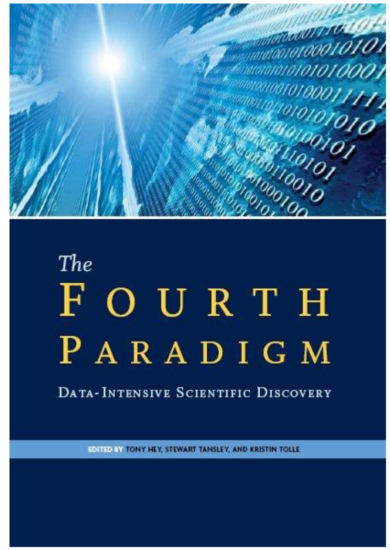
AM++: A Generalized Active Message Framework

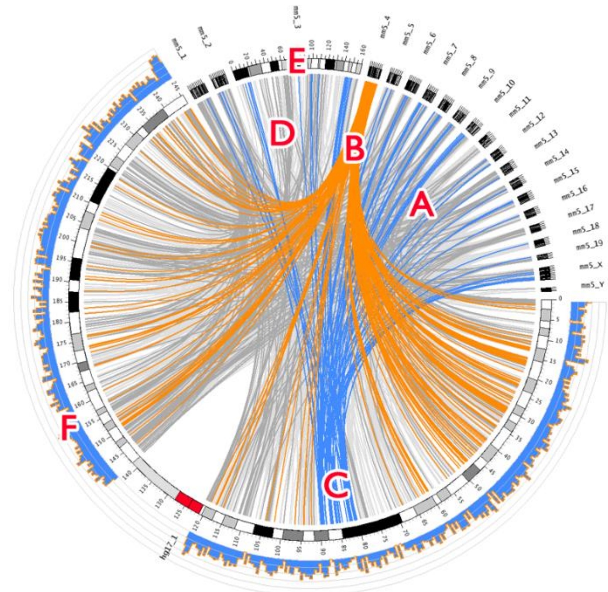
Jeremiah Willcock, Torsten Hoefler, Nicholas Edmonds,
and Andrew Lumsdaine

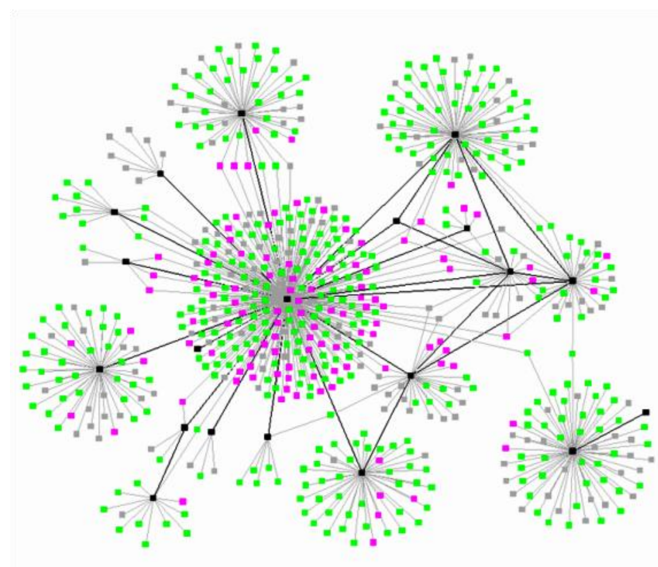
INDIANA UNIVERSITY
PERVASIVE TECHNOLOGY INSTITUTE

Large-Scale Computing

- Not just for PDEs anymore
- Many new, important HPC applications are data-driven (“informatics applications”)
  - Social network analysis
  - Bioinformatics







INDIANA UNIVERSITY
PERVASIVE TECHNOLOGY INSTITUTE

Data-Driven Applications

- Different from "traditional" applications
  - Communication highly data-dependent
  - Little memory locality
  - Impractical to load balance
  - Many small messages to random nodes
- Computational ecosystem is a bad match for informatics applications
  - Hardware
  - Software
  - Programming paradigms
  - Problem solving approaches

Two-Sided (BSP) Breadth-First Search

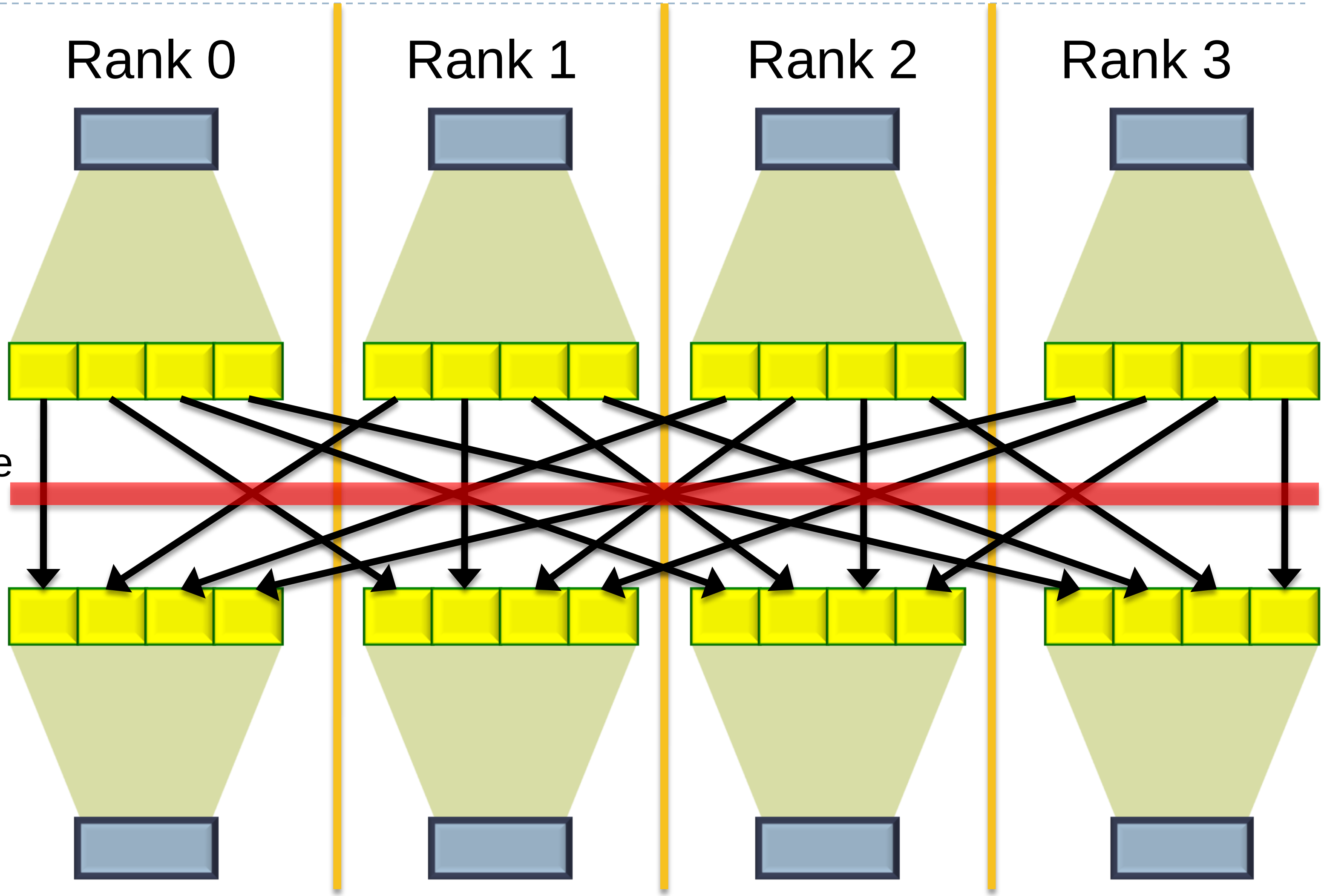
while any rank's *queue* **is not empty**:
  for *i* **in** *ranks*: *out_queue*[*i*] ← empty
  for vertex *v* **in** *in_queue*[*]:
    if *color*(*v*) **is** white:
      color(*v*) ← black
      for vertex *w* **in** neighbors(*v*):
        append *w* **to** *out_queue*[owner(*w*)]
  for *i* **in** *ranks*: **start receiving** *in_queue*[*i*] **from rank** *i*
  for *j* **in** *ranks*: **start sending** *out_queue*[*j*] **to rank** *j*
  synchronize and finish communications

