Scalable Resource Management in High-Performance Computers

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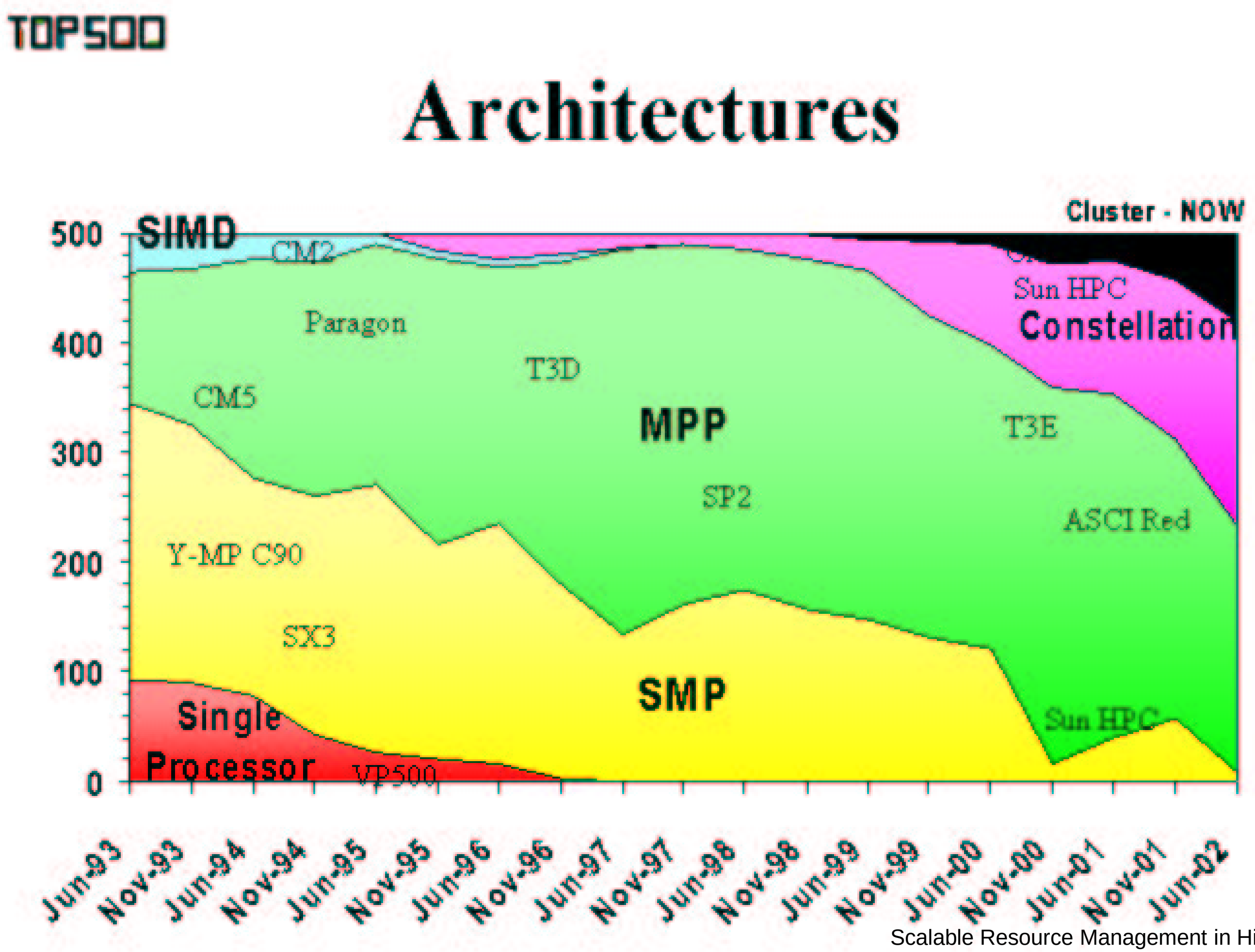
Cluster Resource Management

Clusters and other loosely-coupled systems are becoming ubiquitous and larger



Cluster Resource Management

In the desktop/workstation world:

- Job-launching time is typically very short (< second)
- Timeshared machine enables multitasking and interactivity
- Easy to use and quite reliable

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In the cluster world:

- Jobs run one a time or gang-scheduled with large quanta
- Job-launching time is arbitrarily long (batch) or many seconds (gang-scheduling)
- Reliability and ease-of-use do not scale
- State-of-the-art RMs are typically implemented using Ethernet / TCP-IP, using non-scalable algorithms for control messages

The STORM Approach

Design goals:

