable Process Topology Interface of MPI 2.2, CCPE 2012

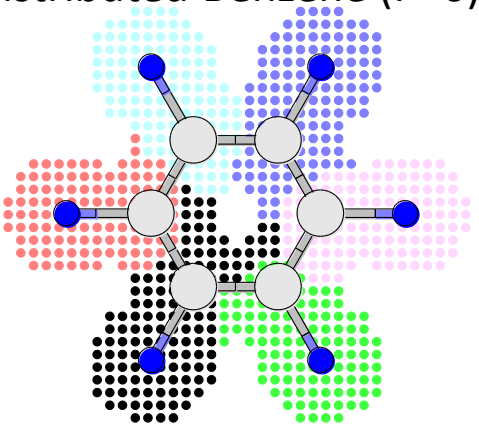
Process Topologies

- Constructors:
  - MPI_Cart_create()
  - MPI_Dist_graph_create()
- Topology mapping
- Accept info arguments
  - Provide optimization hints/assertions

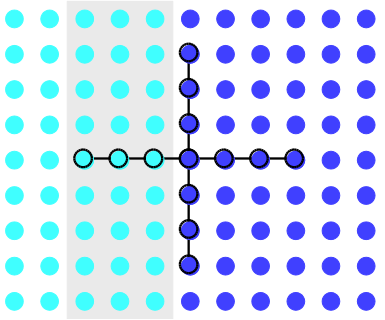




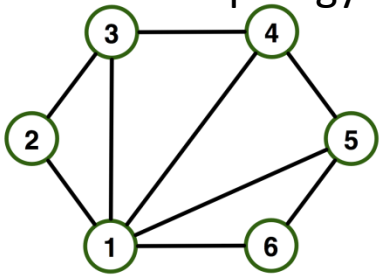
Distributed Benzene (P=6)



+ 13 point stencil



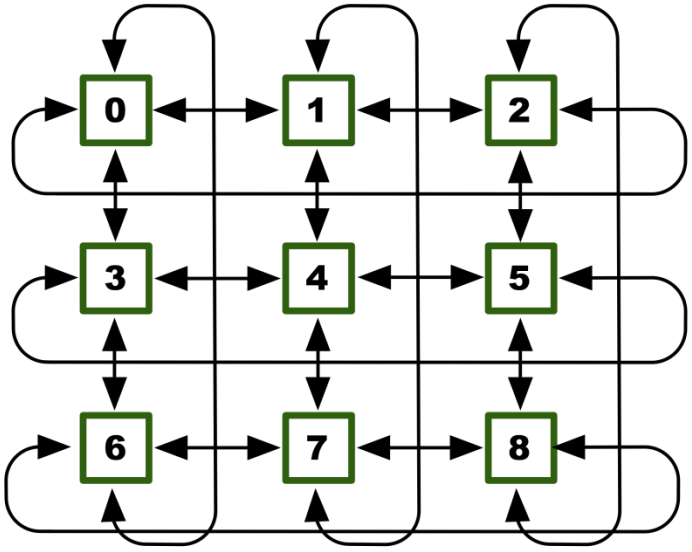
= Process Topology

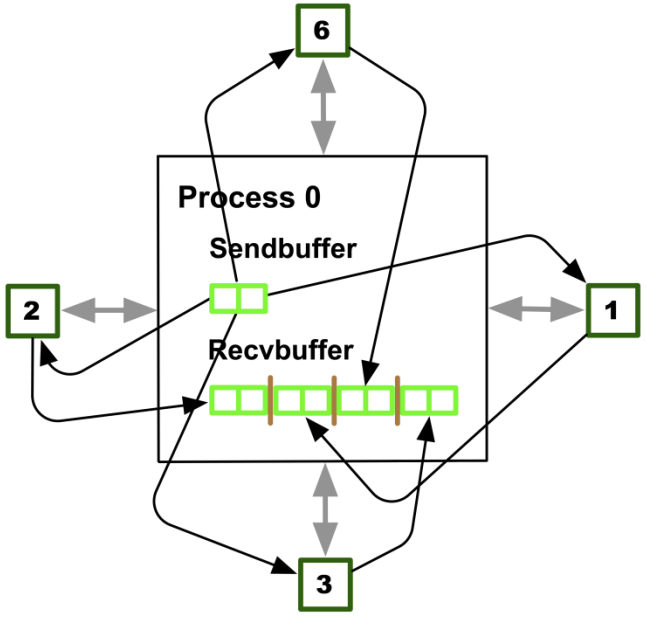


Hoefler et al.: The Scalable Process Topology Interface of MPI 2.2, CCPE 2012

NEIGHBORHOOD ALLGATHER

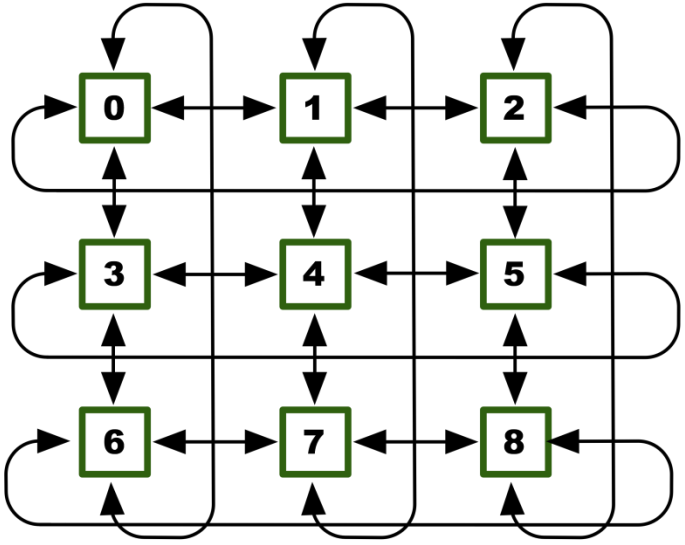
```
int dims[2]={3,3}, periods[2]={1,1};
MPI_Comm comm_cart;
MPI_Cart_create(MPI_COMM_WORLD, 2, dims, periods, 0, &comm_cart);
int sbuf[1], rbuf[4];
MPI_Neighbor_allgather(sbuf, 1, MPI_INT, rbuf, 1, MPI_INT,
    comm_cart);
```

