Advanced MPI

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Nonblocking and collective communications

- Nonblocking communication
  - Prevent deadlocks related to message ordering
  - Overlapping communication/computation
    - If communication progress is provided by the implementation/hardware
- Collective communication
  - Collection of pre-defined routines for generalist communication patterns
    - Optimized by the implementations
- Nonblocking collective communication
  - Combines both advantages
  - System noise/imbalance resiliency
  - Semantic advantages

Nonblocking communications

- Semantics are simple:
  - Function returns immediately
  - Buffers should be used carefully (send buffers can be read but not modified, recv buffers should not be accessed)
  - No requirement for progress (more complicated than point-to-point communications)
- E.g.: MPI_Isend(…, MPI_Request *req);
- Nonblocking tests:
  - Test, Testany, Testall, Testsome
- Blocking wait:
  - Wait, Waitany, Waitall, Waitsome
- Blocking vs. nonblocking communication
  - Mostly equivalent, nonblocking has constant request management overhead
  - Nonblocking may have other non-trivial overheads

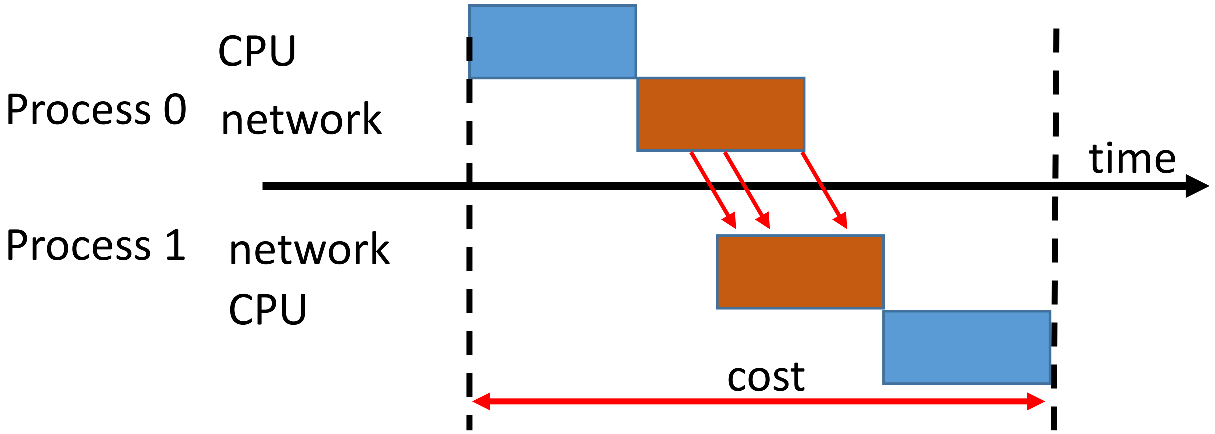
Nonblocking communications

- An important technical detail
  - Eager vs. Rendezvous

- Most/All MPIs switch protocols
  - Small messages are copied to internal remote buffers
    - And then copied to user buffer
    - Frees sender immediately (cf. bsend)
    - Usually below MTU
  - Large messages divided in multiple pieces
    - wait until receiver is ready to prevent temporary memory allocations on the receiver due to unexpected communication
    - Blocks sender until receiver arrived
- Hint: in many cases you can tune these limits (for your environment) and your application
  - Not only for performance reasons but also to minimize the memory used by the MPI library (for internal storage)

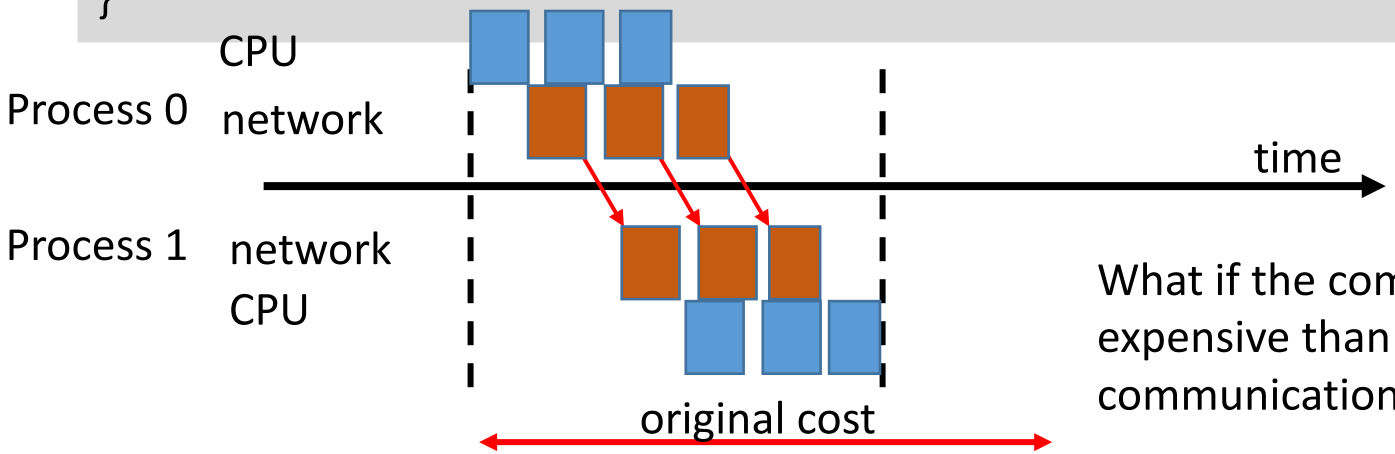
Software Pipelining - Motivation

```
if( 0 == rank ) {
    for( int i = 0; i < MANY; i++ ) {
        buf[i] = compute(buf, size, i);
    }
    MPI_Send(buf, size, MPI_DOUBLE, 1, 42, comm );
} else {
    MPI_Recv(buf, size, MPI_DOUBLE, 0, 42, comm, &status);
    compute(buf, size);
}
```



