Design and Implementation of Open MPI over Quadrics/Elan4

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Presentation Outline

- Motivation
- Communication Requirements and Objectives
- Design Challenges and Implementation
- Performance Evaluation
- Conclusions

Cluster Computing

- Parallel computing architecture
  - Evolving into tens of thousands of processors
  - More high performance interconnects
- MPI and MPI-2
  - The *de facto* industry standard
  - MPI-2 extends MPI with dynamic process management, IO, one-side communication, more collectives, language bindings, etc

Open MPI

- A new implementation of MPI-2
  - Component-based dynamic architecture
  - Dynamic, fault tolerant process management
  - Concurrent communication over multiple networks
  - Dual-mode communication progress

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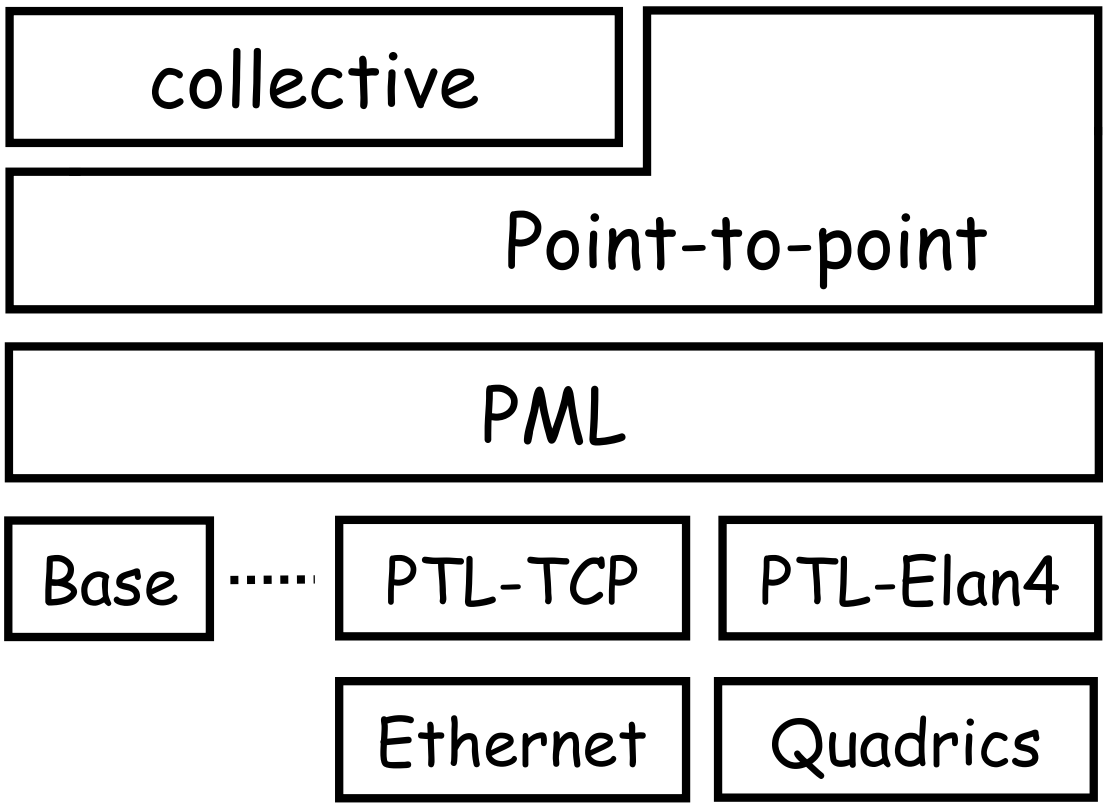
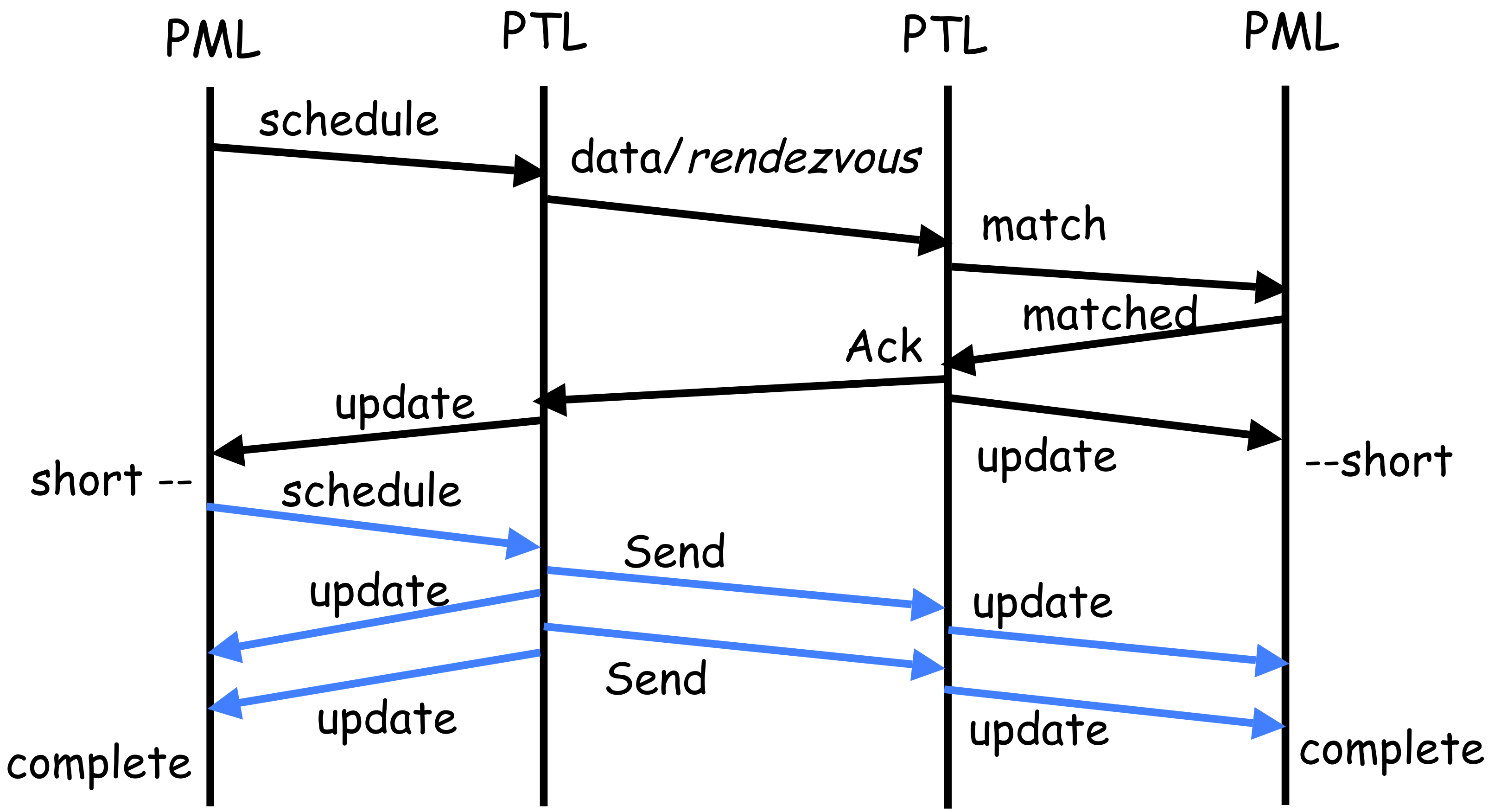
Open MPI Communication