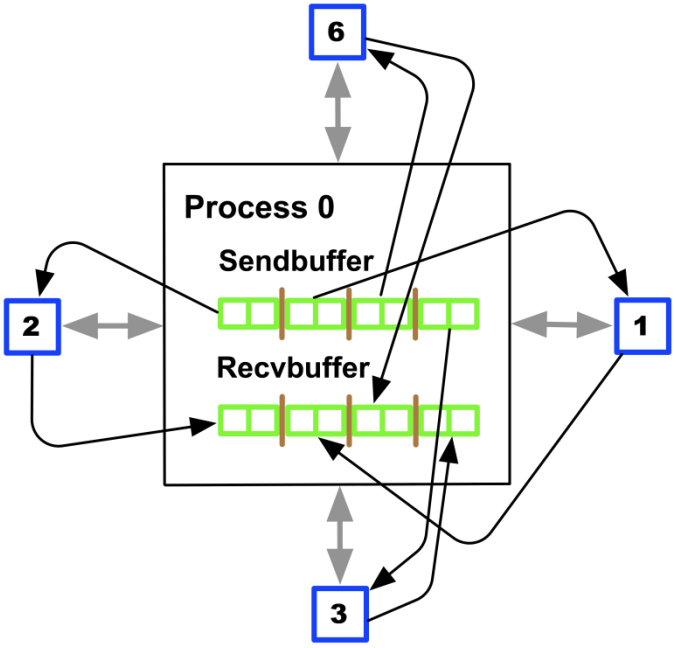




NEIGHBORHOOD ALLTOALL

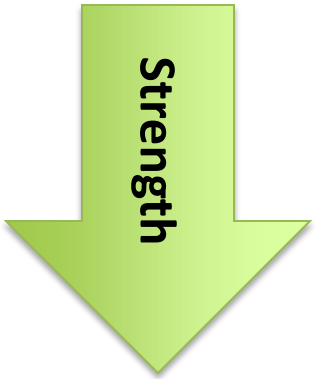
```
int dims[2]={3,3}, periods[2]={1,1};
MPI_Comm comm_cart;
MPI_Cart_create(MPI_COMM_WORLD, 2, dims, periods, 0, &comm_cart);
int sbuf[4], rbuf[4];
MPI_Neighbor_alltoall(sbuf, 1, MPI_INT, rbuf, 1, MPI_INT,
    comm_cart);
```





Communication Persistence

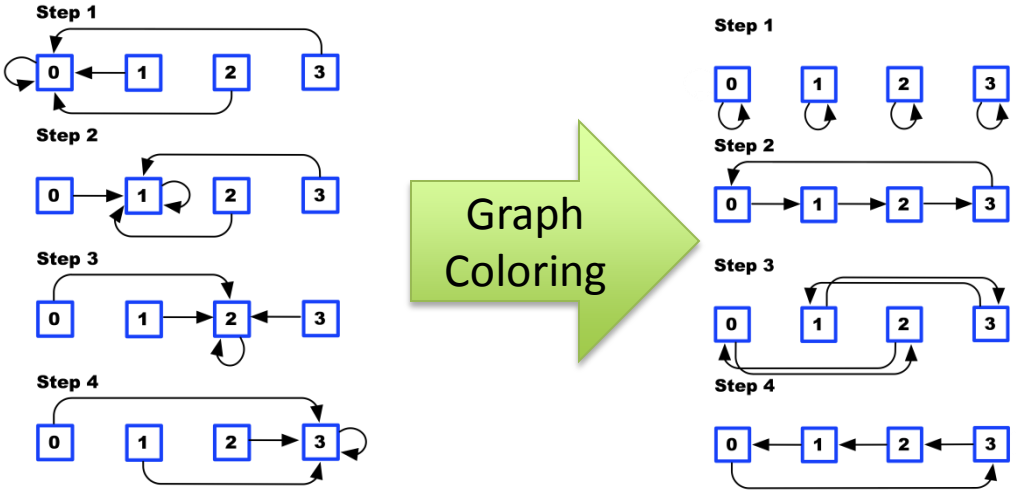
- Three persistence hierarchy levels:
  - Communication topology
  - Message sizes
  - Communication buffers
- Communicated via info arguments
  - Per collective and communicator
  - Side-effect: persistent collectives!