Software Pipelining - Implementation

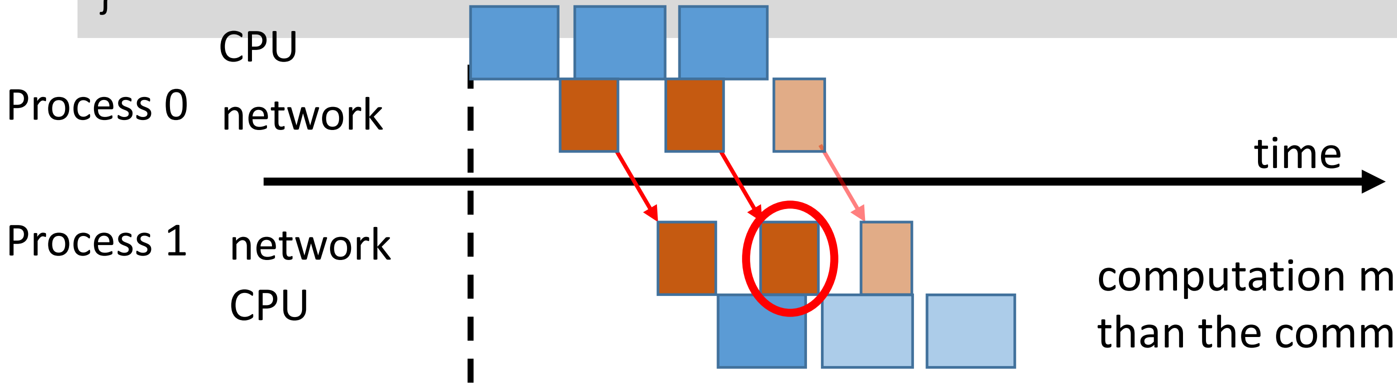
```
MPI_Request req = MPI_REQUEST_NULL;
if( 0 == rank ) {
   for( int b = 0; b < (size / BSIZE); b++ ) {
      MPI_wait( req, &status);  /* complete previous step */
      for( int i = b * BSIZE; i < ((b+1) * BSIZE); i++ )
         buf[i] = compute(buf, size, i);
      MPI_Isend(&buf[b * BSIZE], BSIZE, MPI_DOUBLE, 1, 42, comm, &req );
   }
} else {
   for( int b = 0; b < (size / BSIZE); b++ ) {
      MPI_Recv(&buf[b*BSIZE], BSIZE, MPI_DOUBLE, 0, 42, comm, &status);
      compute(&buf[b*BSIZE], BSIZE);
   }
}
```



What if the computation is more expensive than the communication ?

Software Pipelining - Implementation

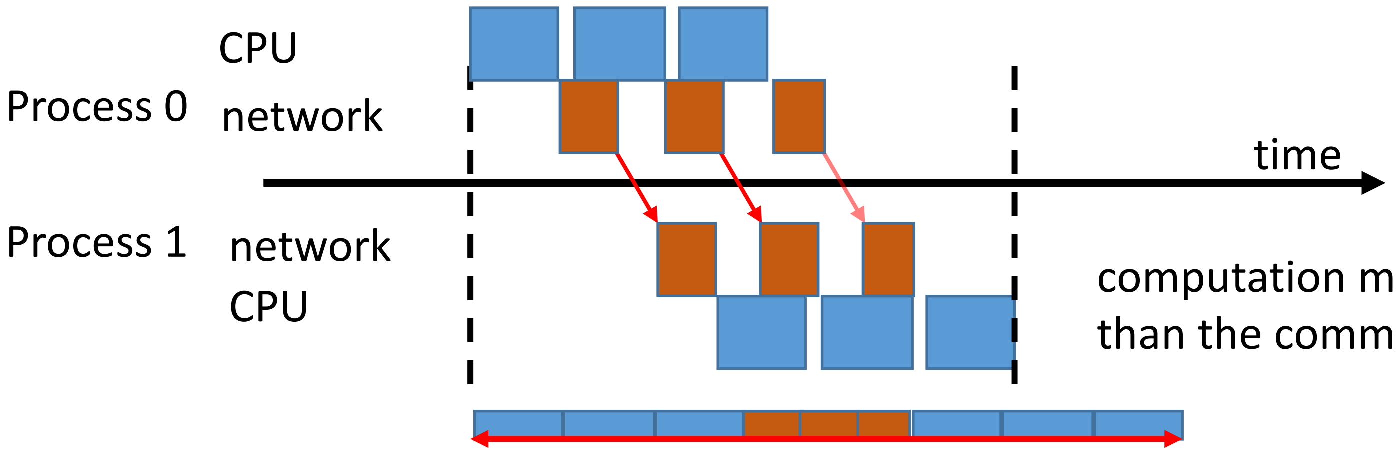
```
MPI_Request req = MPI_REQUEST_NULL;
if( 0 == rank ) {
   for( int b = 0; b < (size / BSIZE); b++ ) {
      MPI_wait( req, &status);  /* complete previous step */
      for( int i = b * BSIZE; i < ((b+1) * BSIZE); i++ )
         buf[i] = compute(buf, size, i);
      MPI_Isend(&buf[b * BSIZE], BSIZE, MPI_DOUBLE, 1, 42, comm, &req );
   }
} else {
   for( int b = 0; b < (size / BSIZE); b++ ) {
      MPI_Recv(&buf[b*BSIZE], BSIZE, MPI_DOUBLE, 0, 42, comm, &status);
      compute(&buf[b*BSIZE], BSIZE);
   }
}
```