Two-Sided (BSP) Breadth-First Search

Get neighbors

Redistribute queues

Combine received queues

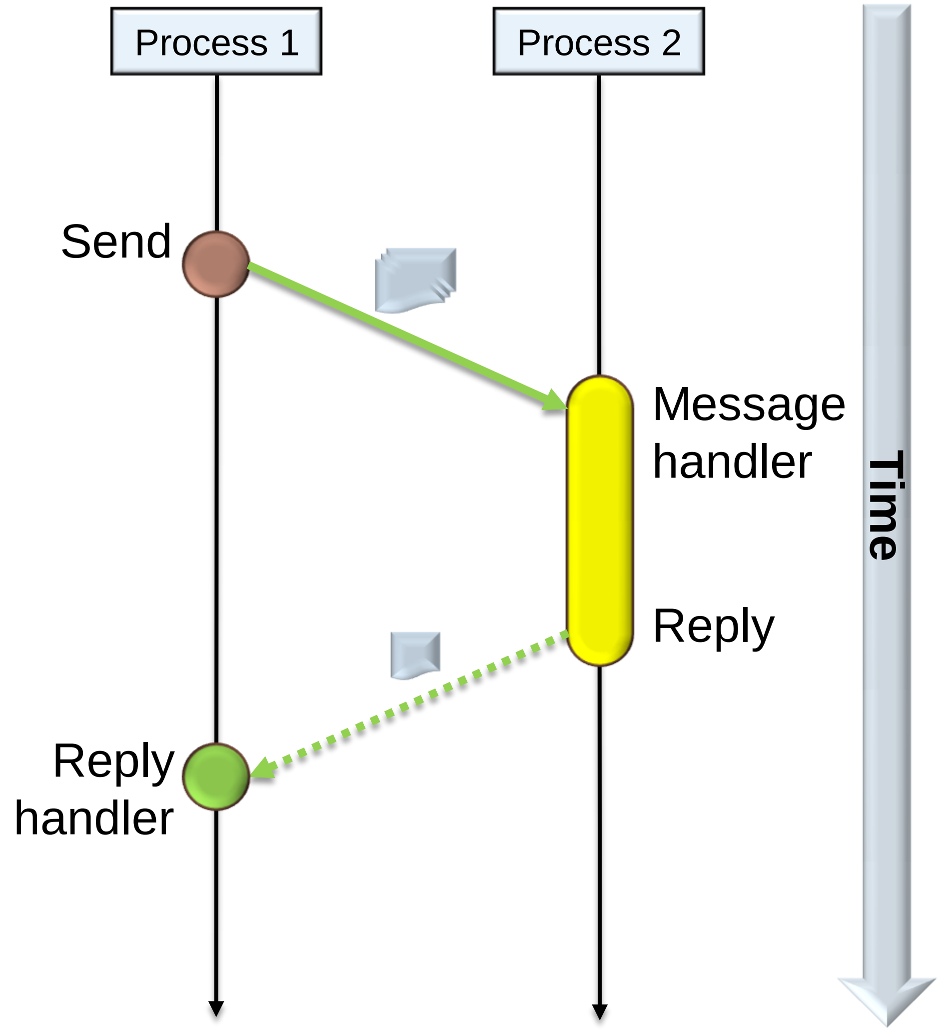


Messaging Models

- Two-sided
  - MPI
  - Explicit sends and receives
- One-sided
  - MPI-2 one-sided, ARMCI, PGAS languages
  - Remote put and get operations
  - Limited set of atomic updates into remote memory
- Active messages
  - GASNet, DCMF, LAPI, Charm++, X10, etc.
  - Explicit sends, implicit receives
  - User-defined handler called on receiver for each message

Active Messages

- Created by von Eicken et al, for Split-C (1992)
- Messages sent explicitly
- Receivers register handlers but not involved with individual messages
- Messages often asynchronous for higher throughput