Persistent Communication Topology

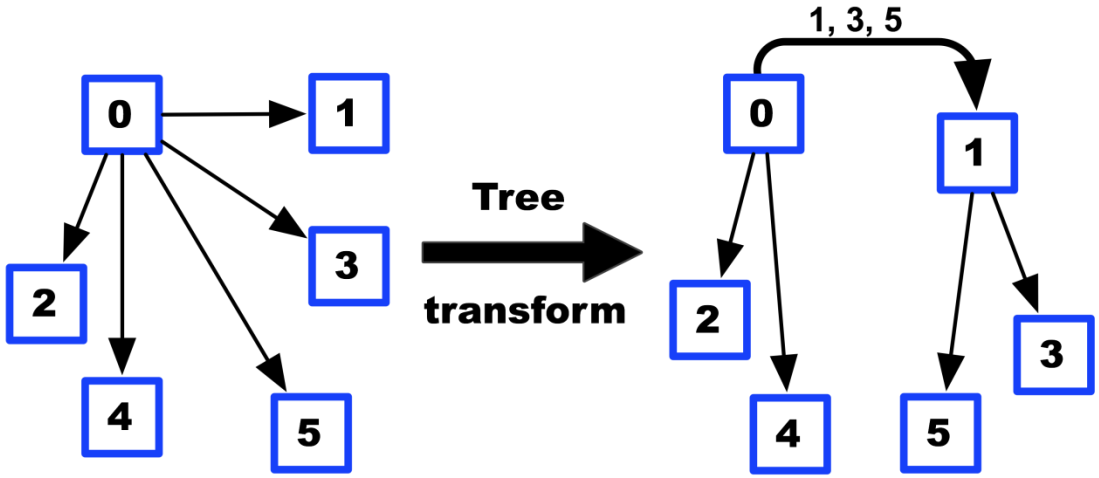
- Enables:
  - Fixed channel semantics (pre-connect)
  - RDMA synchronization trees
  - Communication scheduling

```
for(int i=0; i<p; ++i) {
  MPI_Irecv(..., src=i, ...);
  MPI_Isend(..., dst=i, ...);
}
MPI_Waitall(...);
```