computation more expensive than the communication

Software Pipelining - Implementation

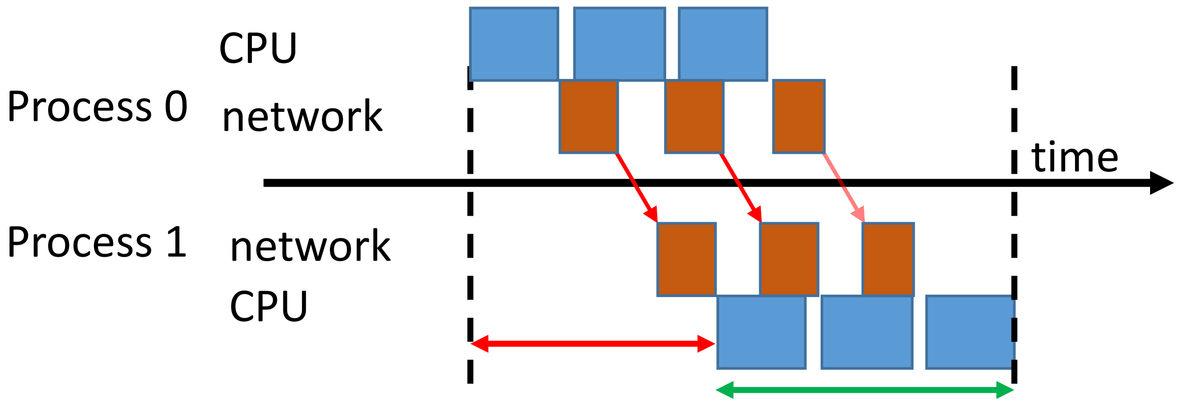
```
MPI_Request req[2] = {MPI_REQUEST_NULL};
if( 0 == rank ) {
   /* keep the same send code */
} else { idx = 0;
   MPI_Irecv(&buf[0*BSIZE], BSIZE, MPI_DOUBLE, 0, 42, comm, &req[idx]);
   for( int b = 0; b < (size / BSIZE); b++ ) {
      MPI_Wait(&req[idx], &status);
      if( (b+1)*BSIZE < size ) { idx = (idx + 1) % 2;
         MPI_Irecv(&buf[(b+1)*BSIZE], BSIZE, …, comm, &req[idx]); }
      compute(&buf[b*BSIZE], BSIZE);
   }
}
```



computation more expensive than the communication

Software pipelining - modelization

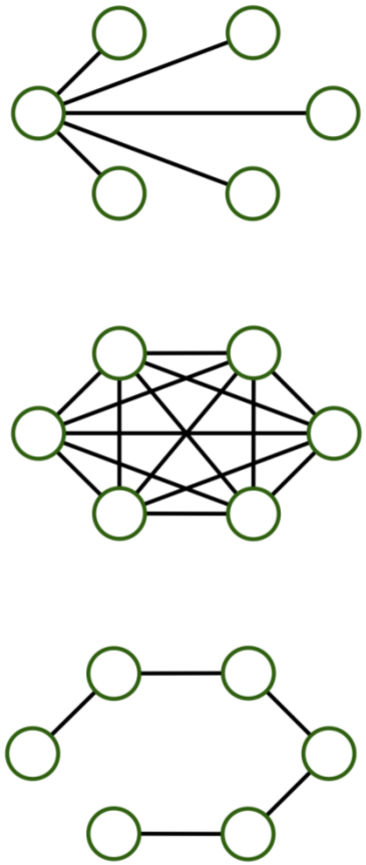
- No pipeline
  - $T = T_{comp}(s) + T_{comm}(s) + T_{startc}(s) + T'_{comp}(s)$
- Pipeline
  - $T = T_{comp}(bs) + T_{comm}(bs) + T_{startc}(bs) +$
    $nblocks * max(T_{comp}(bs), T_{comm}(bs), T_{startc}(bs), T'_{comp}(bs))$



Communicators - Collectives

- Simple classification by operation class
- **One-To-All** (simplex mode)
  - One process contributes to the result. All processes receive the result.
    - MPI_Bcast
    - MPI_Scatter, MPI_Scatterv
- **All-To-One** (simplex mode)
  - All processes contribute to the result. One process receives the result.
    - MPI_Gather, MPI_Gatherv
    - MPI_Reduce
- **All-To-All** (duplex mode)
  - All processes contribute to the result. All processes receive the result.
    - MPI_Allgather, MPI_Allgatherv
    - MPI_Alltoall, MPI_Alltoallv
    - MPI_Allreduce, MPI_Reduce_scatter
- **Other**
  - Collective operations that do not fit into one of the above categories.
    - MPI_Scan
    - MPI_Barrier
- Common semantics:
  - Blocking semantics (return when complete)
  - Therefore no tags (communicators can serve as such)
  - Not necessarily synchronizing (only barrier and all*)

Collective Communications



- Most algorithms are log(P)
- They classify in 3 major communication patterns
  - Scatter, Gather, Reduce
  - Barrier, AllReduce, Allgather, Alltoall
  - Scan, Exscan