1. Scalable, high-performance mechanisms for RM, leveraging modern interconnect capabilities
2. Support most current and future scheduling algorithms (FCFS, GS, SB, BCS, FCS, ...)
3. Platform for studying system-level fault tolerance

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Main differences from standard RMs:

1. Important parts of the RM run on the NIC
2. STORM uses scalable HW multicast mechanism (constant time)
3. STORM uses pipelined IO-bypass protocol
4. File transfer overlaps disk I/O and multicasts

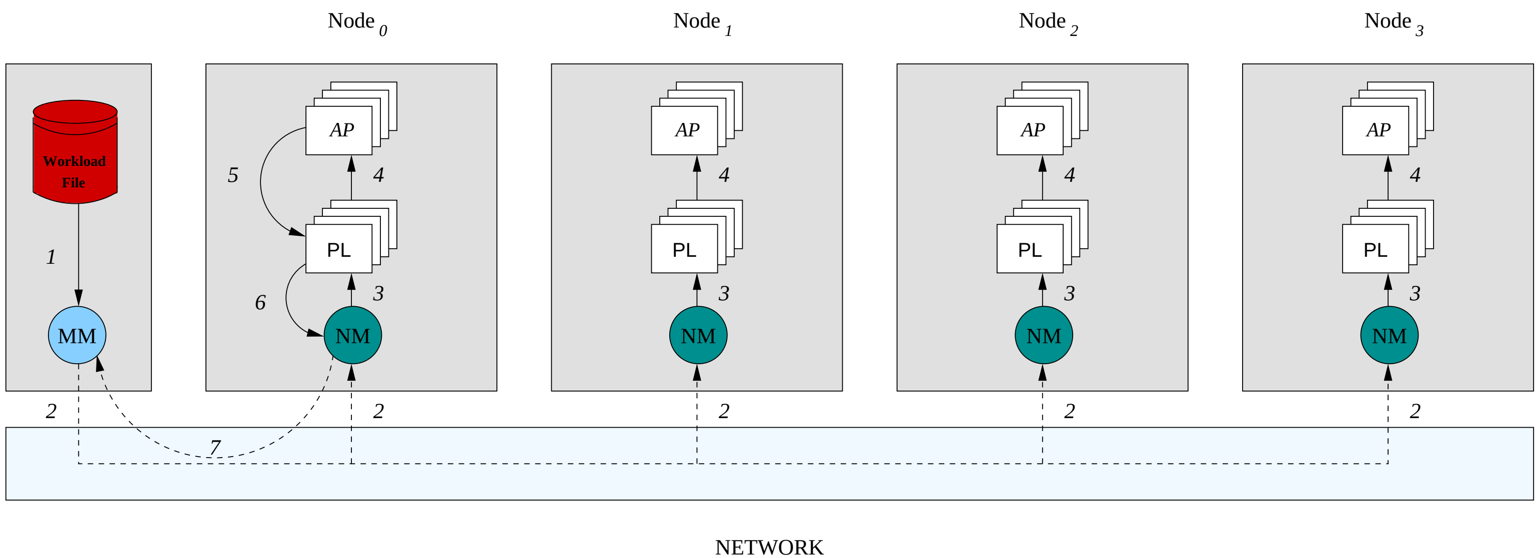
STORM Layers

STORM functions	Heartbeat, file txfr, termination detection
Helper functions	Flow control, queue management

STORM mechanisms	`XFER-AND-SIGNAL`
	`TEST-EVENT`
	`COMPARE-AND-WRITE`

Network primitives	Remote DMA, signaling, event testing

STORM Architecture



- Set of layered, modular dæmons (per node and per machine)
- Lightweight, and Loosely-coupled, using the communication primitives
- “Pluggable” scheduling algorithms: FCFS, GS, SB, Local, FCS...

Performance Testing

The 'Wolverine' cluster at LANL (listed 134th at top500):

- 64-node AlphaServer ES40, running RH Linux 7.1
- 4 Alpha EV68 CPUs ($833MHz$), $8GB$ RAM per node
- Two-rail Quadrics interconnect
- Files are placed in local RAM disks to isolate RM performance

