The Case for Collective Pattern Specification

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Motivation and Main Theses

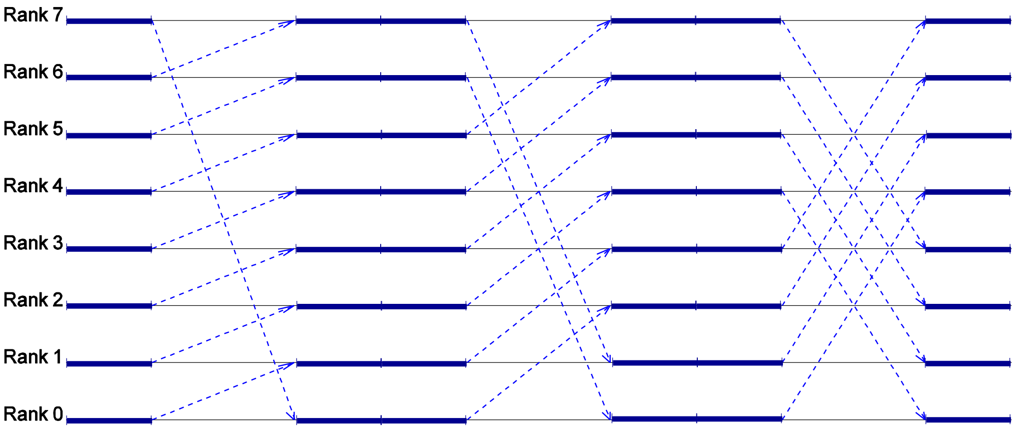
- Message Passing (MP) is a useful programming concept
  - Reasoning is simple and (often) deterministic
  - Message Passing Interface (MPI) is a proven interface definition
- MPI often cited as *"assembly language of parallel computing"*
  - Not quite true as MPI offers *collective communication*
  - But: Many relevant patterns are not covered
    - e.g., nearest neighbor halo exchange
- Bulk Synchronous Parallelism is a useful programming model for MP programs
  - Easy to reason about the state of the program
    - cf. structured programming vs. goto

Valiant's BSP Model

- Envisioned as hardware and software model
  - SPMD program execution is split into *k* supersteps
  - All instances are in the same superstep
    - Implies synchronization / synchronous execution
  - Messages can be sent and received during superstep *i*
    - Received messages can be accessed in superstep *i* +1
- Our claim:
  - Many algorithm communication patterns are constant or exhibit temporal locality
    - Should be defined as such!
    - Allows various optimizations
    - Takes the MPI abstractions to a new (higher) level

Classification of Communication Patterns

- We classify applications (or algorithms) into five main classes of communication patterns

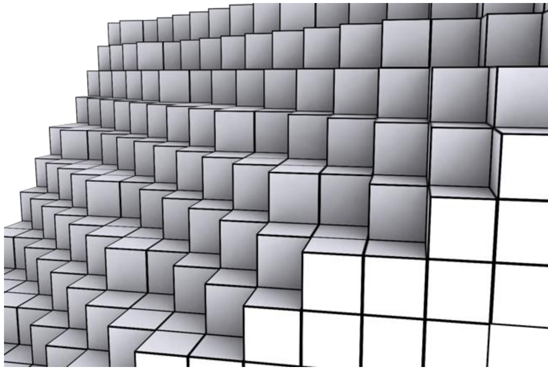


1. Compile-time static
2. Run-time static
3. Run-time flexible
4. Dynamic

5. (Massively parallel)
   - Mostly for completeness and not discussed further

Compile-time static

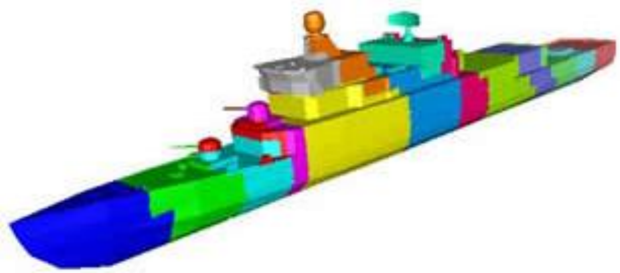
- Communication pattern is completely described in source code
  - *Shape* is independent of all input parameters
- Implementation in MPI
  - Either collectives or bunch of send/recvs
  - Proposal for *"Sparse collectives"* allows definition of arbitrary collectives (MPI 3?)