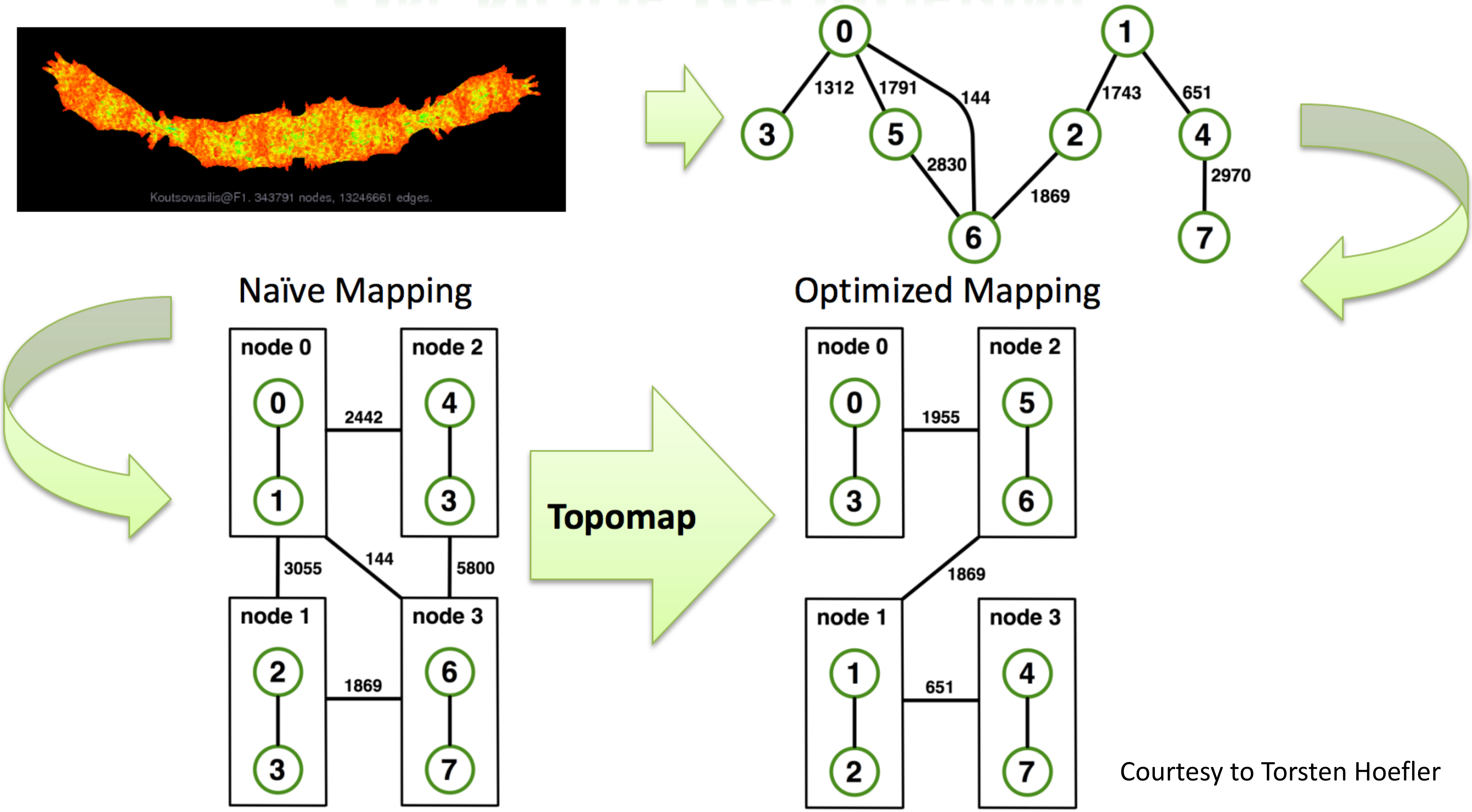
Nonblocking collectives

- Nonblocking variants of all collectives
  - MPI_Ibcast(…, MPI_Request *req);
- Semantics:
  - Function returns no matter what
  - No guaranteed progress (quality of implementation)
  - Usual completion calls (wait, test) + mixing
  - Out-of order completion
- Restrictions:
  - No tags, in-order matching
  - Send and vector buffers may not be touched during operation
  - MPI_Cancel not supported
  - No matching with blocking collectives

Nonblocking collectives

- Semantic advantages:
  - Enable asynchronous progression (and manual)
    - Software pipelining
  - Decouple data transfer and synchronization
    - Noise resiliency!
  - Allow overlapping communicators
    - See also neighborhood collectives
  - Multiple outstanding operations at any time
    - Enables pipelining window
- Complex progression
  - MPI's global progress rule!
  - Higher CPU overhead (offloading?)
  - Differences in asymptotic behavior
    - Collective time often
    - Computation
    - Performance modeling (more complicated than for blocking)
    - One term often dominates and complicates overlap

Topologies and Neighborhood



Courtesy to Torsten Hoefler

- Rank reordering (transform the original, resource manager provided allocation) and map the processes on it based on the communication pattern

MPI topologies support

- MPI-1: Basic support Convenience functions
  - Create and query a graph
  - Useful especially for Cartesian topologies
  - Query neighbors in n-dimensional space
  - Non-scalable: the graph knowledge must be global as each rank must specify the full graph
- MPI-2.2: Scalable Graph topology
  - Distributed Graph: each rank specifies its neighbors or arbitrary subset of the graph
- MPI-3.0: Neighborhood collectives
  - Adding communication functions defined on graph topologies (neighborhood of distance one)

Cartesian topology creation

- Specify ndims-dimensional topology
  - Optionally periodic in each dimension (Torus)
- Some processes may return MPI_COMM_NULL
  - Product sum of dims must be <= P
- Reorder argument allows for topology mapping
  - Each calling process may have a new rank in the created communicator
  - Application must adapt to rank changing between the old and the new communicator, i.e. data must be manually remapped
- MPI provides support for creating the dimensions array (”square” topologies via MPI_Dims_create)
  - Non-zero entries on the dims array will not be changed

```
MPI_Cart_create(MPI_Comm old_comm,
                int ndims, const int*dims, const int *periods,
                int reorder, MPI_Comm *comm)
MPI_Dims_create(int nnodes, int ndims, int *dims)
```