Job Launching

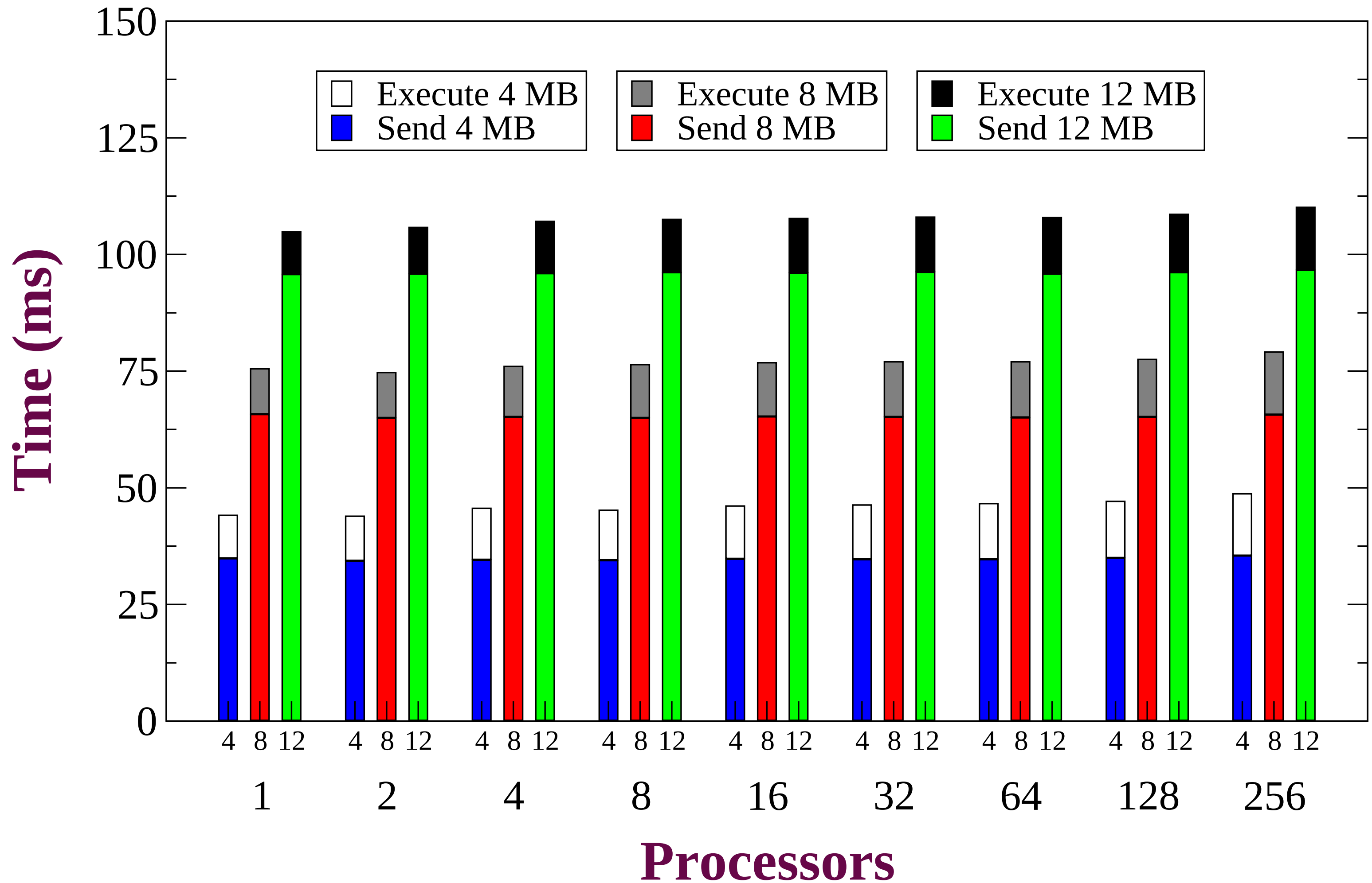
Job launching time becomes an issue when:

- Machine size grows (usual methods scale poorly)
- Debugging or running short/interactive jobs