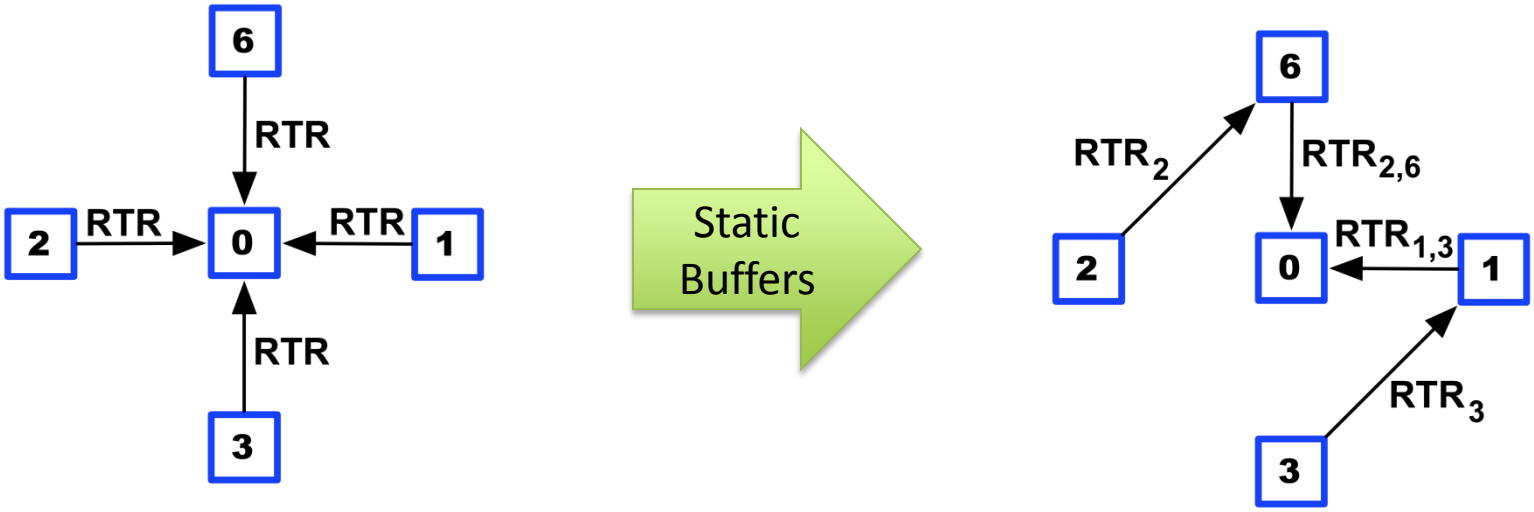
Persistent Message Sizes

- Enables:
  - Balance communications
  - Tree transformations



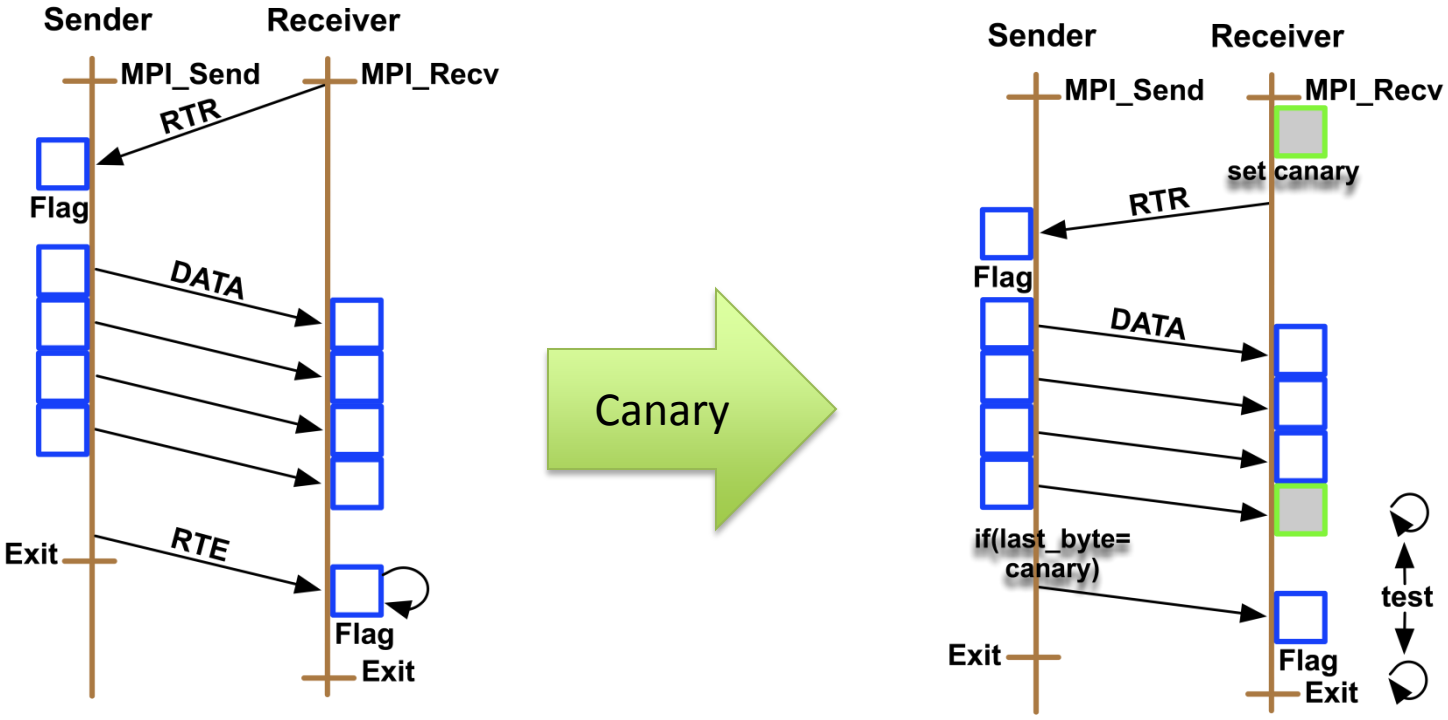
Persistent Message Buffers

- Enables:
  - Static (persistent) RDMA regions
  - Collective RDMA RTR protocols



Persistent Message Buffers

- Canary RTE protocol (system dependent)

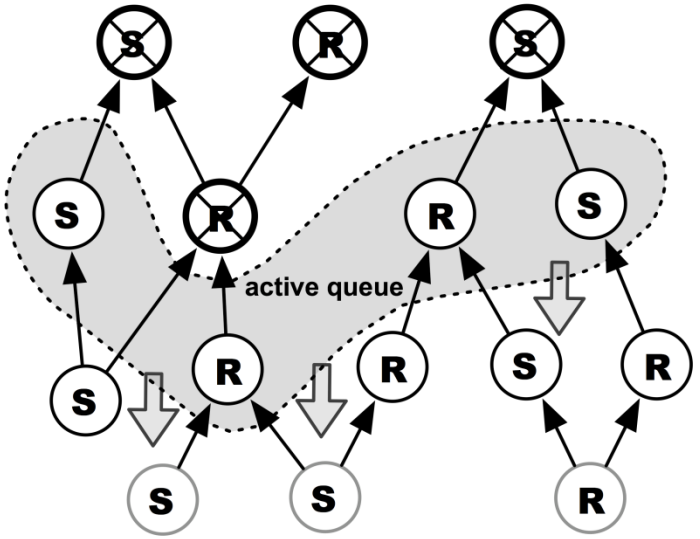


Implementation

- LibNBC acts as reference implementation
  - Naïve post all recvs, then all sends, waitall
  - We compare to hard-coded MPI versions!
- Two low-level interfaces:
  - Cray DMAPP
    - Canary protocol up to 64 bytes
  - XPMEM (shared memory)
    - Linux kernel module enables page sharing

cDAG – Communication DAG

- Express arbitrary communication relations as directed acyclic graph (DAG)
  - Easy translation from MPI calls
  - Enables DAG transformations
  - Highly optimized scheduled execution

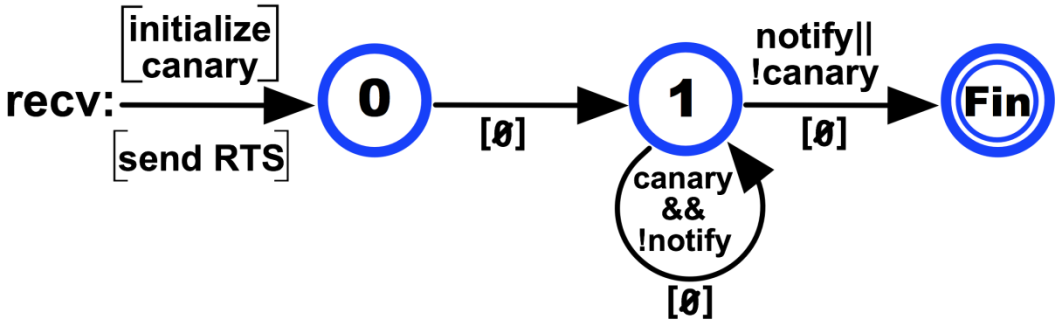


When to apply Optimizations?

- Persistent communication topology
  - During communicator creation
- Persistent message sizes
  - At first call of collective
  - Remember schedules/sizes for later calls
- Persistent communication buffers
  - At first call of collective
  - Remember schedules/buffers for later calls
  - Auto-tune?