- First implemented over TCP/IP
  - Able to aggregate messages over multiple NICs
  - Delivers comparable performance
- Communication stacks on top of two layers:
  - Point-to-point message management layer (PML)
    - Message fragmentation and assembly
    - Ordered *reliable* delivery
    - Scheduling and striping
  - Point-to-point message transport layer (PTL)
    - Network specific, managing network status and communication
    - Presents communication support to PML

Communication Architecture



Flow of Open MPI Communication



PML Requirements to PTL Communication Support

- Fault-tolerance
  - Dynamic joining and disjoining of PTLs
  - Communication state monitoring and synchronization
- Concurrent communication
  - PML provides abstraction to handle semantics differences between networks
- Communication progress
  - Non-blocking polling-mode and thread-based asynchronous mode

Overview of Quadrics/Elan4

- Quadrics Network: QsNet^{II}
  - Tport (MPI oriented) and SHMEM libraries
  - Static communication model between processes
  - Hardware-based collectives
    - broadcast, barrier
- Communication mechanisms
  - Queue-based model
    - for messages up to 2KB
  - Remote DMA
    - Arbitrary size messages. RDMA write/read
  - Event mechanism
    - Completion notification

Objectives

- Support MPI-2 dynamic processes over Quadrics
- Incorporate Quadrics RDMA capabilities
- Support dual-mode communication progress

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Design Challenges

- Dynamic MPI-2 process model
  - Communication Initialization and finalization
- Integrating RDMA Capabilities
  - Memory semantics compatibility
  - Protocol mapping
- Communication Progress
  - How to support asynchronous progress?