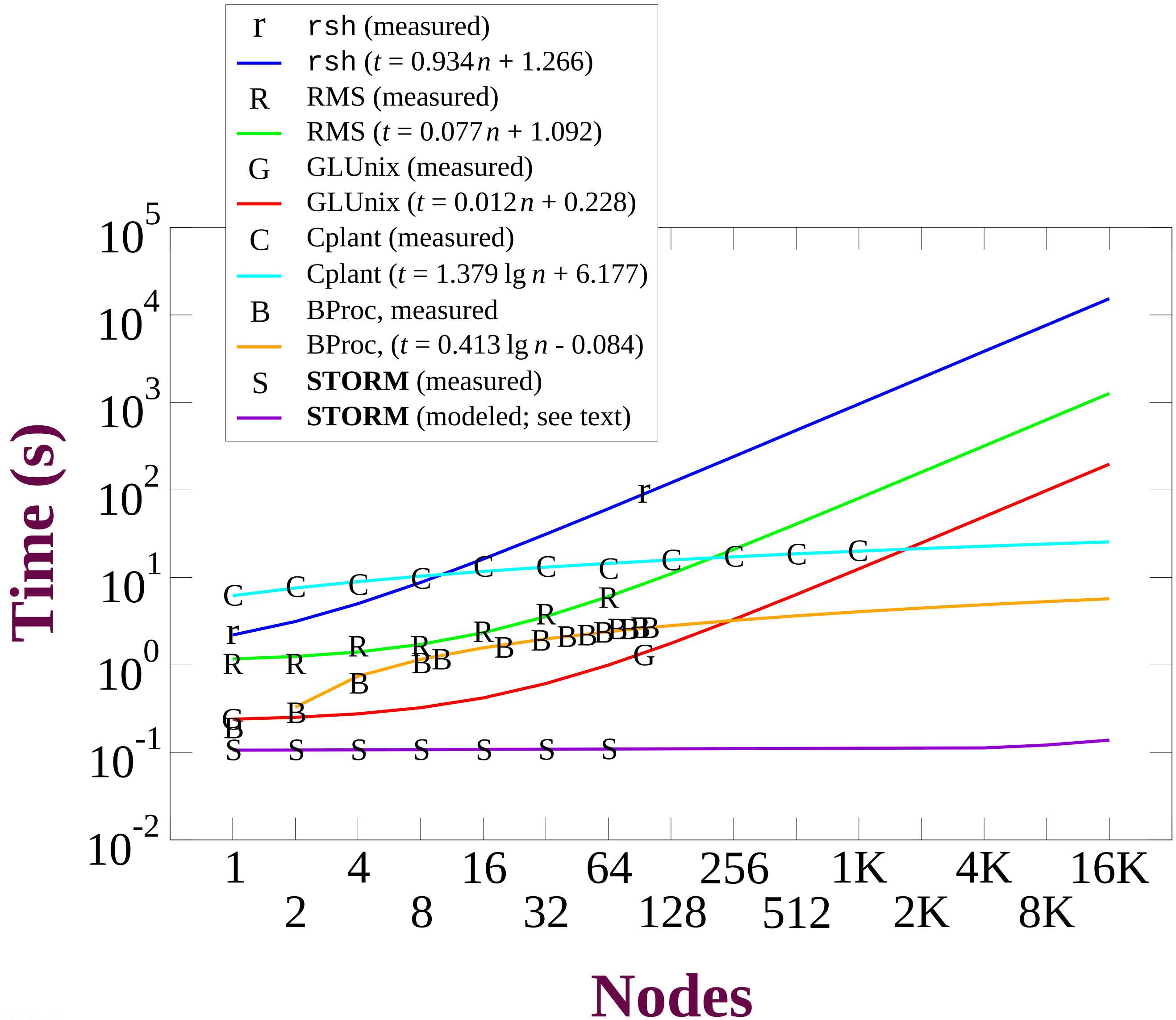
Job Launching Breakdown

- Reading binary and data files
- disseminating to compute nodes (NFS, tree, ...)
- Executing program
- Notifying job control of termination