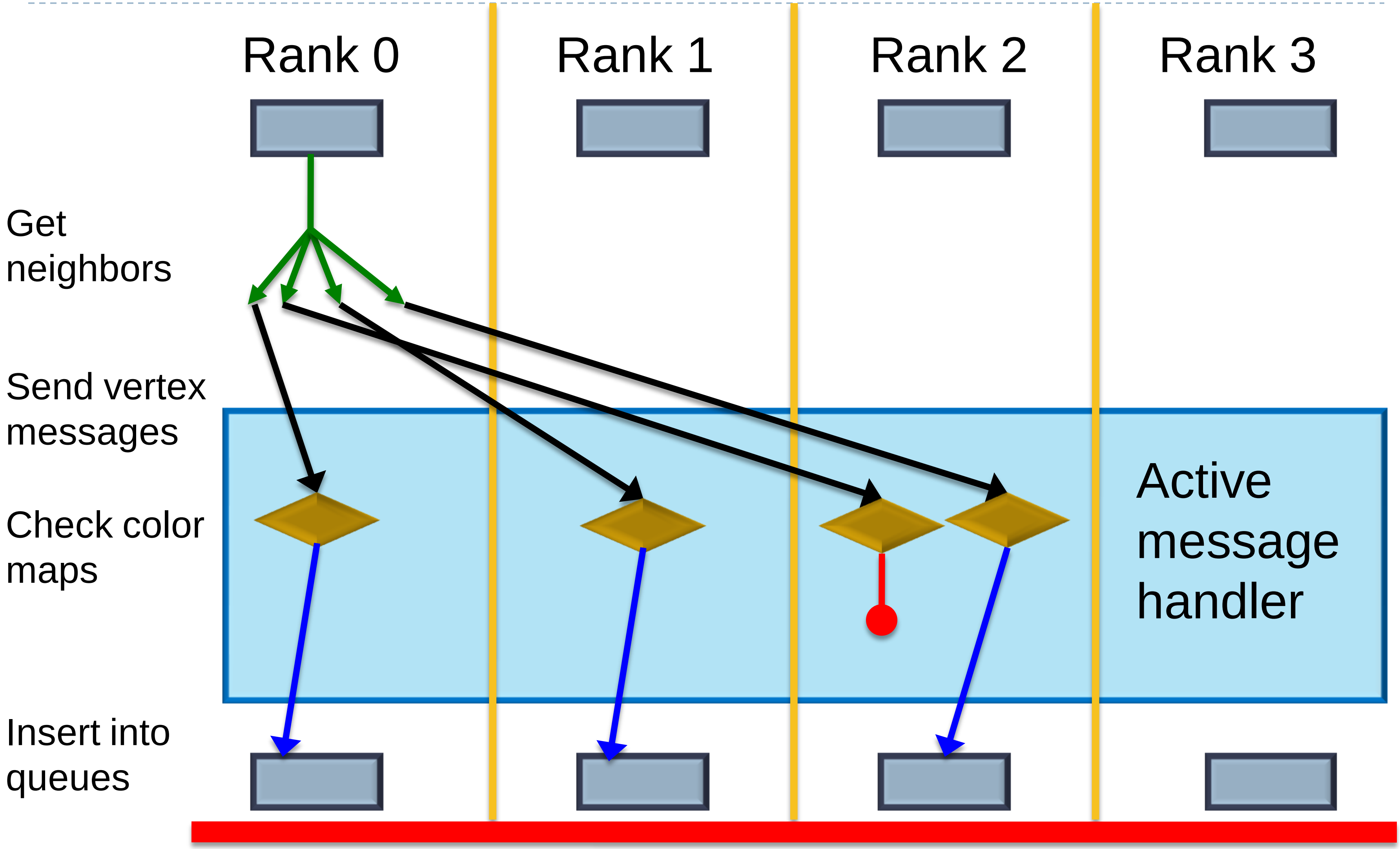


Active Message Breadth-First Search

```
handler vertex_handler(vertex v):
  if color(v) is white:
    color(v) ← black
    append v to new_queue

while any rank's queue is not empty:
  new_queue ← empty
  begin active message epoch
  for vertex v in queue:
    for vertex w in neighbors(v):
      tell owner(w) to run vertex_handler(w)
  end active message epoch
  queue ← new_queue
```

Active Message Breadth-First Search

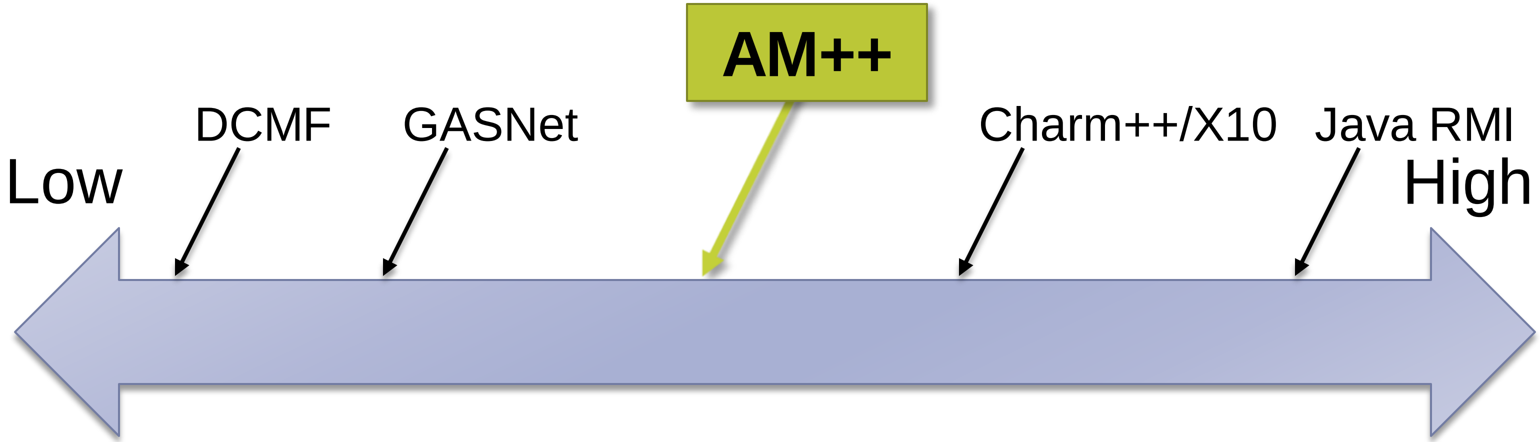


Low-Level vs. High-Level AM Systems

- Active messaging systems (loosely) on a spectrum of features vs. performance
  - Low-level systems typically have restrictions on message handler behavior, explicit buffer management, etc.
  - High-level systems often provide dynamic load balancing, service discovery, authentication/security, etc.

The AM++ Framework

- AM++ provides a "middle ground" between low- and high-level systems
  - Gets performance from low-level systems
  - Gets programmability from high-level systems
- High-level features can be built on top of AM++



Key Characteristics

- For use by applications
- AM handlers can send messages
- Mix of generative (template) and object-oriented approaches
  - Object-orientation for flexibility and type erasure
  - Templates for optimal performance
- Flexible/application-specific message coalescing
- Messages sent to processes, not objects

Example

```
mpi_transport trans(MPI_COMM_WORLD);

basic_coalesced_message_type<my_message_data, my_handler, mpi_transport>
  msg_type(trans, 256);

msg_type.set_handler(my_handler());

scoped_termination_detection_level_request<mpi_transport> td_req(trans, 0);

{
  scoped_epoch<mpi_transport> epoch(trans);
  if (trans.rank() == 0)
    msg_type.send(my_message_data(1.5), 2);
}
```

Create Message Transport
(Not restricted to MPI)