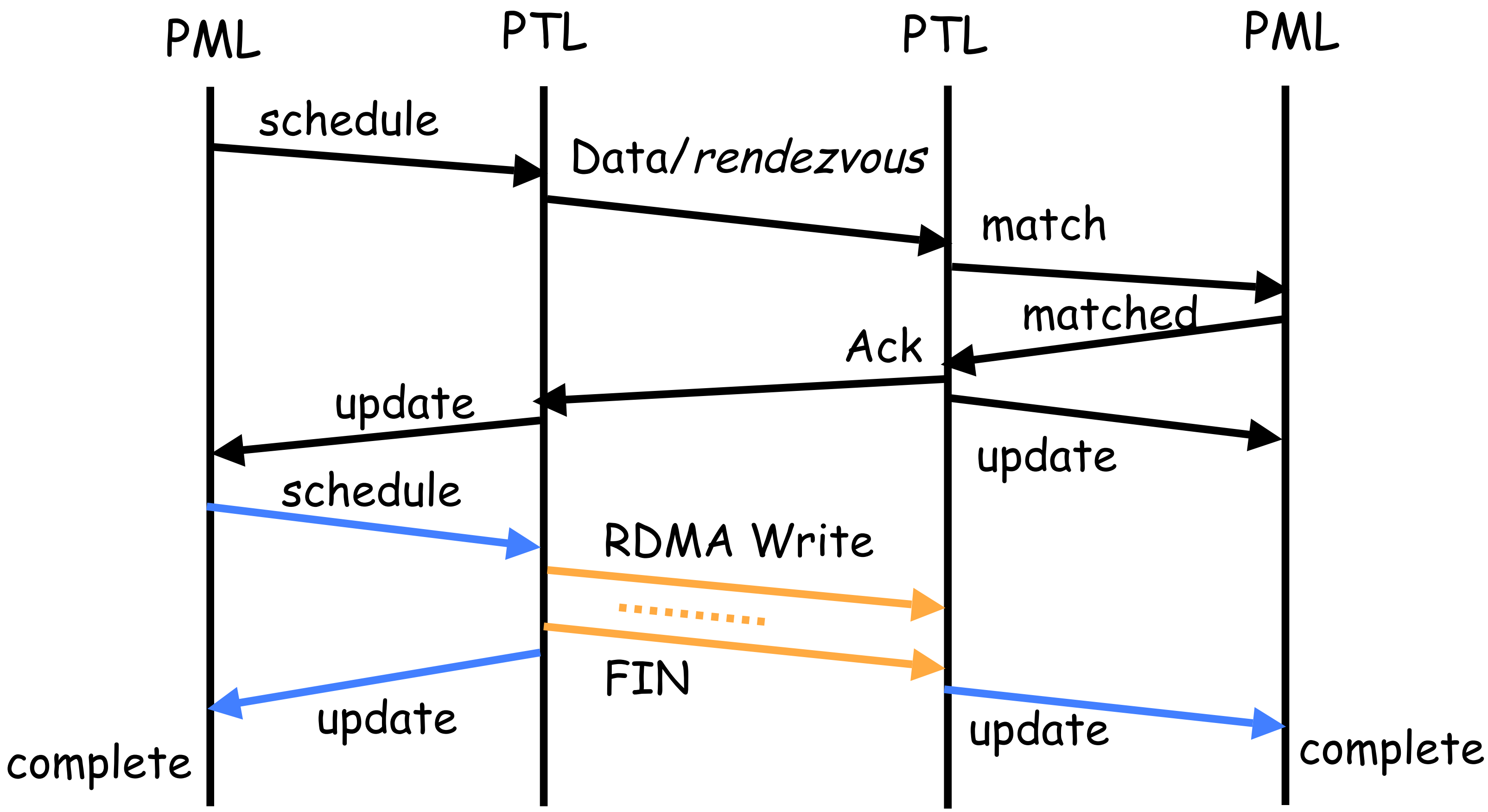
Dynamic MPI-2 Process Pool

- Communication Initialization and finalization
  - Break the coupling of MPI Rank and VPID
  - Remove the reliance on Global virtual memory
  - Allocate a capability with more contexts
  - Support dynamic and synchronized joining and disjoining of processes

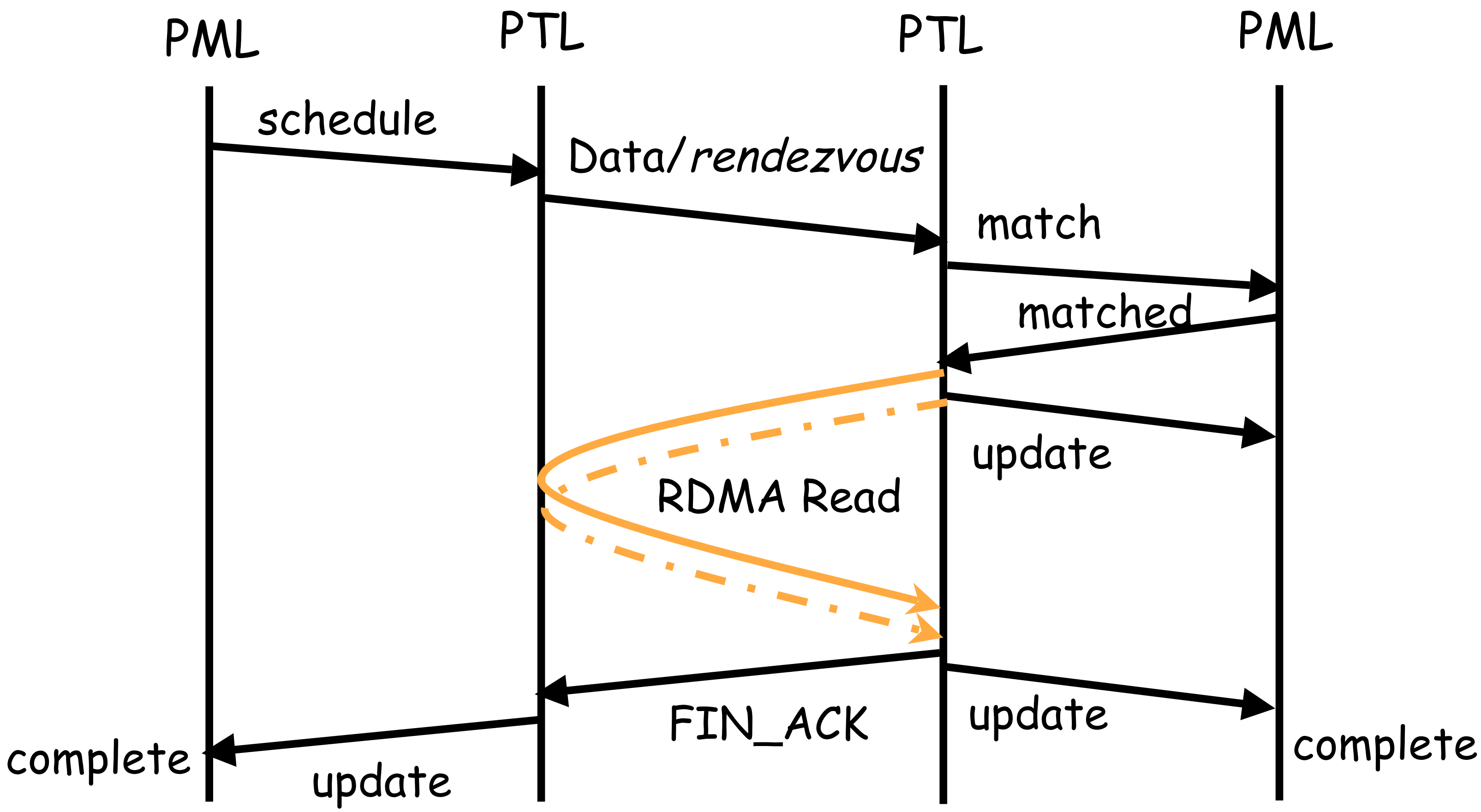
Integrating RDMA Capabilities

- Memory Descriptor
  - Right now, an expansion with Elan4_Addr
- Communication and Completion notification
  - Using RDMA write/read
  - FIN with RDMA write
  - FIN_ACK with RDMA read
- Optimization
  - Chains the control message with RDMA
  - Provides fast, automatic transmission of control messages