Job Launching Performance



Performance Comparison



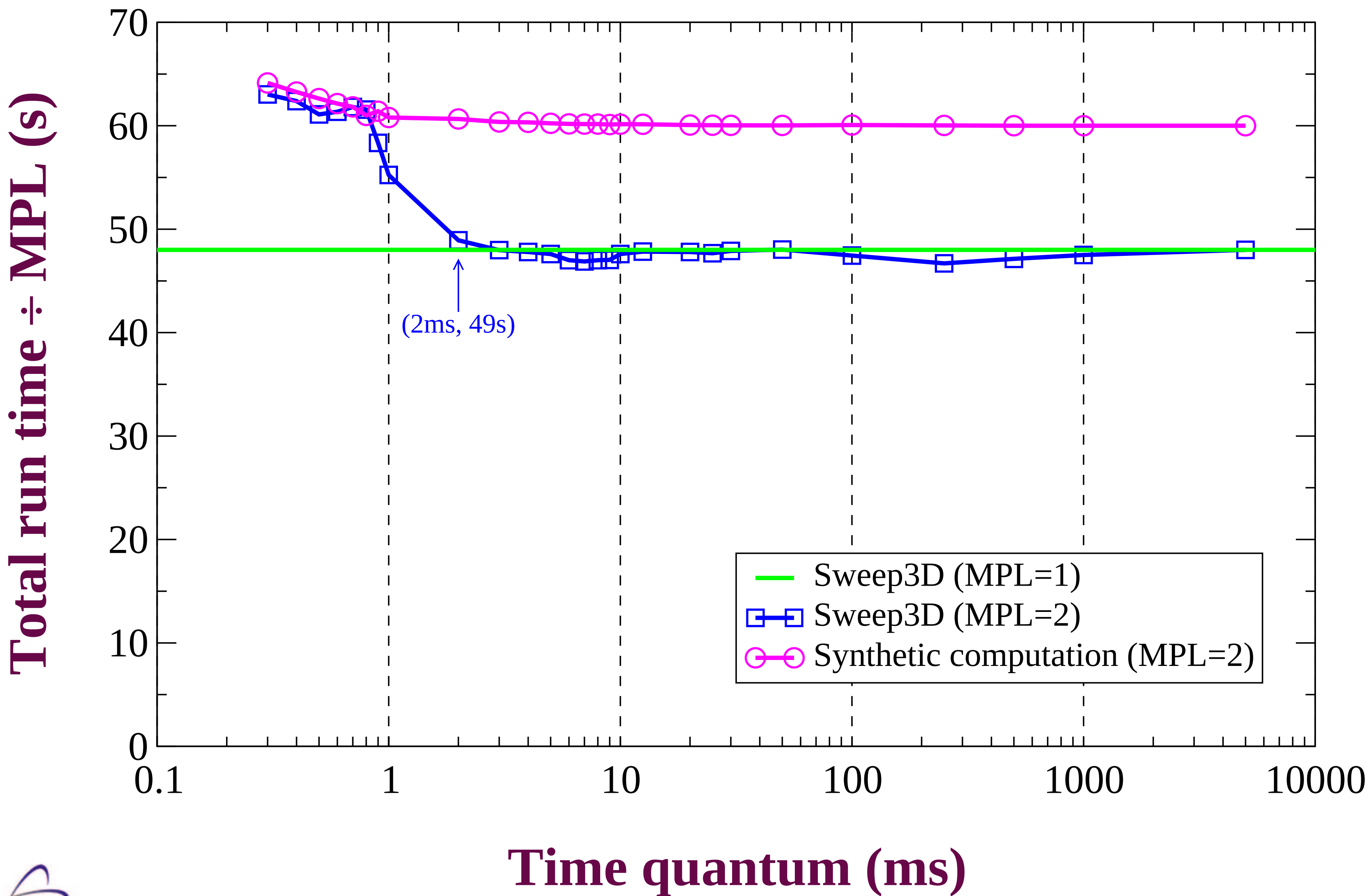
Multiprogramming

Suspending a parallel job in the machine and starting another can be useful for:

- Preempting a job for a higher-priority job and restarting later
- Improving system responsiveness and resource utilization through gang-scheduling
- Running more than one interactive application (e.g. viz.)

Gang-Scheduling isn't used much, partly due to the performance penalty of context switching.
The combination of STORM's mechanisms and modern HW can make the performance hit negligible.

Context Switch Overhead



Context Switch Overhead Comparison

Comparison of minimum feasible scheduling quantum with RMS and SCore-D:

RM	quantum (ms)	observed overhead
RMS	$30,000$ (15 nodes)	1.8% slowdown
SCore-D	100 (64 nodes)	2% slowdown
STORM	2 (64 nodes)	no observable slowdown

Future work

1. Load balancing jobs with different requirements
2. Improve resource utilization
3. Making systems deterministic and debuggable
4. System-level transparent fault tolerance

Conclusion

- Efficient combination of SW methods with modern interconnect HW can offer extremely scalable resource management
- Relatively simple to implement (10K-30K lines of C code)
- High-performance job launching and multiprogramming
- Global process coordination is as efficient in a large cluster as in a small cluster or even a desktop machine
- One step ahead in usability for large-scale machines