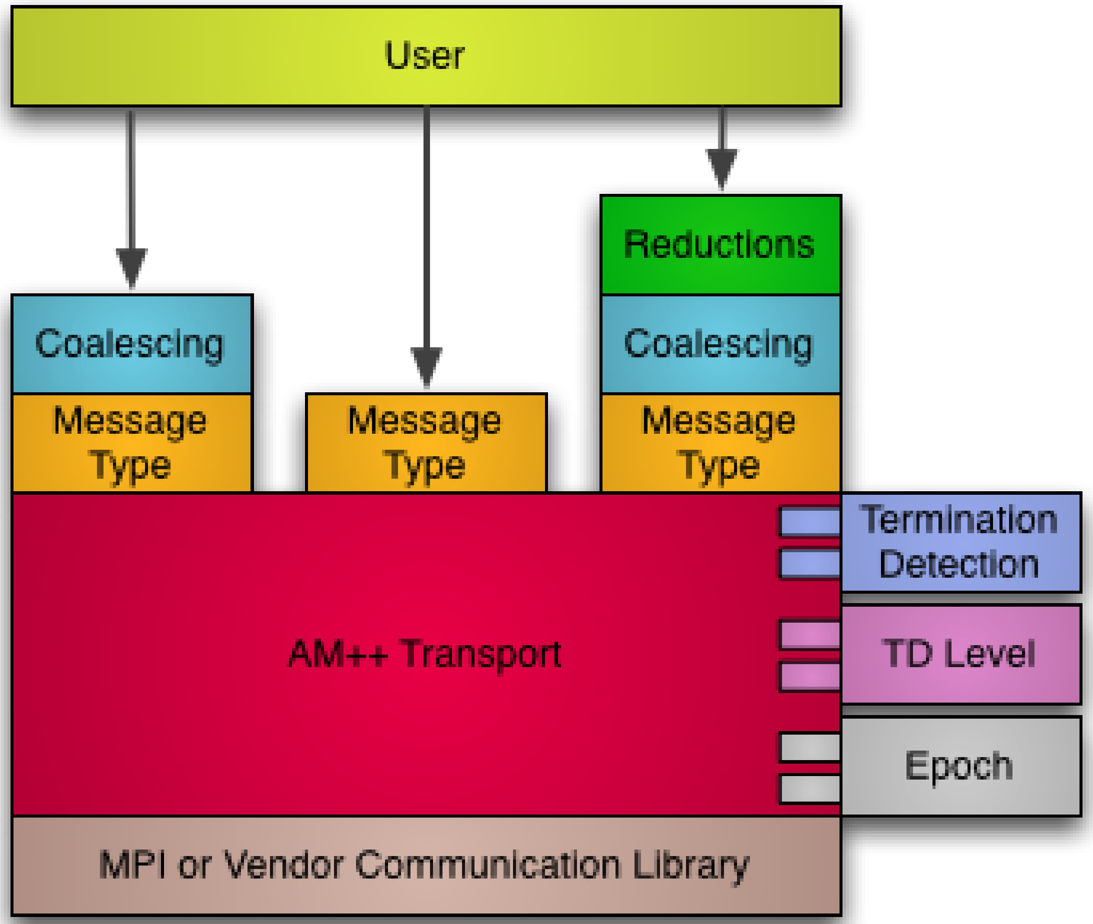
Coalescing layer
(and underlying message type)

Message Handler

Messages are nested to depth 0

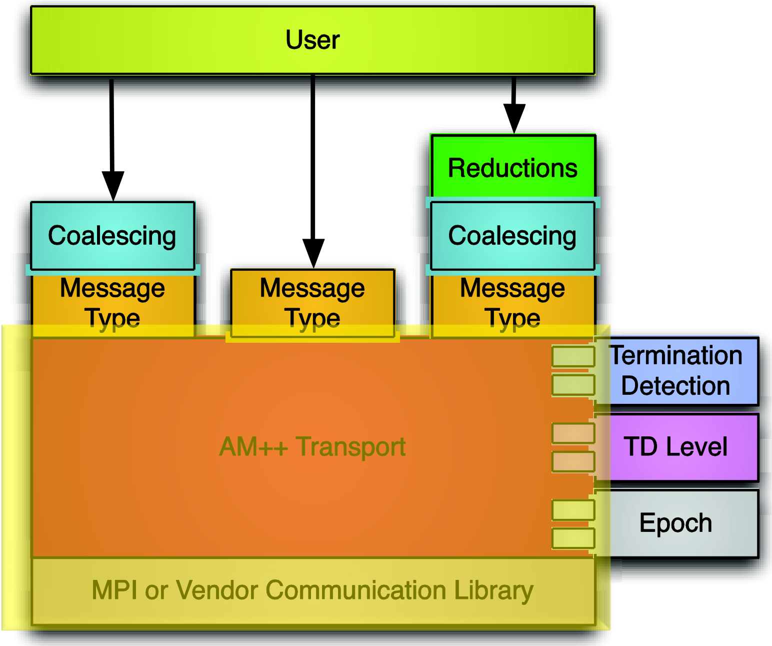
Epoch scope

AM++ Design


User
Reductions
Coalescing
Coalescing
Message Type
Message Type
Message Type
Termination Detection
AM++ Transport
TD Level
Epoch
MPI or Vendor Communication Library

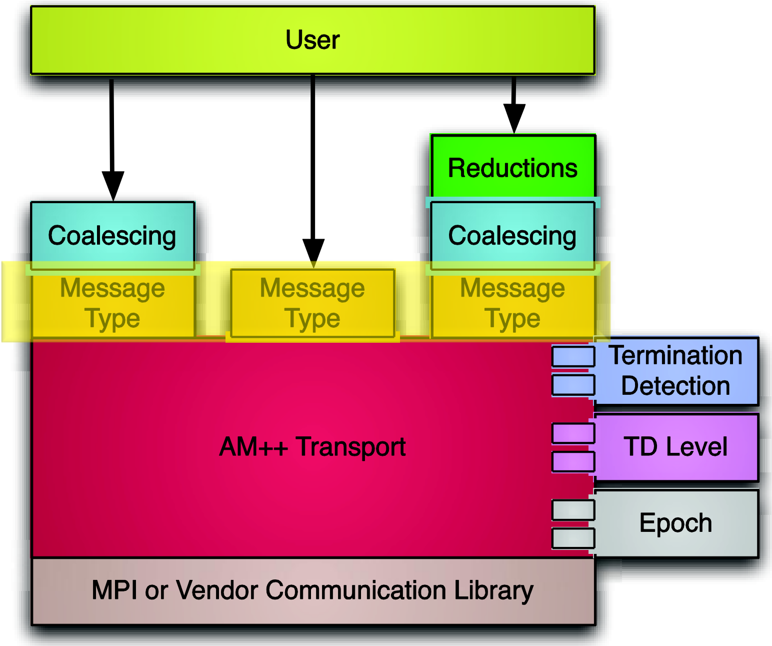
Transport

- Interface to underlying communication layer
  - MPI and GASNet currently
- Designed to send large messages produced by higher-level components
  - Object-oriented techniques allow run-time flexibility (type erasure)
- MPI-style progress model
  - Progress thread optional
  - User must call into AM++