RDMA Write


PML
PTL
PTL
PML
schedule
Data/*rendezvous*
match
matched
Ack
update
update
schedule
RDMA Write
FIN
update
update
complete
complete

RDMA Read


PML
PTL
PTL
PML
schedule
Data/*rendezvous*
match
matched
update
RDMA Read
FIN_ACK
update
complete
complete
update

Communication Progress

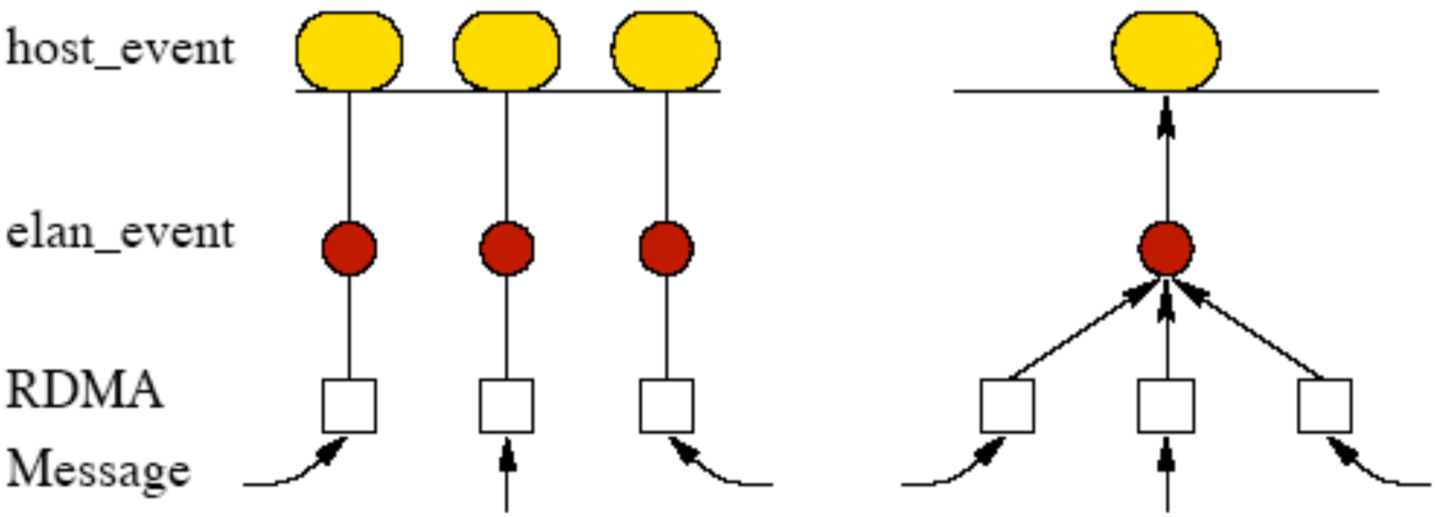
- Non-blocking Polling Mode
  - PML iteratively checks all outstanding send and receive queues
- Thread-base asynchronous communication
  - Two thread based Communication Progress
    - One for the local completion of DMA descriptors
    - Another for the completion of incoming QDMA messages
  - One thread-based communication progress
    - QDMA messages + local DMA completion to a combined queue

Challenges in Asynchronous Progress with RDMA

- RDMA completion can only be detected with a separated event.
- The event mechanism
  - Supports the completion of N DMA operations with a count N
  - Cannot have one thread per RDMA descriptor

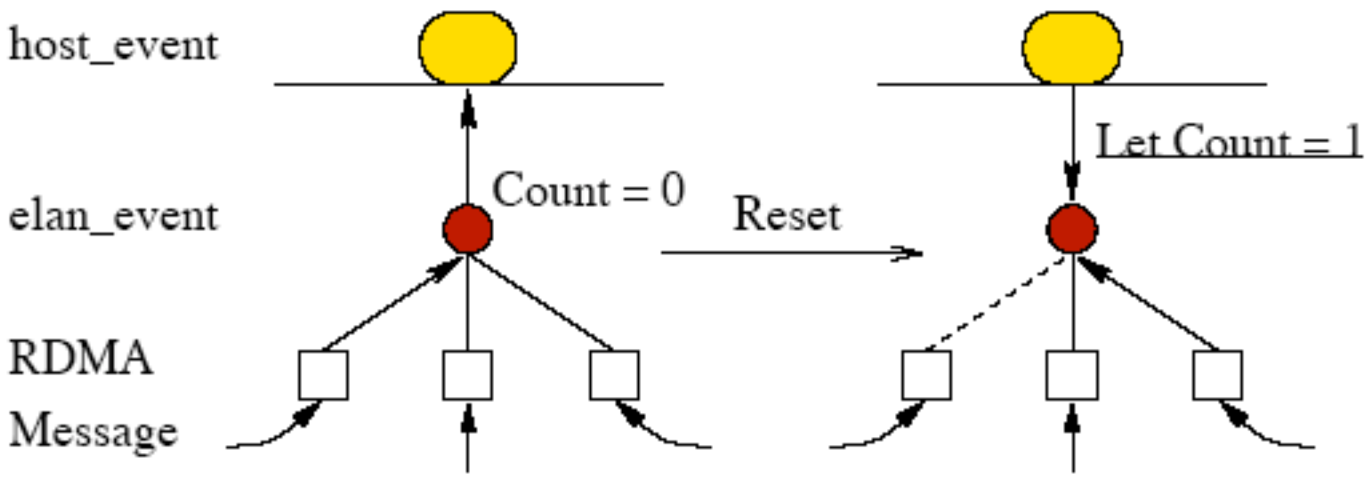
Chained Event

- Is it possible to use events with a count N for shared completion?