For more information:
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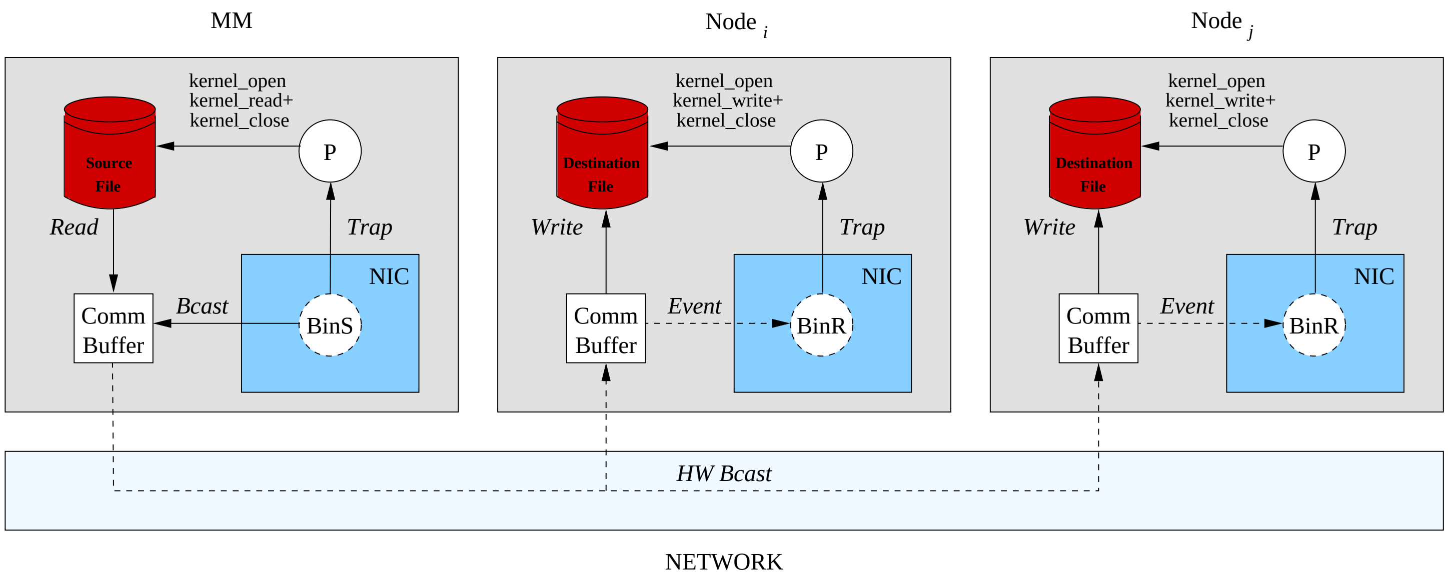
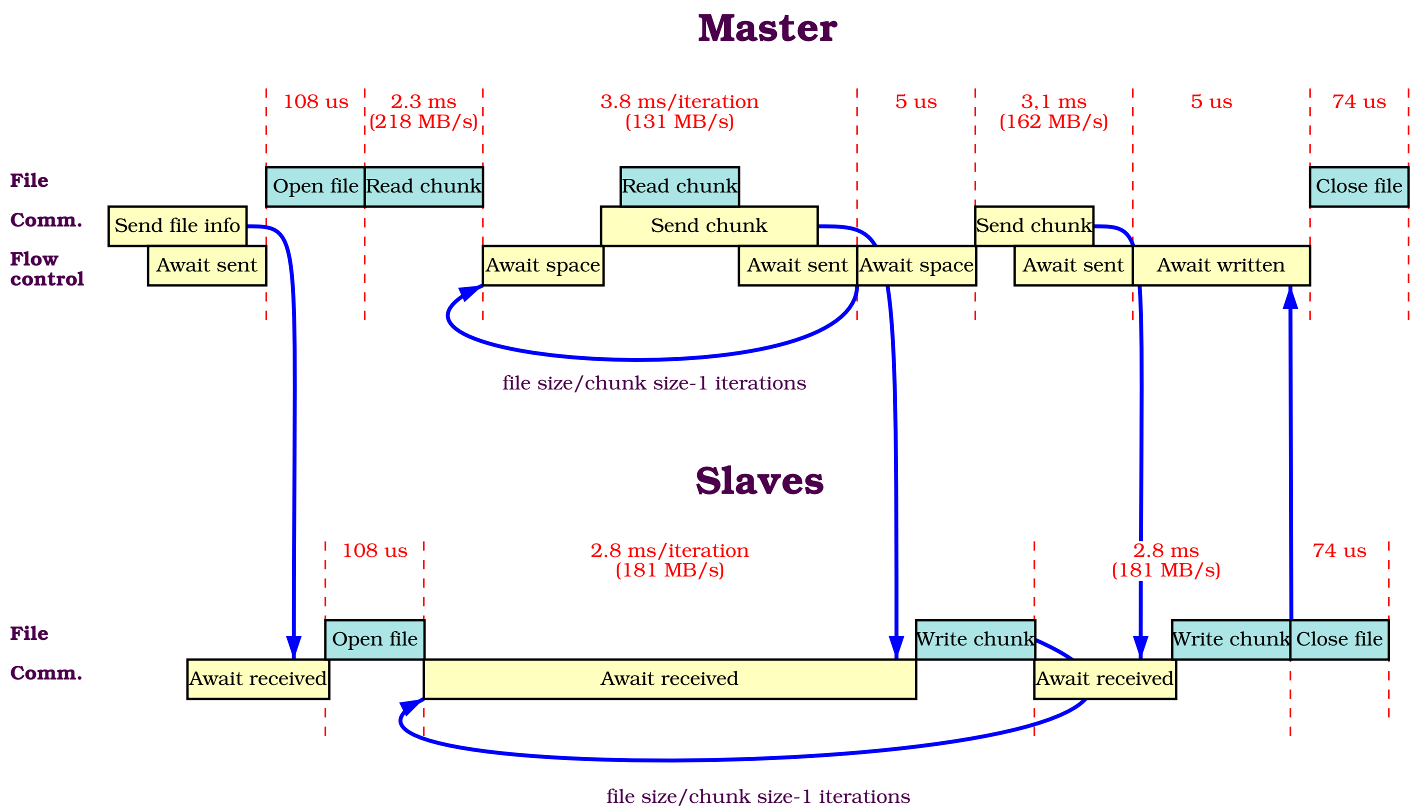
I/O bypass mechanism in STORM