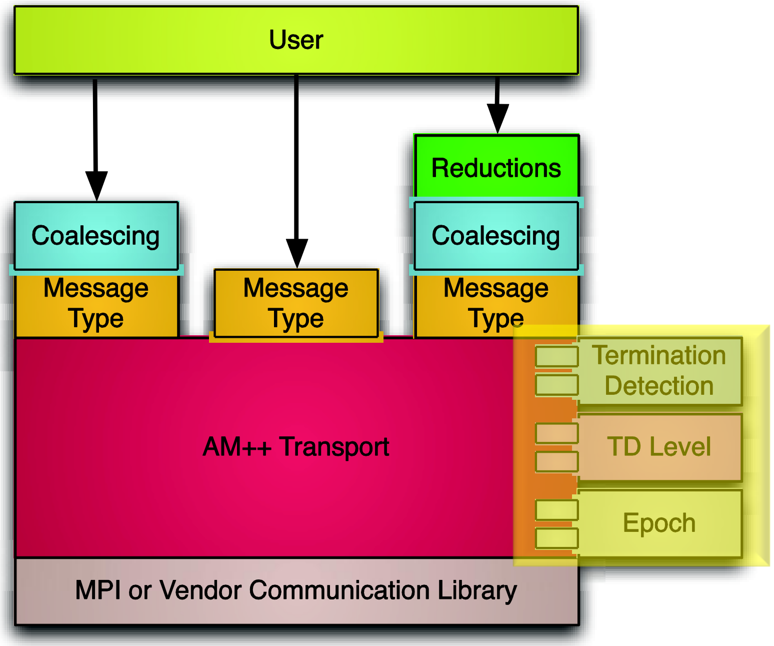
Message Types

- Handler registration for messages within transport
- Type-safe interface to reduce user casts and errors
- Automatic data buffer handling



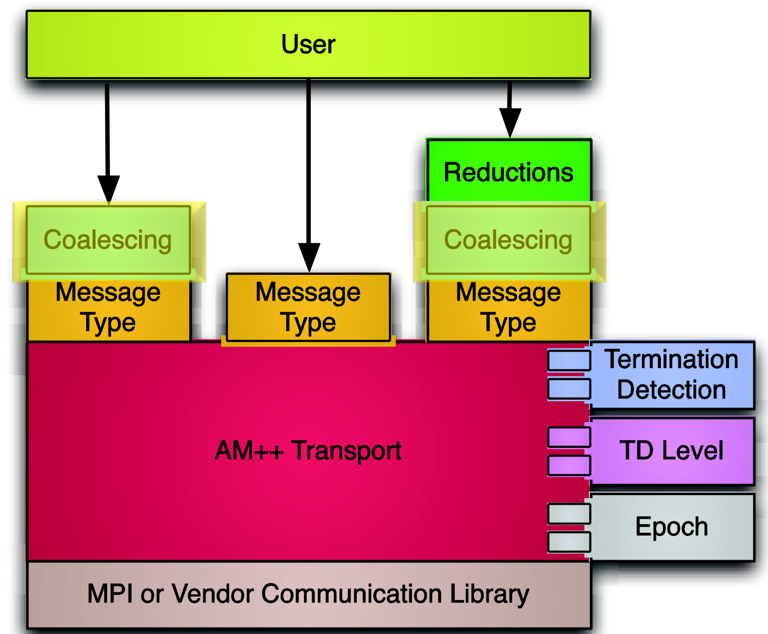
Termination Detection/Epochs

- AM++ handlers can send messages
  - When have they all been sent and handled?
- *Termination detection* – a standard distributed computing problem
- Some applications send a fixed depth of nested messages
- Time divided into epochs



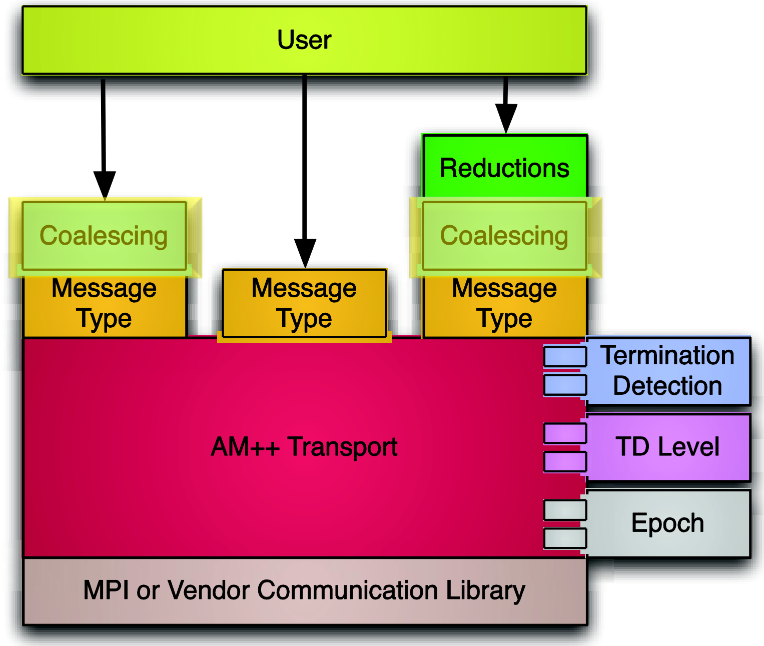
Message Coalescing

- Standard way to amortize overheads
  - Trade off latency for throughput
- Layered on transport and message type
- Can be specific to application or message type
- Handlers apply to one small message at a time
- Sends are of a single small message



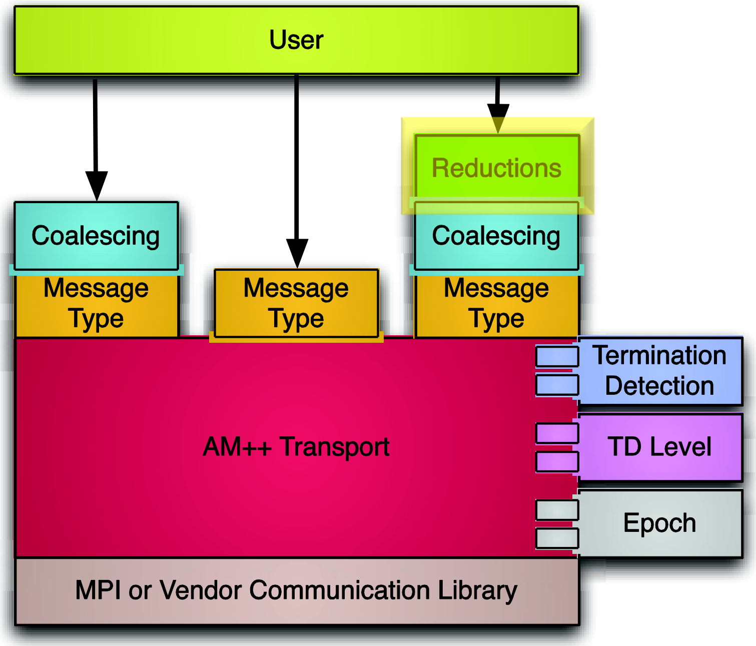
Message Handler Optimizations

- Coalescing uses generative programming and C++ templates for performance on high message rates
- Small-message handler type is known statically
- Simple loop calls handler
- Compiler can optimize using standard techniques