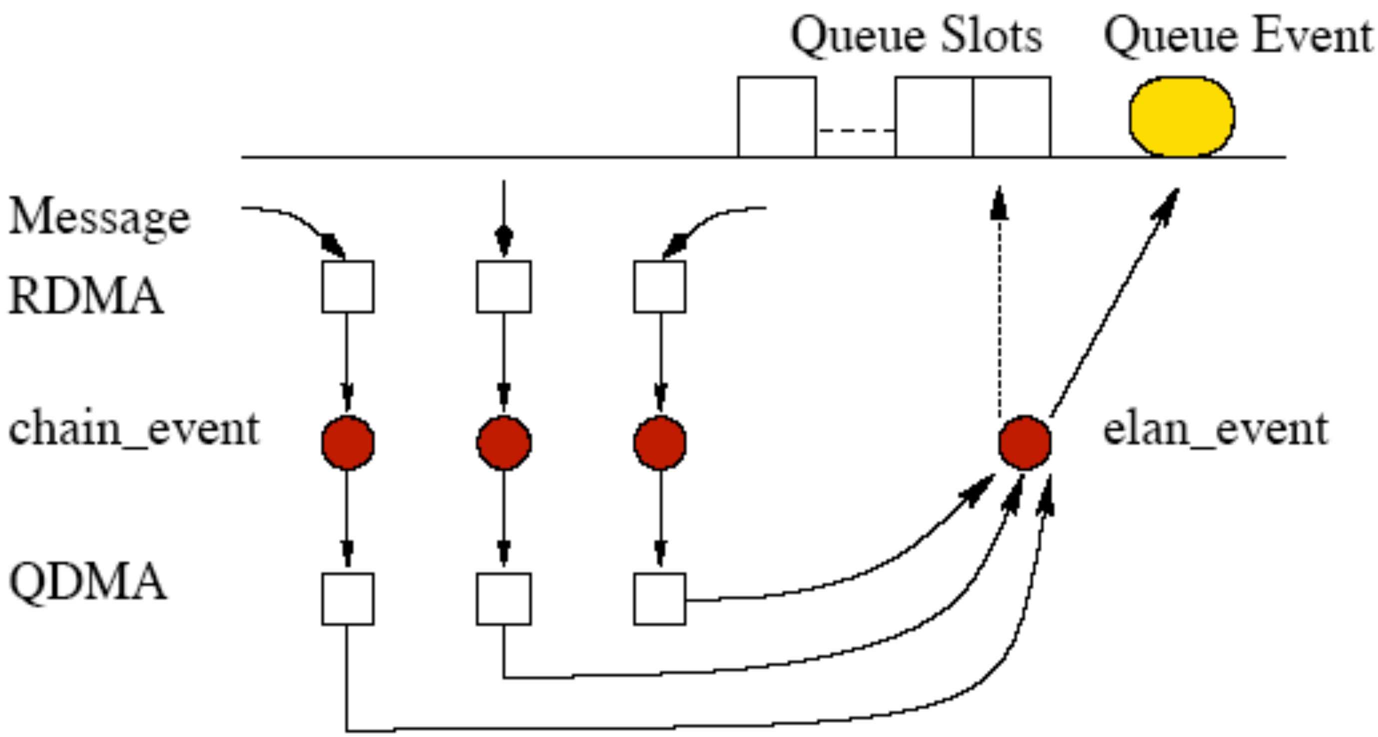
(a) Separated Events (b) Event with Count N

Possible Race Condition?



(c) A Count 1 Event Fired (d) Racing condition

Chained Event + QDMA



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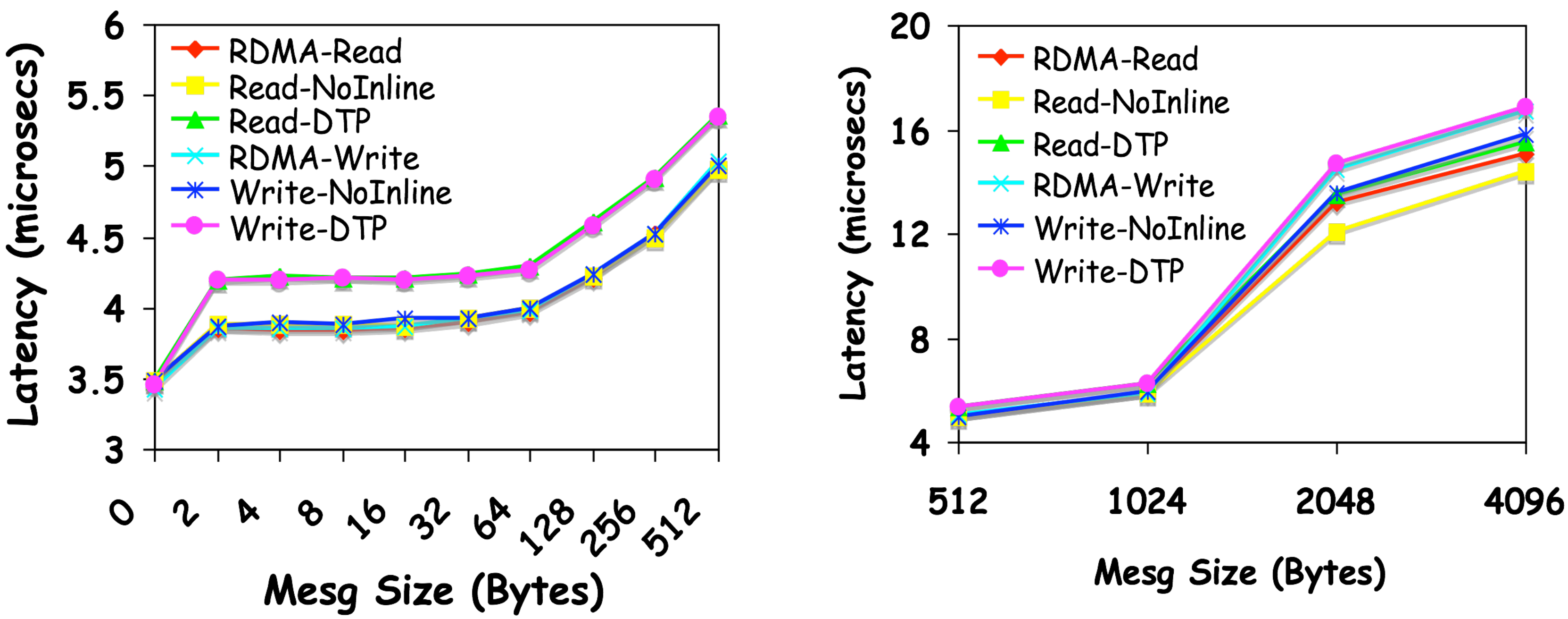
Performance Evaluation