Graph Creation

- nnodes is the total number of nodes in the graph
- index[i] stores the total number of neighbors for the first i nodes (sum)
  - Acts as offset into edges array
- edges stores the edge list for all processes
  - Edge list for process j starts at index[j] in edges
  - Process j has index[j+1]-index[j] edges
- Each process must know the entire topology
  - Not scalable

```
MPI_Graph_create(MPI_Comm comm_old, int nnodes,
                 const int *index, const int *edges, int reorder,
                 MPI_Comm *comm_graph)
```

Distributed graph creation

- Scalable, allows distributed graph specification
  - Each nodes specifies either the local neighbors or any edge in the graph (knowledge is now globally distributed)
- Specify edge weights
  - Optimization opportunity for reordering despite the fact that the meaning is undefined
  - Each edge must be specified twice, once as out-edge (at the source) and once as in-edge (at the dest)
- Info arguments
  - Communicate assertions of semantics to the MPI library
  - E.g., semantics of edge weights

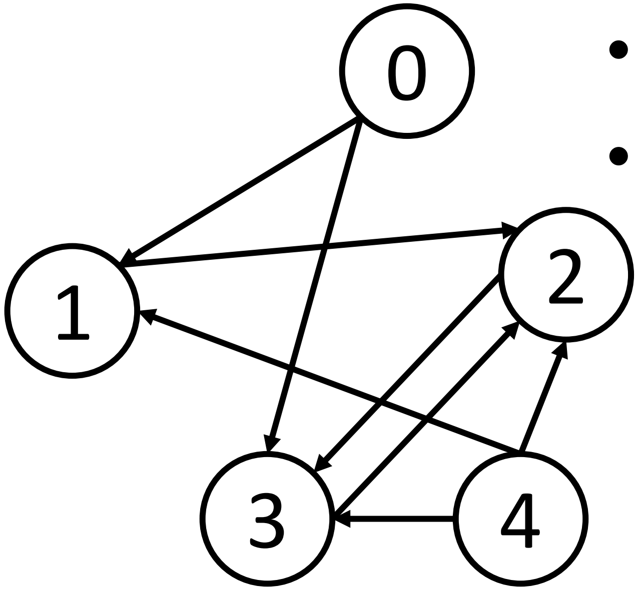
Distributed graph creation

```
MPI_Dist_graph_create_adjacent(MPI_Comm old_comm
        int indegree, const int sources[], const int sourceweights[],
        int outdegree, const int destinations[], const int destweights[],
        MPI_Info info, int reorder, MPI_Comm *comm_dist_graph)
```

- n – number of source nodes
- sources – n source nodes
- degrees – number of edges for each source
- destinations, weights – dest. processor specification
- info, reorder – as usual
- MPI_Dist_graph_create requires global communications to redistribute the information (as each process will eventually need to know it's neighbors)

```
MPI_Dist_graph_create(MPI_Comm comm_old, int n,
    const int sources[], const int degrees[], const int destinations[],
    const int weights[], MPI_Info info, int reorder,
    MPI_Comm*comm_dist_graph)
```

Example: distributed graph creation



- MPI_Dist_graph_create_adjacent
- MPI_Dist_graph_create

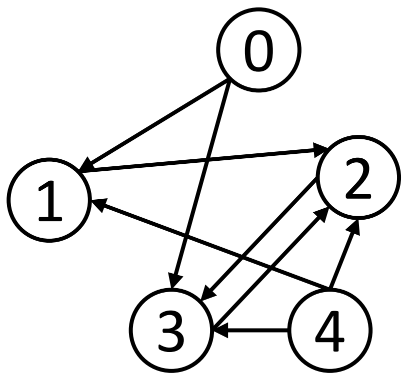
	P0	P1	P2	P3	P4
indegree	{0}	{2}	{3}	{3}	{0}
sources	{}	{0, 4}	{1, 3, 4}	{0, 2, 4}	{}
outdegree	{2}	{1}	{1}	{1}	{3}
destinations	{1, 3}	{2}	{3}	{2}	{1, 2, 3}

- The order is not important, but it must reflect on how the topology will be used
  - Define the buffers order in the neighborhood collectives
- MPI_Dist_graph_create can be any permutation of the same edges representation

Distributed Graph query functions

- Query information (the number of neighbors and the neighbors) about the calling process
  - MPI_Dist_graph_neighbors_count return counts for the indegree, outdegree and weight.

```
MPI_Dist_graph_neighbors_count(MPI_Comm comm,
                int *indegree, int *outdegree, int *weighted)
MPI_Dist_graph_neighbors(MPI_Comm comm,
                int maxindegree, int sources[], int sourceweights[],
                int maxoutdegree, int destinations[],int destweights[])
```



	P0	P1	P2	P3	P4
indegree	{0}	{2}	{3}	{3}	{0}
sources	{}	{0, 4}	{1, 3, 4}	{0, 2, 4}	{}
outdegree	{2}	{1}	{1}	{1}	{3}
destinations	{1, 3}	{2}	{3}	{2}	{1, 2, 3}

MPI_Dist_graph_neighbors_count MPI_Dist_graph_neighbors

Neighborhood Collectives

- Collective communications over topologies
  - They are still **collective** (all processes in the communicator **must** do the call, *including processes without neighbors*)
  - Buffers are accessed in the neighbors sequence
    - Order is determined by order of neighbors as returned by the corresponding query functions ([dist_]graph_neighbors).
    - Defined by order of dimensions, first negative, then positive
    - Cartesians 2*ndims sources and destinations
    - Distributed graphs are directed and may have different numbers of send/recv neighbors
    - Processes at borders (MPI_PROC_NULL) leave holes in buffers (will not be updated or communicated)!
  - Every process is root in its own neighborhood (!)