Message Reductions

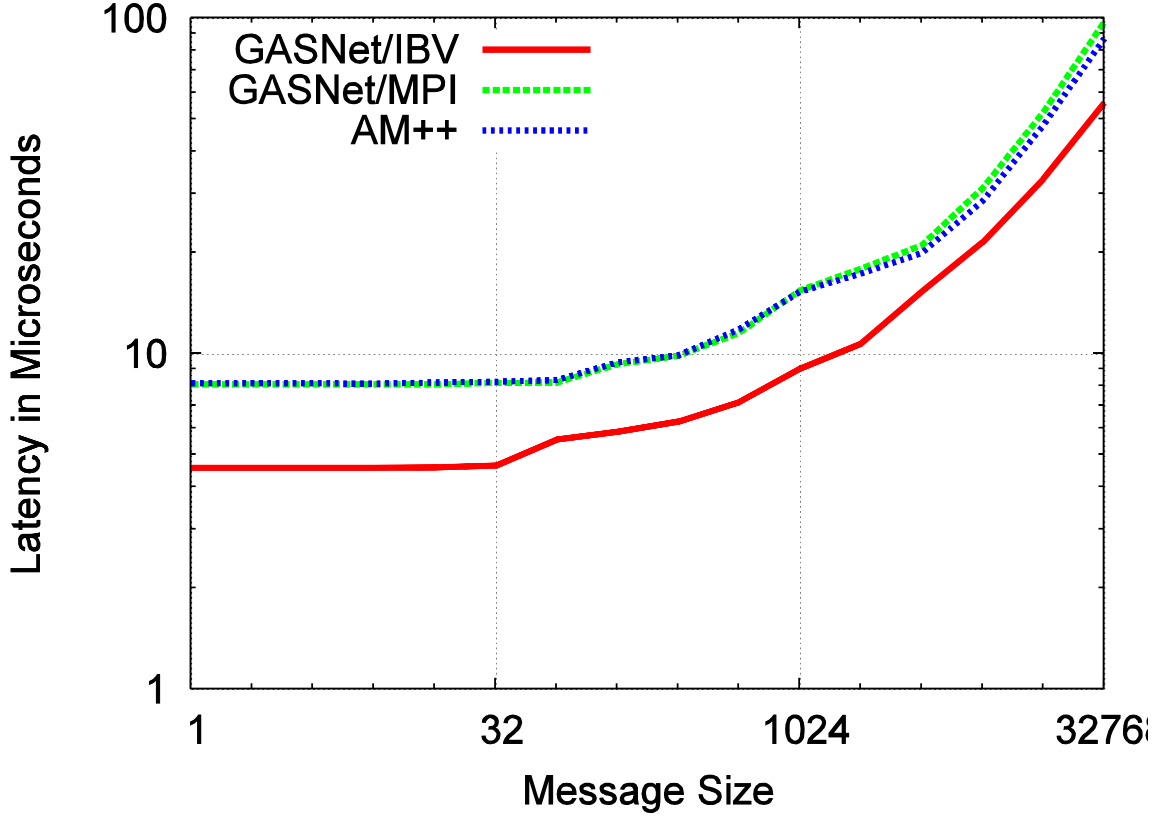
- Some applications have messages that are
  - Idempotent: duplicate messages can be ignored
  - Reducible: some messages can be combined
- Detect some at sender
  - Cache



AM++ and Threads

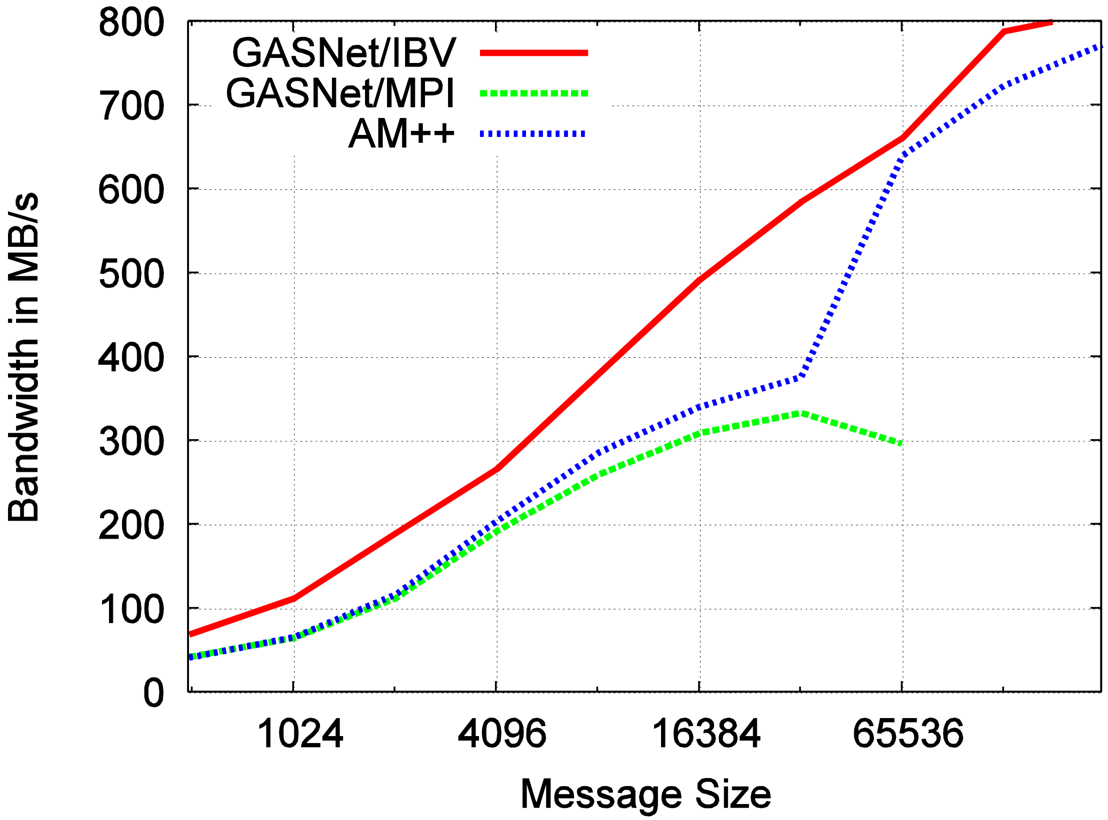
- AM++ is thread-safe
- Models for thread use:
  - Run separate handlers in separate threads
  - Split a single message across several threads
- Coalescing buffer sizes affect parallelism in both models