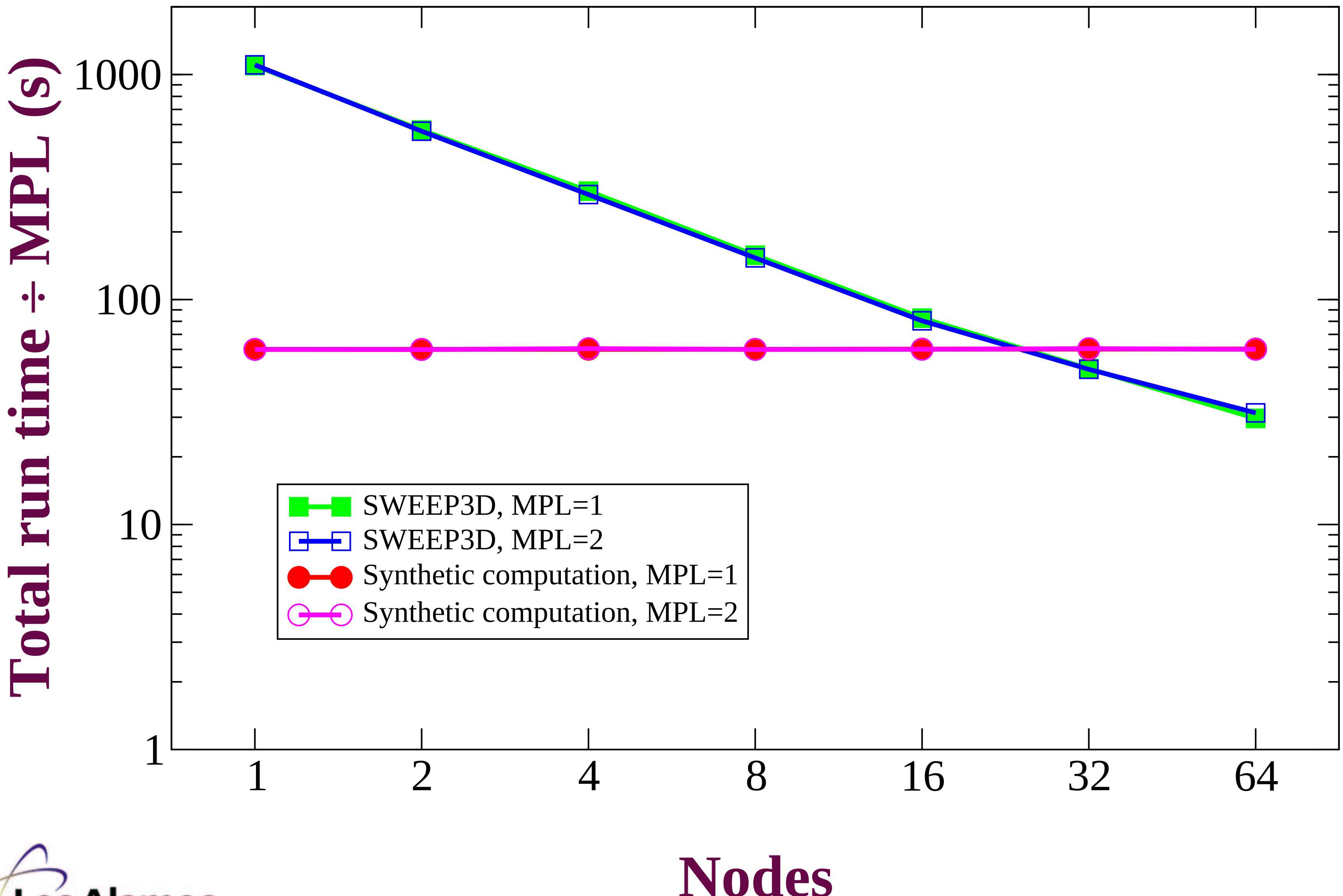
Portability Issues

Network	`COMPARE-AND-WRITE` (μs)	`XFER-AND-SIGNAL` (MB/s)
Gigabit Ethernet	$46 log\, n$	Not available
Myrinet	$20 log\, n$	$15n$
Infiniband	$20 log\, n$	Not available
QsNET	< 10	$> 150n$
BlueGene/L	< 2	$700n$