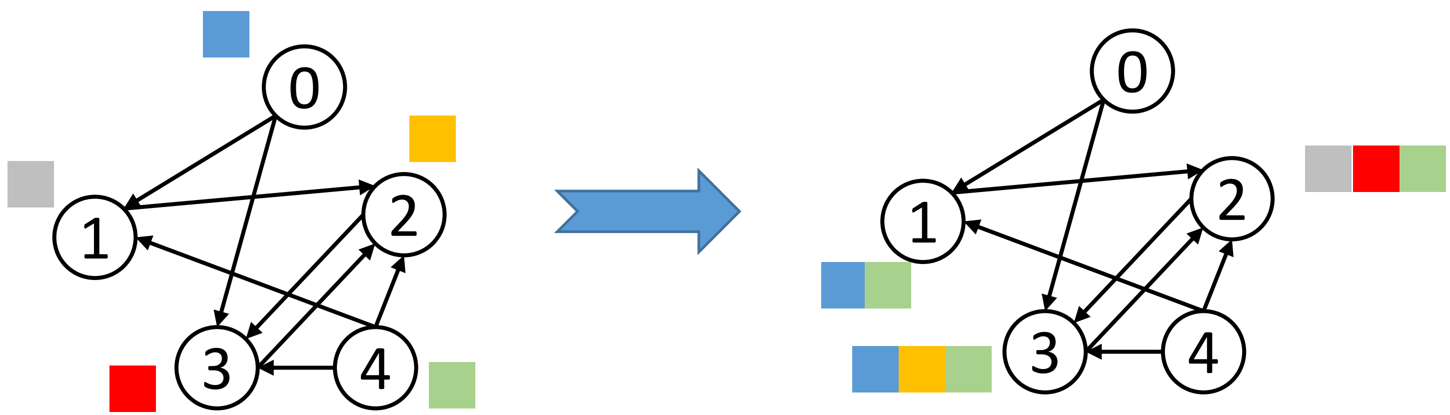
MPI_Neighbor_allgather

- Each process send the same message to all neighbors (the sendbuf)
- Each process receives indegree messages, one from each neighbors in their corresponding order from the query functions
- Similar to MPI_gather where each process is the root on the neighborhood
    - Despite the fact that name starts with all

```
MPI_Neighbor_allgather(
    const void* sendbuf, int sendcount, MPI_Datatype sendtype,
    void* recvbuf, int recvcount, MPI_Datatype recvtype,
    MPI_Comm comm)
```

MPI_Neighbor_allgather

```
MPI_Neighbor_allgather(
    const void* sendbuf, int sendcount, MPI_Datatype sendtype,
    void* recvbuf, int recvcount, MPI_Datatype recvtype,
    MPI_Comm comm)
```



	P0	P1	P2	P3	P4
indegree	{0}	{2}	{3}	{3}	{0}
sources	{}	{0, 4}	{1, 3, 4}	{0, 2, 4}	{}
outdegree	{2}	{1}	{1}	{1}	{3}
destinations	{1, 3}	{2}	{3}	{2}	{1, 2, 3}

Nonblocking versions

- Full support for all nonblocking neighborhood collectives
  - Same collective invocation requirement
  - Matching will be done in order of the collective post for each collective
    - As each communicator can only have a single topology
- Think about the Jacobi where the communications are done with neighbor collectives

One-sided communications

- In MPI we are talking about epoch: a window of memory updates
  - Somewhat similar to memory transactions
  - Everything in an epoch is visible at once on the remote peers
  - Allow to decouple data transfers and synchronizations
- Terms:
  - Origin process: Process with the source buffer, initiates the operation
  - Target process: Process with the destination buffer, does not explicitly call communication functions
  - Epoch: Virtual time where operations are in flight. Data is consistent after new epoch is started.
    - Access epoch: rank acts as origin for RMA calls
    - Exposure epoch: rank acts as target for RMA calls
  - Ordering: only for accumulate operations: order of messages between two processes (default: in order, can be relaxed)
  - Assert: assertions about how the one sided functions are used, "fast" optimization hints, cf. Info objects (slower)

Overview

- Window creation
  - Static
    - Expose allocated memory: MPI_Win_create
    - Allocate and expose memory: MPI_Win_allocate
  - Dynamic
    - MPI_Win_create_dynamic
- Communications
  - Data movements: Put, Rput, Get, Rget
  - Accumulate (acc, racc, get_acc, rget_acc)
  - Atomic operations (fetch&op, compare and swap)
- Synchronizations
  - Active: Collective (fence); Group
  - Passive: P2P (lock/unlock); One epoch (lock _all)

Memory Exposure

- Collective calls (attached to a communicator)
- Info
  - no_locks – user asserts to not lock win
  - accumulate_ordering – comma-separated rar, war, raw, waw
  - accumulate_ops – same_op or same_op_no_op (default) – assert used ops for related accumulates
  - same_size – if true, user asserts that size is identical on all calling processes (only for MPI_Win_allocate)
- MPI_Win_allocate is preferred, as the implementation is allowed to prepare the memory (pinning and co.)
- MPI_Win_free will free the memory allocated by the MPI library (special care for MPI_Win_allocate)

```
MPI_Win_create(void *base, MPI_Aint size, int disp_unit,
               MPI_Info info, MPI_Comm comm, MPI_Win *win)
MPI_Win_allocate(MPI_Aint size, int disp_unit, MPI_Info info,
                 MPI_Comm comm, void *baseptr, MPI_Win *win)
MPI_Win_create_dynamic(MPI_Info info, MPI_Comm comm, MPI_Win *win)
  MPI_Win_attach(MPI_Win win, void *base, MPI_Aint size)
  MPI_Win_detach(MPI_Win win, const void *base)
MPI_Win_free(MPI_Win *win)
```