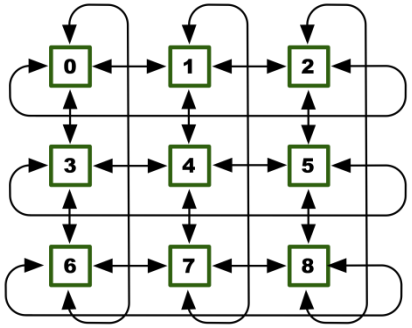
Protocol Drivers

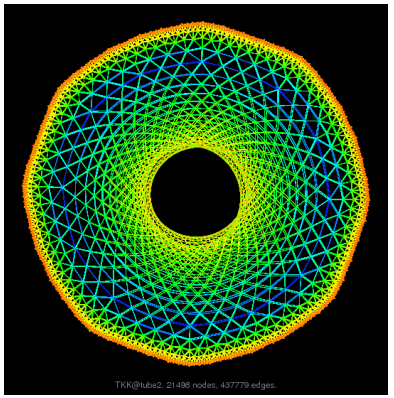
- cDAG transforms execution schedule
  - Scheduler executes on DMAPP and XPMEM
  - Represented by state machines
    - E.g., DMAPP small message recv:



Evaluation

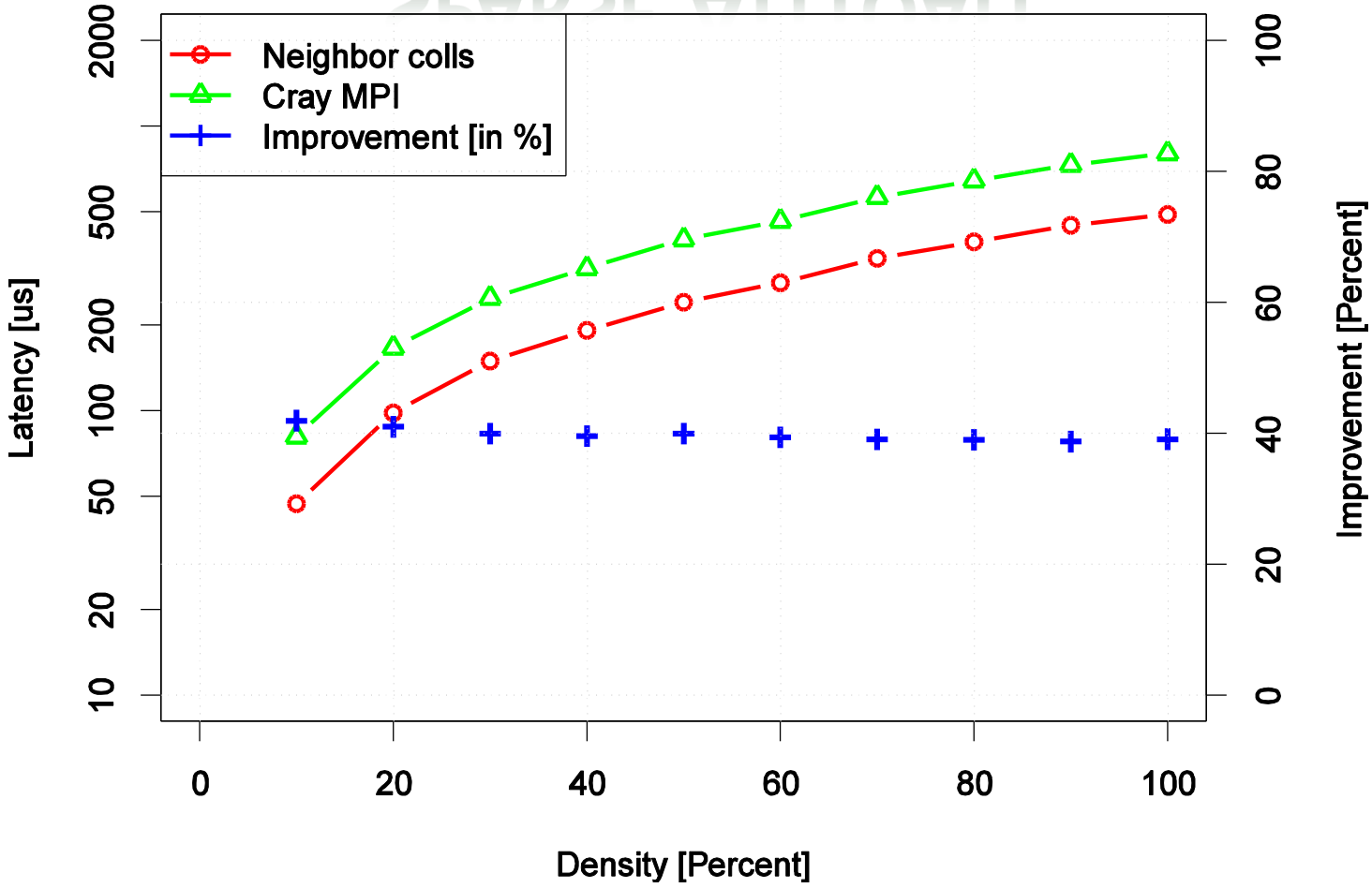
- Test system: Blue Waters test machine (JYC)
  - 50 nodes Cray XE6, ~1600 cores
  - Cray CCE 4.0.46
- Microbenchmark patterns
  - Sparse alltoall + Cartesian stencil
- Application patterns
  - WRF+ UFL sparse matvec