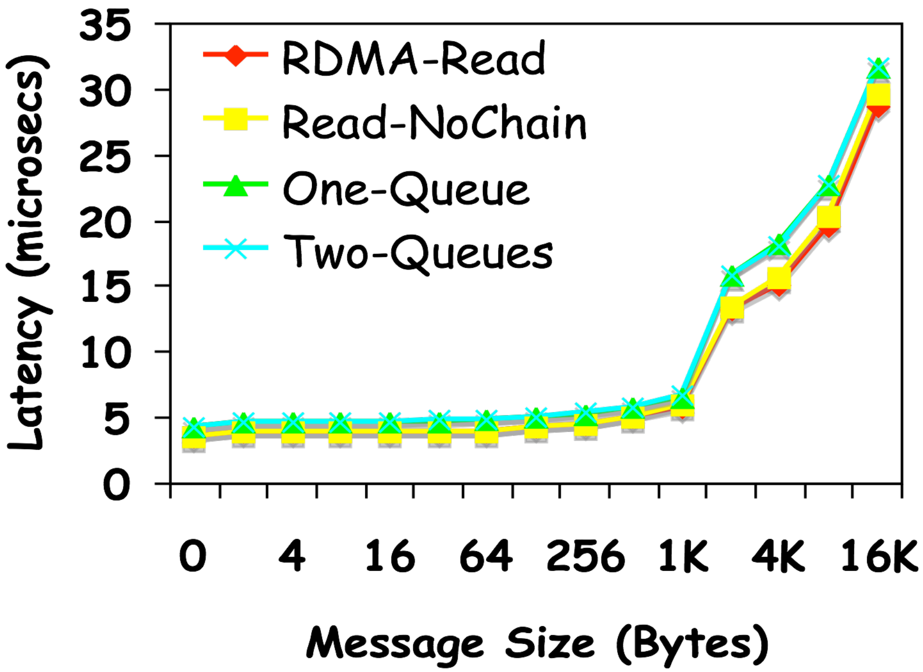
- **Experimental Testbed:**
  - A Quadrics cluster: QS-8A switch, Elan4 cards
  - Dual-SMP Intel Xeon 3.0GHz Processors
  - PCI-X 133MHz/64bit
  - 533MHz FSB
  - 1GB SDRAM memory
- **Experimental Results**
  - Performance with different numbers of completion queues
  - Communication cost in different layers
  - Threading cost
  - Overall performance

Basic Performance with RDMA Read and Write



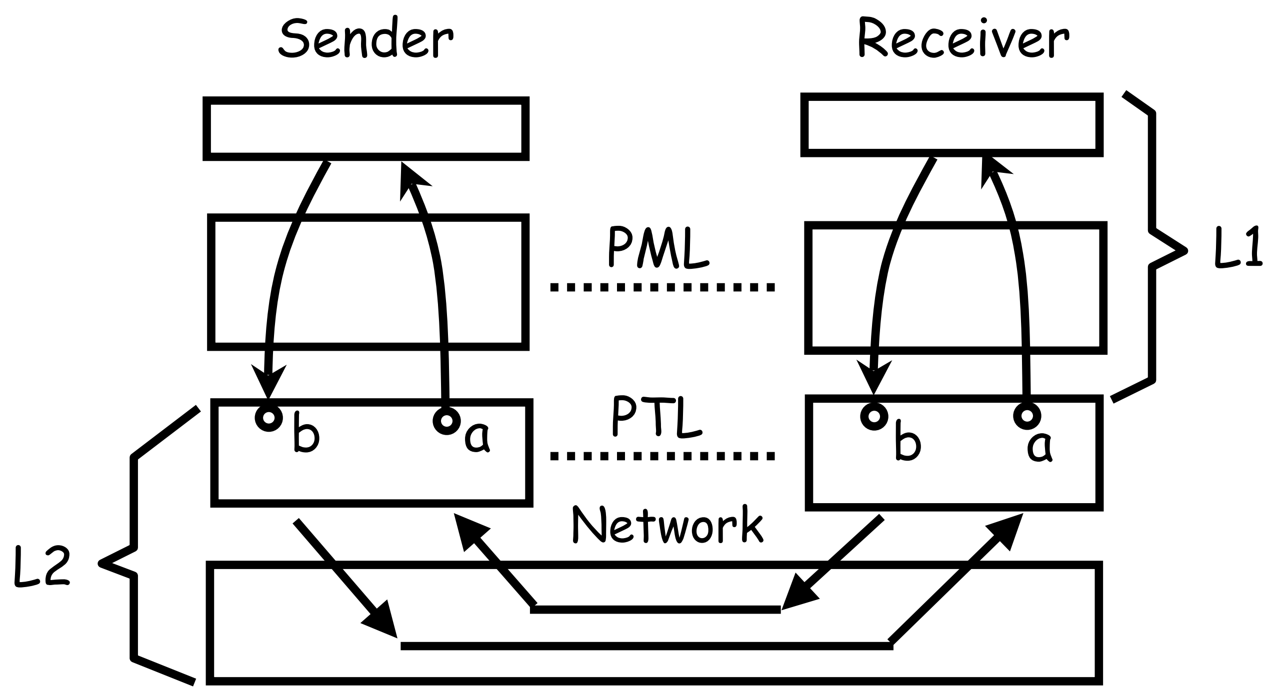
- RDMA read performs better than RDMA write
- Rendezvous Message without inline data improves performance
- memcpy() is replacing the sophisticated datatype engine for