Evaluation: Message Latency



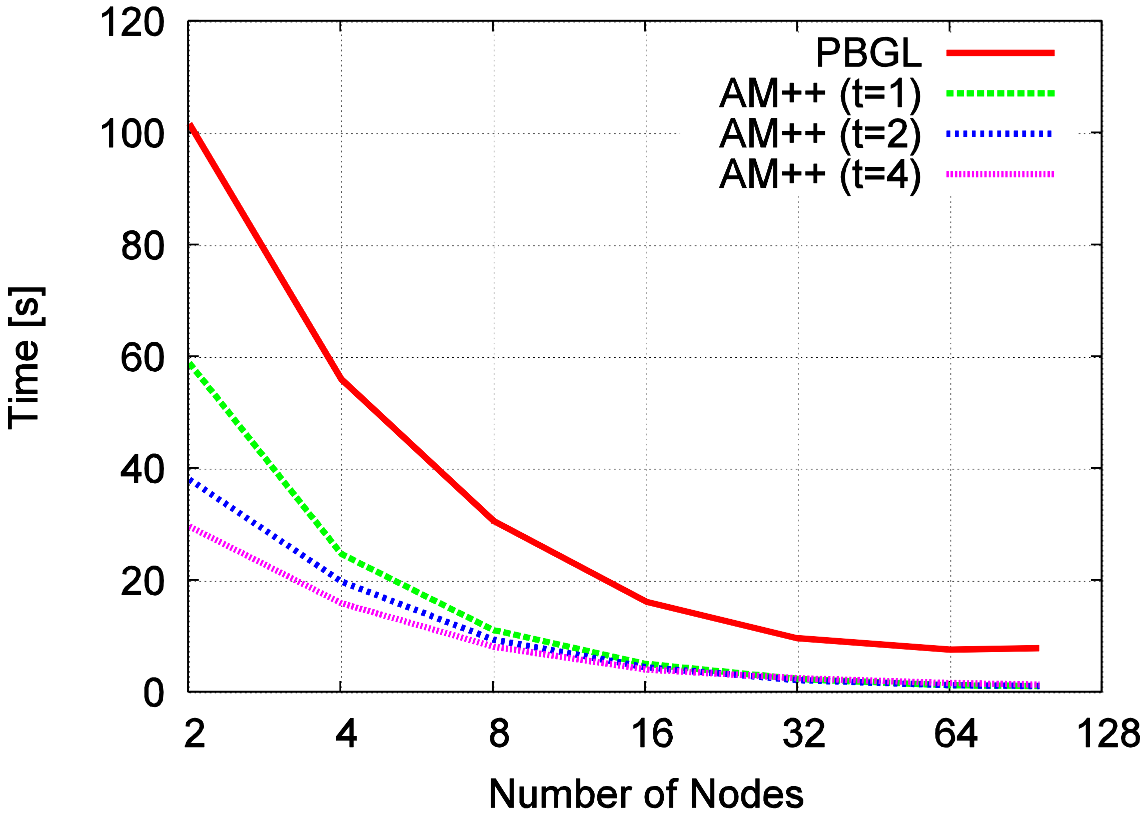
Single-data-rate InfiniBand, GASNet 1.14.0 **`testam`** section L

Evaluation: Message Bandwidth



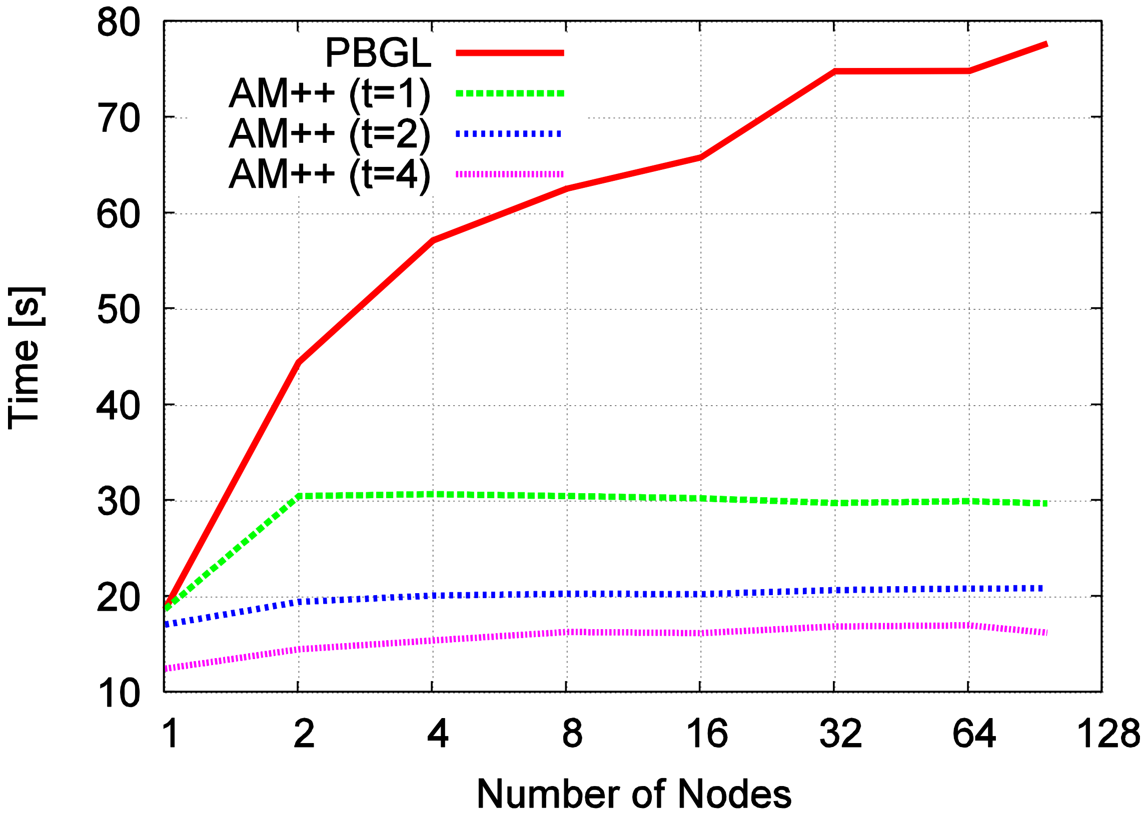
Single-data-rate InfiniBand, GASNet 1.14.0 **`testam`** section L