One Sided communications

- Put and Get have symmetric behaviors
- Nonblocking, they will complete at the end of the epoch
- Conflicting accesses (for more than one byte) are allowed, but their outcome is undefined
- The request based version can be waited using any MPI completion mechanism (MPI_Test* or MPI_Wait*)
- Similarly to MPI_Send completion of the request only has a local meaning
  - GET: the data is stored in the local buffer
  - PUT: The local buffer can be safely reused (no remote completion)

```
MPI_Put(const void *origin_addr, int origin_count, MPI_Datatype origin_datatype,
        int target_rank, MPI_Aint target_disp, int target_count, MPI_Datatype target_datatype,
        MPI_Win win)
MPI_Rput(…, MPI_Request *request)
```

One Sided Accumulate

- Atomic update of remote memory based on a combination of the existing data and local data
  - Except if OP is MPI_REPLACE (when it is equivalent to MPI_Put)
  - Non overlapping entries at the target (because memory consistency and ordering accesses)
- MPI_Get_accumulate similar behavior to fetch_and_* operations
  - Accumulate origin into target, returns content before accumulate in result
  - The accumulate operation is atomic
- Order between operations can be relaxed with info (accumulate_ordering = raw, waw, rar, war) during window creation

```
MPI_Accumulate(const void *origin_addr, int origin_count, MPI_Datatype origin_datatype,
    int target_rank, MPI_Aint target_disp, int target_count, MPI_Datatype target_datatype,
    MPI_Op op, MPI_Win win)
MPI_Get_accumulate(const void *origin_addr, int origin_count, MPI_Datatype origin_datatype,
    void *result_addr, int result_count, MPI_Datatype result_datatype,
    int target_rank, MPI_Aint target_disp, int target_count, MPI_Datatype target_datatype,
    MPI_Op op, MPI_Win win)
```

One Sided Atomic Operations

- Similar to the atomic operations on the processor
- Fetch_and_op common use case for single element
  - Supposed to be a faster version of the MPI_Get_accumulate because of the restriction on the datatype and count
- Compare and swap
  - Compares compare buffer with target and replaces value at target with origin if compare and target are identical. Original target value is returned in result.

```
MPI_Fetch_and_op(const void *origin_addr, void *result_addr, MPI_Datatype datatype,
    int target_rank, MPI_Aint target_disp, MPI_Op op, MPI_Win win)
MPI_Compare_and_swap(const void *origin_addr, const void *compare_addr, void *result_addr,
    MPI_Datatype datatype, int target_rank, MPI_Aint target_disp, MPI_Win win)
```

One Sided Synchronizations

- Active / Passive

```
MPI_Win_fence(int assert, MPI_Win win)
```

- Collective Synchronization: all operations started before will complete by the time we return
  - Ends the exposure epoch for the entire window
  - Optimization possible via the MPI_MODE_NOPRECEDE assert (no local or remote operations with target the local processor exists)

```
MPI_Win_post(MPI_Group group, int assert, MPI_Win win)
MPI_Win_start(MPI_Group group, int assert, MPI_Win win)
MPI_Win_complete(MPI_Win win)
MPI_Win_wait(MPI_Win win)
```

- Specification of access/exposure epochs separately:
  - Post: start exposure epoch to group, nonblocking
  - Start: start access epoch to group, may wait for post
  - Complete: finish prev. access epoch, origin completion only (not target)
  - Wait: will wait for complete, completes at (active) target
- As asynchronous as possible

One Sided Synchronizations

```
MPI_Win_lock(int lock_type, int rank, int assert, MPI_Win win)
MPI_Win_unlock(int rank, MPI_Win win)
```

- Initiates RMA access epoch to rank
  - No concept of exposure epoch
- Unlock closes access epoch
  - Operations have completed at origin and target
- Type:
  - Exclusive: no other process may hold lock to rank
    - More like a real lock, e.g., for local accesses
  - Shared: other processes may also hold lock

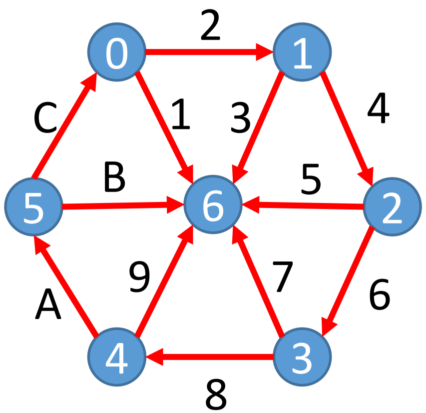
```
MPI_Win_lock_all(int assert, MPI_Win win)
MPI_Win_unlock_all(MPI_Win win)
```

- Starts a shared access epoch from origin to all ranks!
  - Not collective!
- Does not really lock anything
  - Opens a different mode of use

More advanced MPI and mixed programming topics

Extracting messages from MPI

- MPI_Recv delivers each message from a peer in the order in which these messages were send
  - No coordination between peers is possible



- Take a scenario where we have a ring of processors with (P-1) participants, and a lone process that centralize messages from all peers.
- Each processor (except 0) waits for a message from its predecessor in the ring before sending a message to the coordinator
- In which order the messages are received at the coordinator ?
- How we can implement this if each ring participant send a message of a different length ?
- What if we assume a large number of processes?