Performance with Chained DMA and Completion Queues



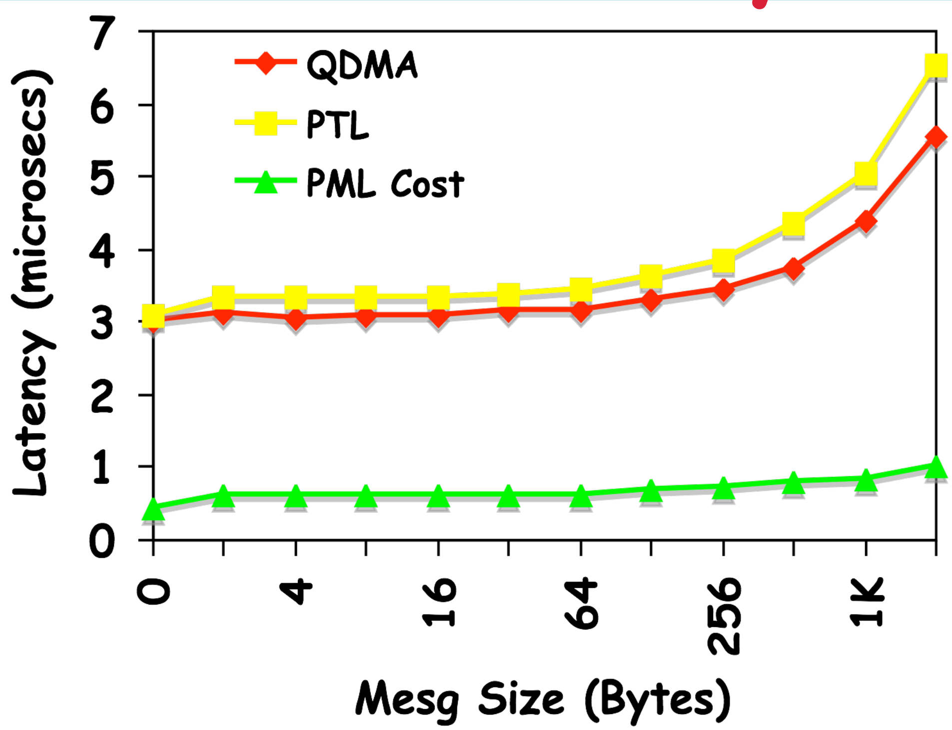
- Chain DMA provides little performance improvement
- ~1us penalty for shared completion queue
- No performance difference with one-Queue or two Queue

Measuring Communication Cost



- L1: PML cost
- L2: PTL latency

Communication Cost in Different Layers



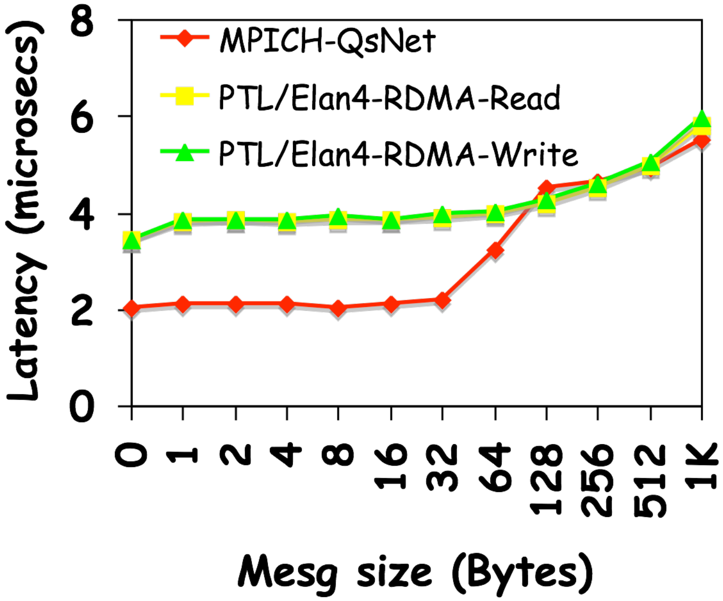
- PML has about 0.5us overhead
- Compared to QDMA, PTL/Elan4 has virtually no overhead for 0-byte messages.