- Examples:
  - MIMD Lattice Computation (MILC) – 4d grid
  - Weather Research and Forecasting (WRF) – 2d grid
  - ABINIT – collectives only (Alltoall for 3d FFT)

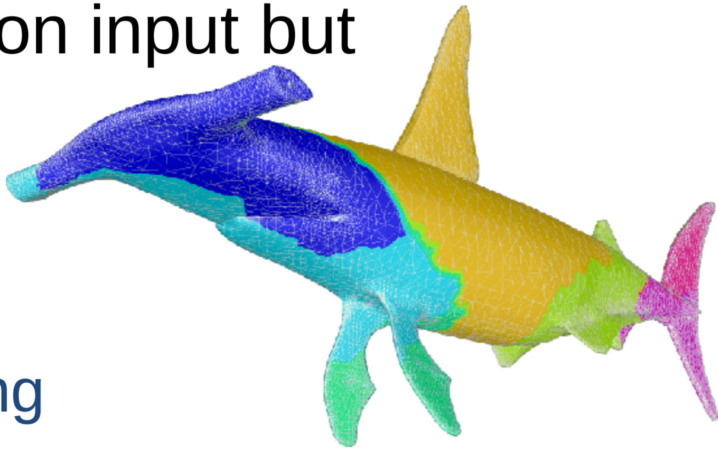
Run-time static

- Communication pattern depends on input but is fixed during execution
  - Can be compiled once at the beginning
- Implementation in MPI
  - Use graph partitioner (ParMetis, Scotch, …)
  - Send/recv communication for halo zones
  - Will be supported by *"Sparse Collectives"*
- Examples:
  - TDDFT/Octopus – finite difference stencil on real domain
  - Cactus framework
  - MTL-4 (sparse matrix computations)



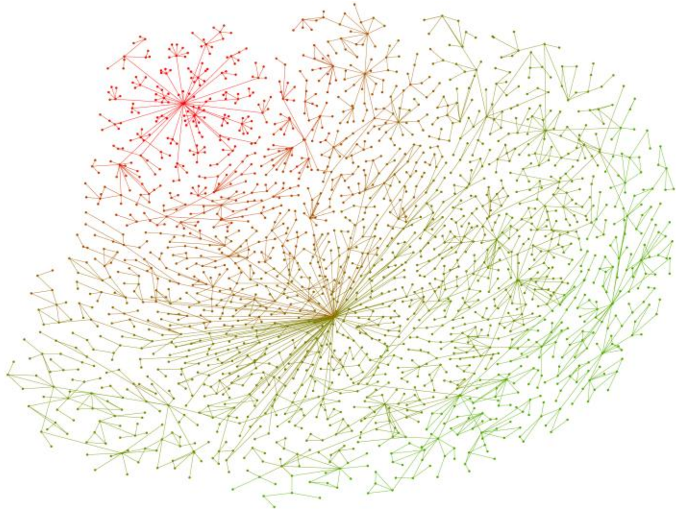
Run-time flexible

- Communication pattern depends on input but changes over time
  - However, there is still some locality
- Implementation in MPI
  - Graph partitioning and load balancing
  - Typically send/recv communication (often request/reply)
  - Static optimization might be of little help if pattern changes too frequently
- Examples:
  - Enzo – cosmology simulation - 3d AMR
  - Cactus framework - Berger-Oliger AMR



Dynamic

- Communication pattern only depends on input and has no locality
  - Little can be done: BSP might not be the ideal model
- Implementation in MPI:
  - Typically send/recv request/reply
    - Active message style
  - Often employ *"manual"* termination detection with collectives (Allreduce)
  - Not a good fit to MPI 2.2 (MPI 3?)
- Examples:
  - Parallel Boost Graph Library (PBGL) – implements various graph algorithms on distributed memory



Our Proposal

- Specify collective operations explicitly
  - MPI has collectives
    - … but they are inadequate
  - Want to express sparse collectives easily

- A *declarative* approach to specifying communication patterns
- Describe the *what*, not the *how*, of communications
- An abstract specification that is implemented efficiently
  - Don't talk about individual messages

Benefits

- Abstract specification
  - Easier for programmers to understand
- Easier for compilers to optimize
  - Overlap communication and computation
  - Message coalescing, pipelining, etc.
  - Does not need to be implemented as BSP (weak sync.)
- An efficient runtime
  - That can choose an implementation approach based on memory/network tradeoffs
  - Use one-sided or two-sided based on hardware