Breadth-First Search: Strong Scaling



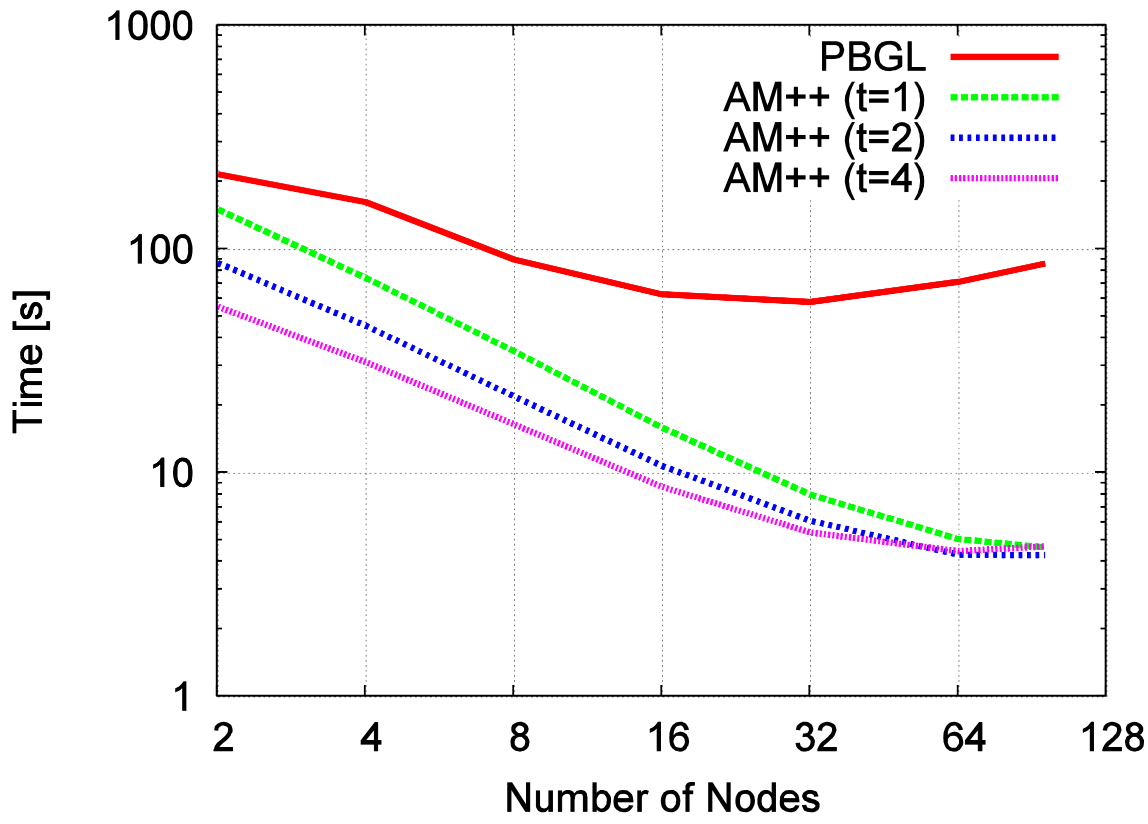
Single-data-rate InfiniBand, dual-socket dual-core, 2^{27} vertices, degree 4

Breadth-First Search: Weak Scaling



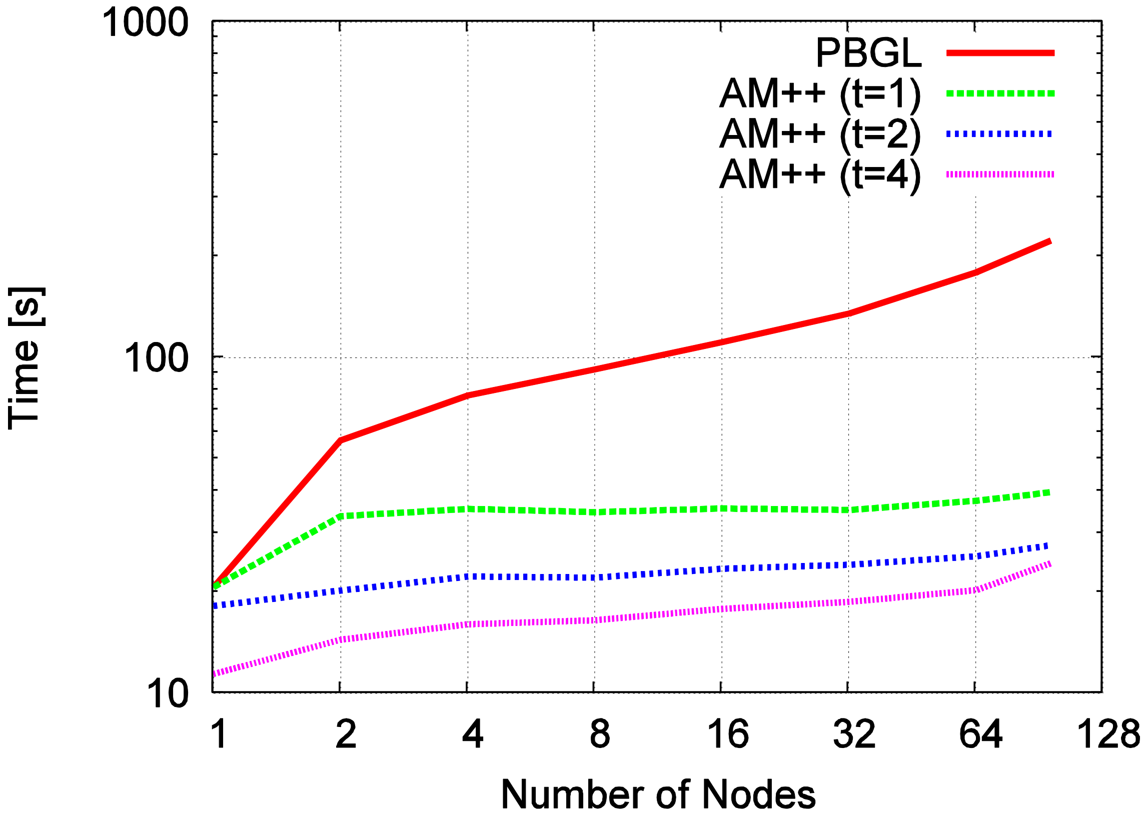
Single-data-rate InfiniBand, dual-socket dual-core, 2^{25} vertices/node, degree 4

Delta-Stepping: Strong Scaling



Single-data-rate InfiniBand, dual-socket dual-core, 2^{27} vertices, degree 4

Delta-Stepping: Weak Scaling



Single-data-rate InfiniBand, dual-socket dual-core, 2^{24} vertices/node, degree 4

Conclusion

- Generative programming techniques used to design a flexible active messaging framework, AM++
  - “Middle ground” between previous low-level and high-level systems
- Features can be composed on that framework
- Performance comparable to other systems