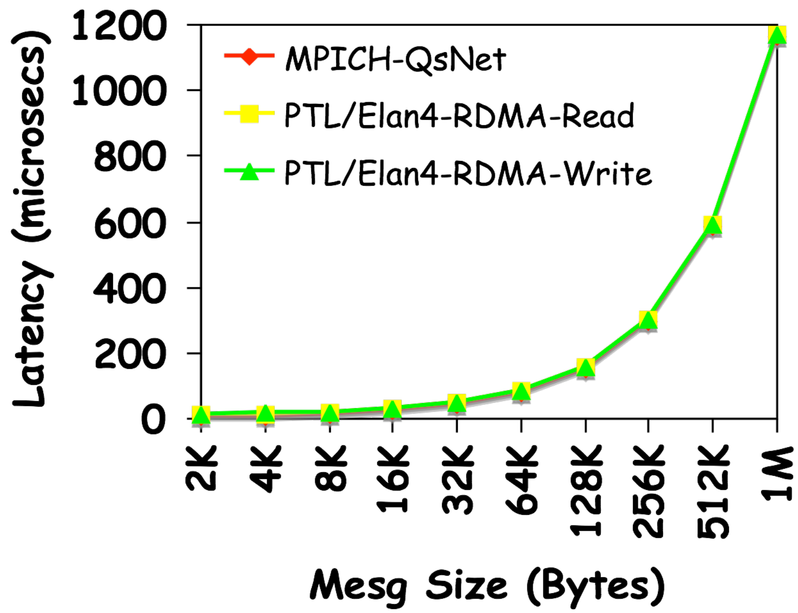
Thread-Based Progress

Performance Analysis of Thread-based Progression (in us)				
Mesg Length	Basic	Interrupt	One-Thread	Two-Threads
RDMA-Read (4B)	3.87	14.70	22.76	27.50
RDMA-Read (4KB)	15.25	27.16	32.80	47.72

- Open MPI w/ PTL/Elan4 thread-based progression has 18us overhead
- ~1us due to shared completion queue
- ~9us due to interrupts, ~8us due to threading

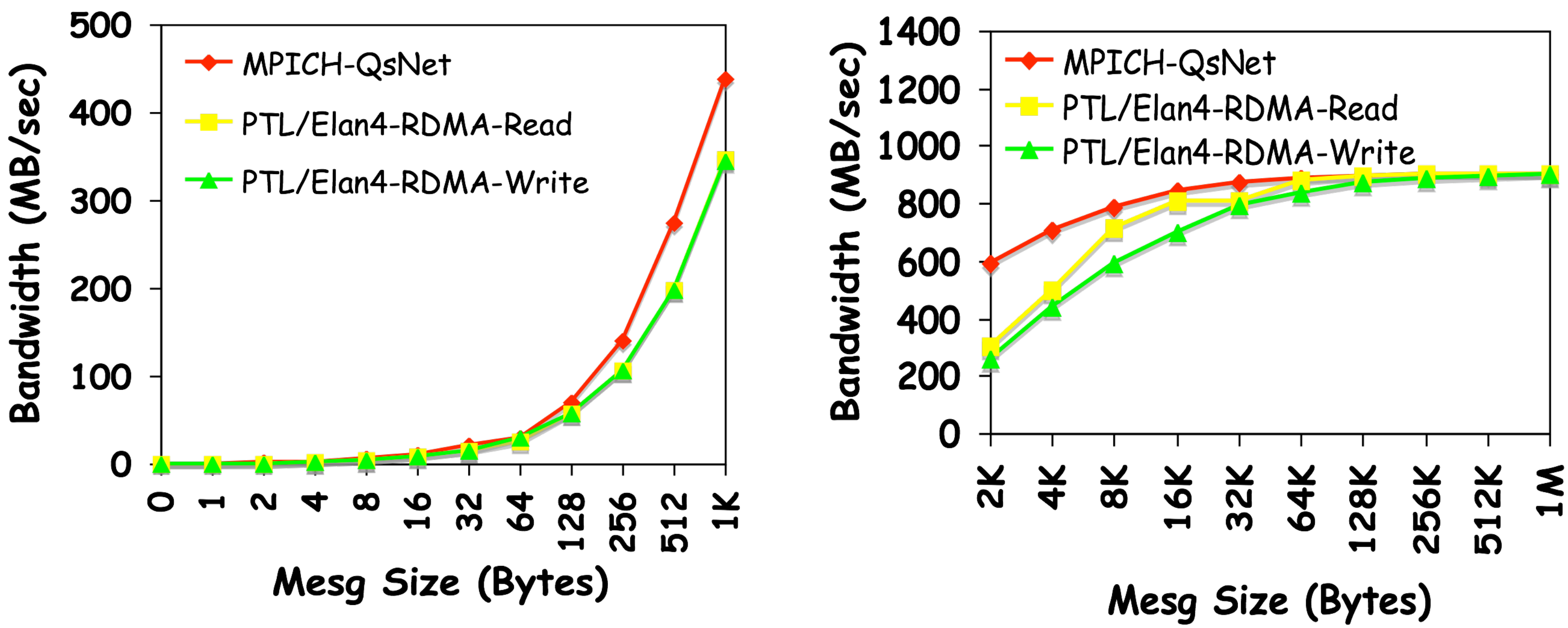
Overall Performance - Latency





- Open MPI w/ PTL/Elan4 achieves similar latency for large messages, compared to MPICH-QsNet
- For small messages, Open MPI w/ PTL/Elan4 has higher cost due to its host-based receive queue and tag matching

Overall Performance – Bandwidth



- Open MPI w/ PTL/Elan4 has slightly lower bandwith compared to MPICH-QsNet for small and large messages
- For medium messages, Open MPI w/ PTL/Elan4 has significant bandwidth because it does no pipelining

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Conclusions

- Designed and implemented Open MPI over Quadrics/Elan4
- Integrated Quadrics RDMA capabilities
- Provided dual-mode communication progress
- Support dynamic MPI-2 process model over Quadrics

Web Pointers

NBC-LAB

Homepage: http://nowlab.cis.ohio-state.edu