Compile-time static

- Communication patterns expressed as a set of individual communication operations
- Built by quantifying over processors, array rows, etc.
- Dense and sparse collectives are supported directly
- Compiler optimizations apply readily

```
for all nodes p in grid:
    send A[0] on p to B[n] on up(p)
    and A[n] on p to B[0] on down(p)
```

Run-time static and flexible

- Collective communication pattern can be generated at run-time, and regenerated as necessary
  - Communication operations can use array references, etc.
- Compiler analyses are more difficult in these cases
  - Run-time optimization must sometimes be used
- Communication patterns may not be known globally
  - Not scalable for large systems
  - Conversion to multicast/… trees may be impossible

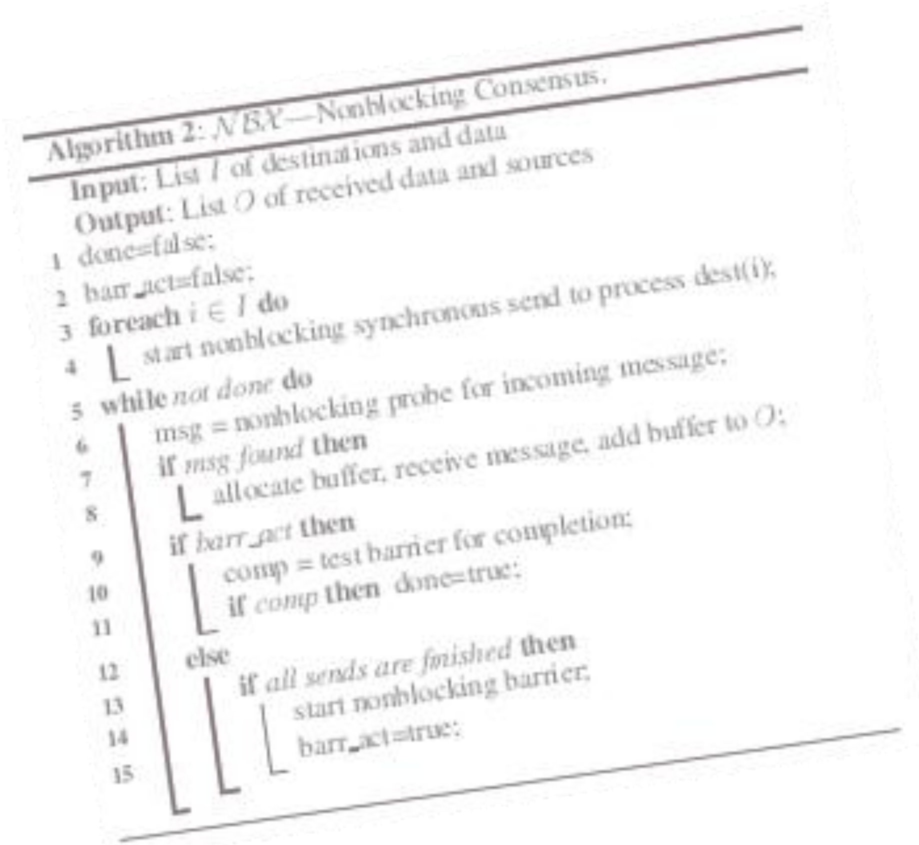
```
for all nodes p in grid:
  send A[0] on p to B[n] on next[p]
```

Summary

- Communications in BSP-style programs should be expressed as *collective operations*
- We suggest using a declarative specification of the communication operations
  - Better ease of development
  - Enables compiler optimizations (e.g., removing strict synchronization)
- Our approach can be embedded into an existing programming language as a library
  - Can be added incrementally to existing applications

Thank you for your attention!

Discussion



```
Algorithm 2: NBX—Nonblocking Consensus.
Input: List I of destinations and data
Output: List O of received data and sources
done=false;
barr_act=false;
foreach i ∈ I do
    start nonblocking synchronous send to process dest(i);
while not done do
    msg = nonblocking probe for incoming message;
    if msg found then
        allocate buffer, receive message, add buffer to O;
    if barr_act then
        comp = test barrier for completion;
        if comp then done=true;
    else
        if all sends are finished then
            start nonblocking barrier;
            barr_act=true;
```