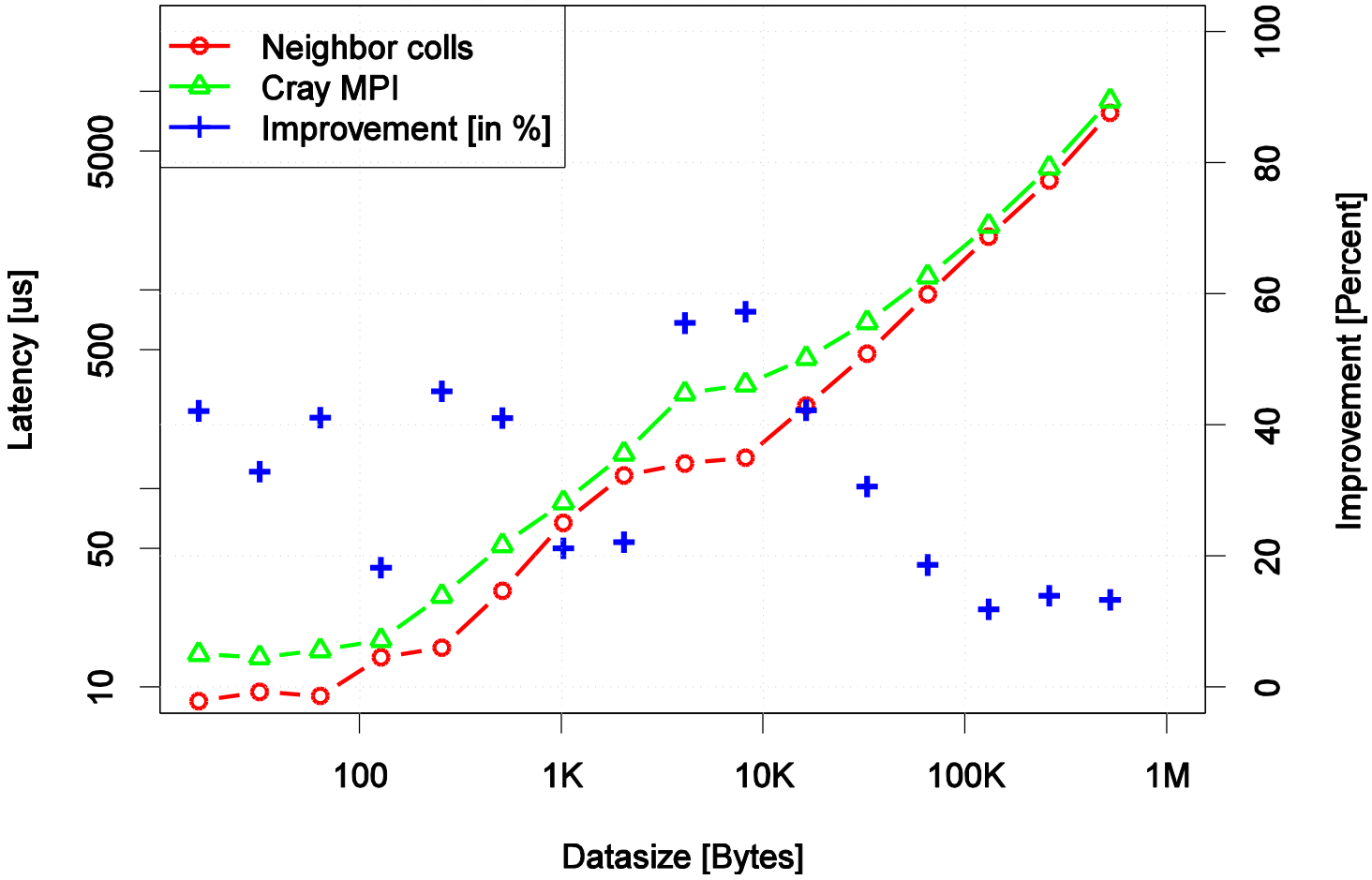
Credits: UFL collection

Sparse Alltoall



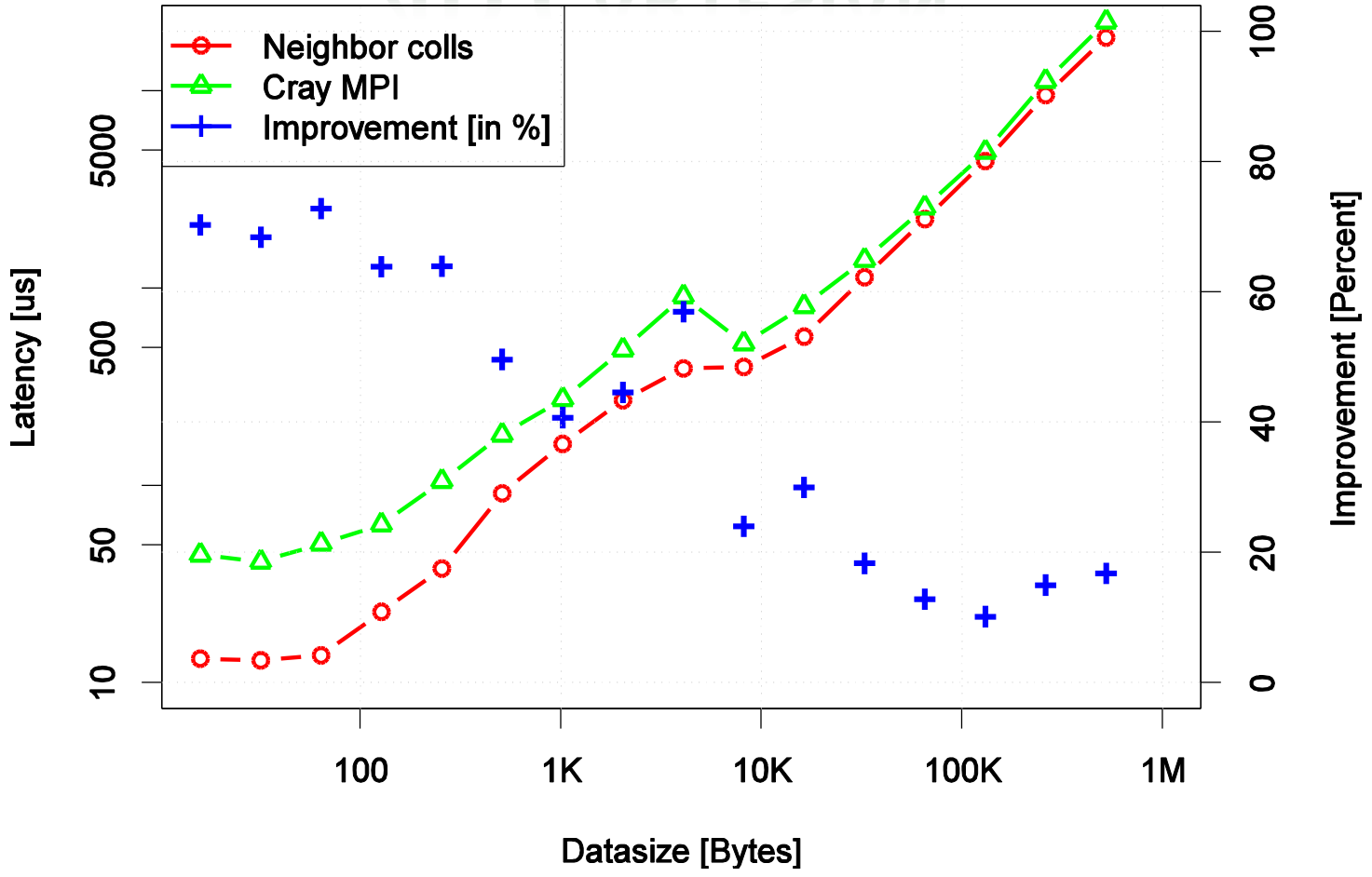
- 1024 processes, 16 Bytes per process

2D Cartesian



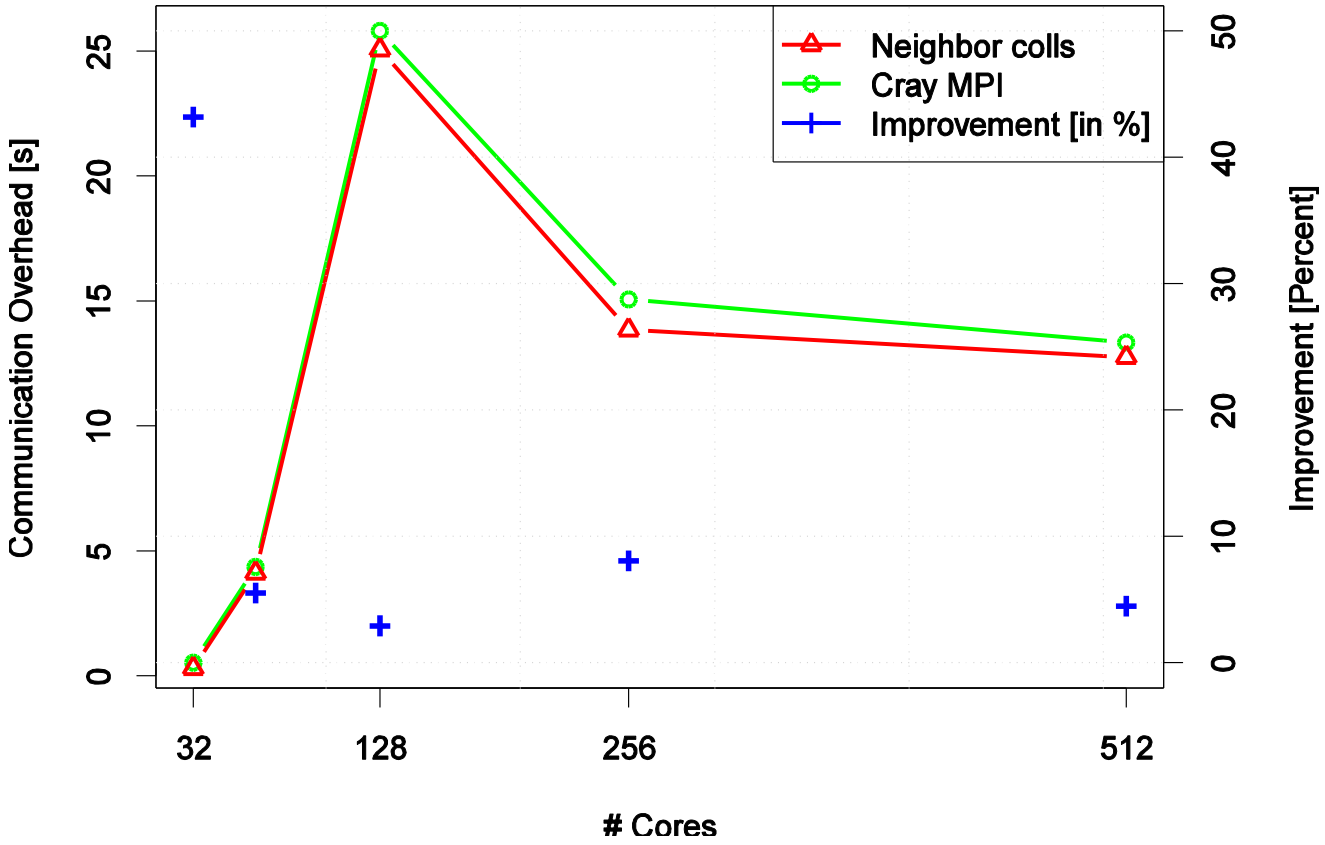
- 512 processes, varying size

4D Cartesian



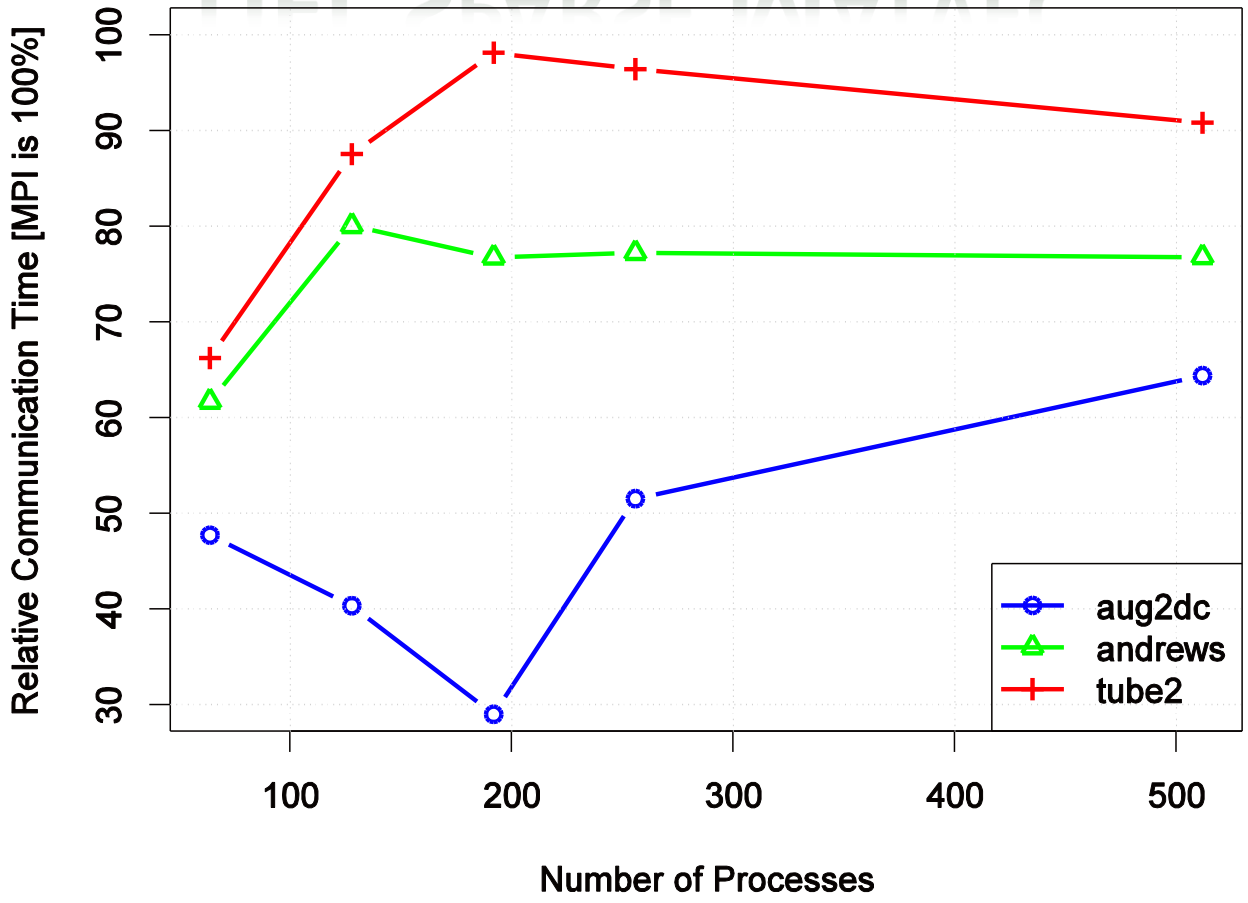
- 512 processes, varying size

WRF COMMUNICATION



- Em_b_wave input, five simulation days, 200k points
- Up to 40% improvement (14% app), average 7-10% (3-5% app)

UFL Sparse Matvec



- METIS partitioned, strong scaling

Discussion

- Most applications have 3-7 neighbors
  - [Vetter, Mueller, JPDC 2003]
- Some applications have up to 66 neighbors
  - [Kamil et al., TPDS 2010]
- Collective optimization is well understood
  - Very limited interface
  - Neighborhood collectives extend to runtime
  - Specialized hardware allows for optimizations
- Our scheme also enables standard-compliant persistent collectives

Collaboration Opportunities

- Use neighborhood collectives in MPI applications
  - Looking for users ☺
- Optimize neighborhood collectives in MPICH?
  - MPICH 3.0 offers an unoptimized version
- Other opportunities
  - Derive specification automatically (compiler)
  - Experiment with auto-tuning (feedback-driven online schedule transformations)

Acknowledgments & Questions

- The MPI Forum
  - Especially the collective WG!
  - Cray (Larry, Duncan, & Howard)

ETH
Eidgenössische Technische Hochschule Zürich
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BLUE WATERS
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DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

Sandia National Laboratories