- Missing functionality: the capability to peek (but not alter) into the network to extract what message will be the next to be locally received
  - Functionality that behaves as MPI_Recv but without altering the matching queue

MPI Probe

```
int MPI_Probe(int source, int tag, MPI_Comm comm, MPI_Status *status);
int MPI_Iprobe(int source, int tag, MPI_Comm comm, int *flag,    MPI_Status *status);
Int MPI_Get_count( MPI_Status* status, MPI_Datatype datatype, int* count);
MPI_Status a structure containing the fields MPI_SOURCE, MPI_TAG and MPI_ERROR
```

- MPI_ANY_SOURCE and MPI_ANY_TAG can be used as markers for unnamed receives
- The usual usage scenario is probe, memory allocation and then receive
  - How can we use this functionality in a thread safe application when all threads work on the same communicator ?
  - Assume 2 threads (X,Y) doing the probe (P), alloc (A) and receive (R) operation each one on its own context
    - $X_P \longrightarrow X_A \longrightarrow X_R \longrightarrow Y_P \longrightarrow Y_A \longrightarrow Y_R$
  - What happens if the order of the operations is $X_P \longrightarrow X_A \longrightarrow Y_P \longrightarrow Y_A \longrightarrow Y_R \longrightarrow X_R$
- The access to the matching queue need to be protected for concurrent accesses

Message Probe

- Functionality that extracts the message from the matching queue but without receiving it
  - Supported by functionality to extract the content of the message into a user provided buffer
  - Any partial ordering between our threads X and Y is now correct: $X_{P'} \longrightarrow X_A \longrightarrow Y_{P'} \longrightarrow Y_A \longrightarrow Y_{R'} \longrightarrow X_{R'}$

```
int MPI_Mprobe(int source, int tag, MPI_Comm comm,    MPI_Message *message,
                    MPI_Status *status);
int MPI_Improbe(int source, int tag, MPI_Comm comm,    int *flag, MPI_Message *message,
                    MPI_Status *status)
int MPI_Mrecv(void *buf, int count, MPI_Datatype type,    MPI_Message *message,
                  MPI_Status *status);
int MPI_Imrecv(void *buf, int count, MPI_Datatype type,    MPI_Message *message,
                  MPI_Request *request);
```

Collective Communication with threads

- What is happening if multiple threads issue in the same communicator in same time
  - Multiple blocking collectives ?
  - Multiple non-blocking collective with the same datatype and count ?
  - Multiple non-blocking collective with the different datatype and count ?

Shared Memory

- Potential for memory reduction as initialization data can be shared between processes
  - Avoid recomputing the same initial state by multiple applications (on the same node)
  - POSIX provides shared memory regions but (1) not all Oses have support for them and (2) it does not integrate with MPI functionality
- Need functionality to split a communicator in disjoint groups with shared capabilities
  - Similar to MPI_Comm_split with architecture aware color (key will then be the rank in the original communicator)
  - Single info key standardized: MPI_COMM_TYPE_SHARED
  - Some MPI implementations provide support for different granularities of sharing ([Open MPI](#))

```
int MPI_Comm_split_type(MPI_Comm comm, int split_type, int key,    MPI_Info info,
                        MPI_Comm *newcomm);
```

Shared Memory Window

- Allocates shared memory regions in win
  - Collective call resulting in a fully capable RMA window
  - Constraint: all processes in the communicator must be capable of physically sharing memory (usually same node)
  - The call returns a pointer to the local part
  - The info key define how the global shared memory region is defined:
    - Contiguous: process i memory starts right after the end of process i-1
    - Non contiguous (key alloc_shared_noncontig): allow the MPI to provide NUMA-aware optimizations.
  - One way to create the communicator needed is to use MPI_Comm_split_type

```
int MPI_Win_allocate_shared (MPI_Aint size, int disp_unit, MPI_Info info, MPI_Comm comm,
                             void *baseptr, MPI_Win *win);
```

Shared Memory Window

- In non contiguous cases we need to extract the remote address in order to complete RMA operations
  - As the memory region might be mapped at different addresses in different processes each process local address has no meaning
    - Unlike in Open SHMEM where the RMA operations applied on symmetric memory (!)
  - Only works for windows of type MPI_WIN_FLAVOR_SHARED (aka. created via MPI_Win_allocate_shared)

```
int MPI_Win_shared_query (MPI_Win win, int rank, MPI_Aint *size, int *disp_unit,
                          void *baseptr);
```

RMA and pt2pt puzzle ?

- Assuming a correctly initialized window what is the outcome of the following code ?

```
for(i = 0; i < len; a[i] = (double)(10*me+i), i++);
if (me == 0) {
    MPI_Win_lock(MPI_LOCK_EXCLUSIVE, 1, 0, win);
    MPI_Send(NULL, 0, MPI_BYTE, 2, 1001, MPI_COMM_WORLD);
    MPI_Get(a,len,MPI_DOUBLE,1,0,len,MPI_DOUBLE,win);
    MPI_Win_unlock(1, win);
    for(i = 0; i < len; i++) printf("a[%d] = %d\n", a[i]);
} else if (me == 2) {    /* this should block till 0 releases the lock. */
    MPI_Recv(NULL, 0, MPI_BYTE, 0, 1001, MPI_COMM_WORLD, MPI_STATUS_IGNORE);
    MPI_Win_lock(MPI_LOCK_EXCLUSIVE, 1, 0, win);
    MPI_Put(a,len,MPI_DOUBLE,1,0,len,MPI_DOUBLE,win);
    MPI_Win_unlock(1, win);
}
```