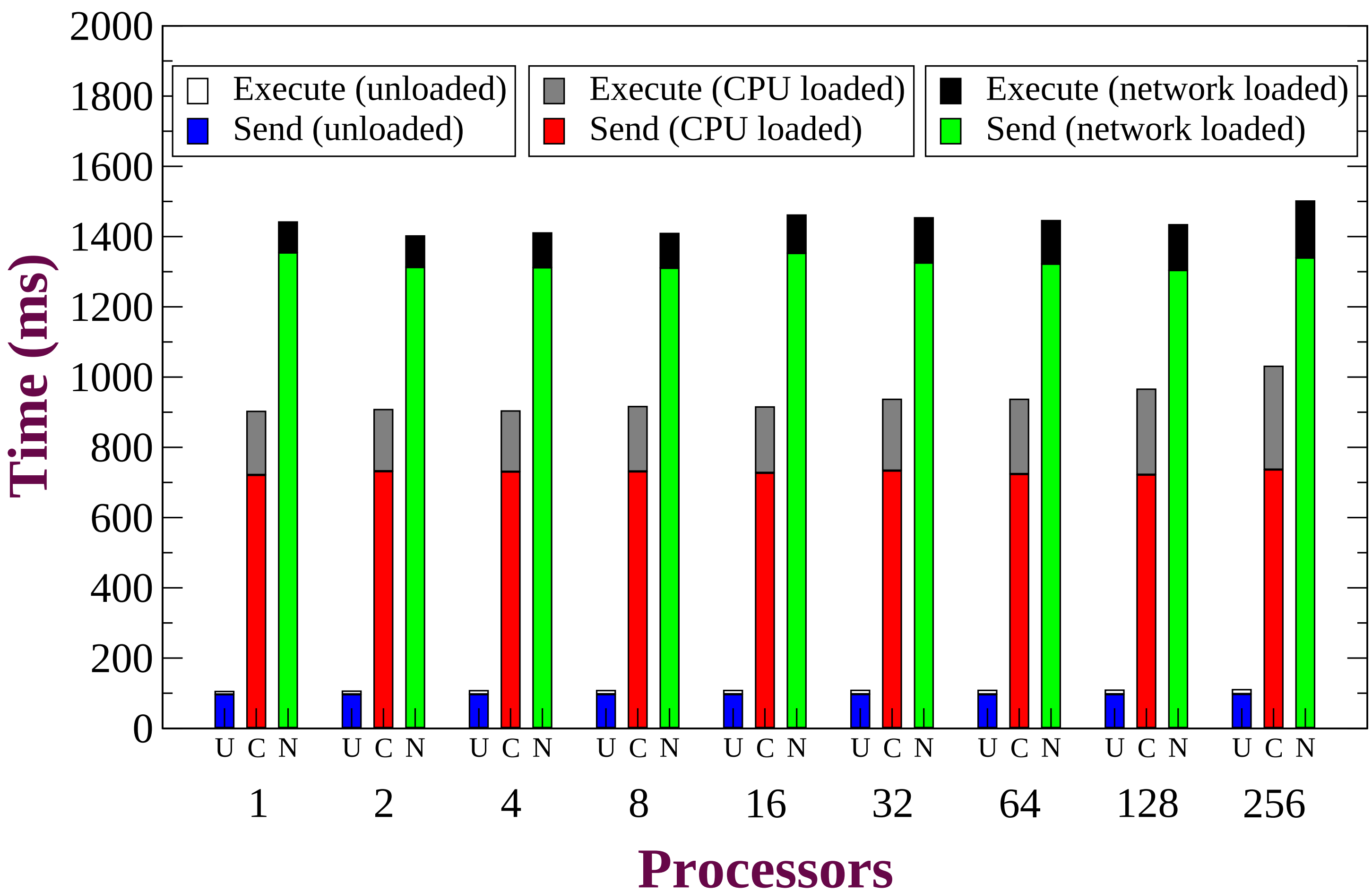
Scalability Model



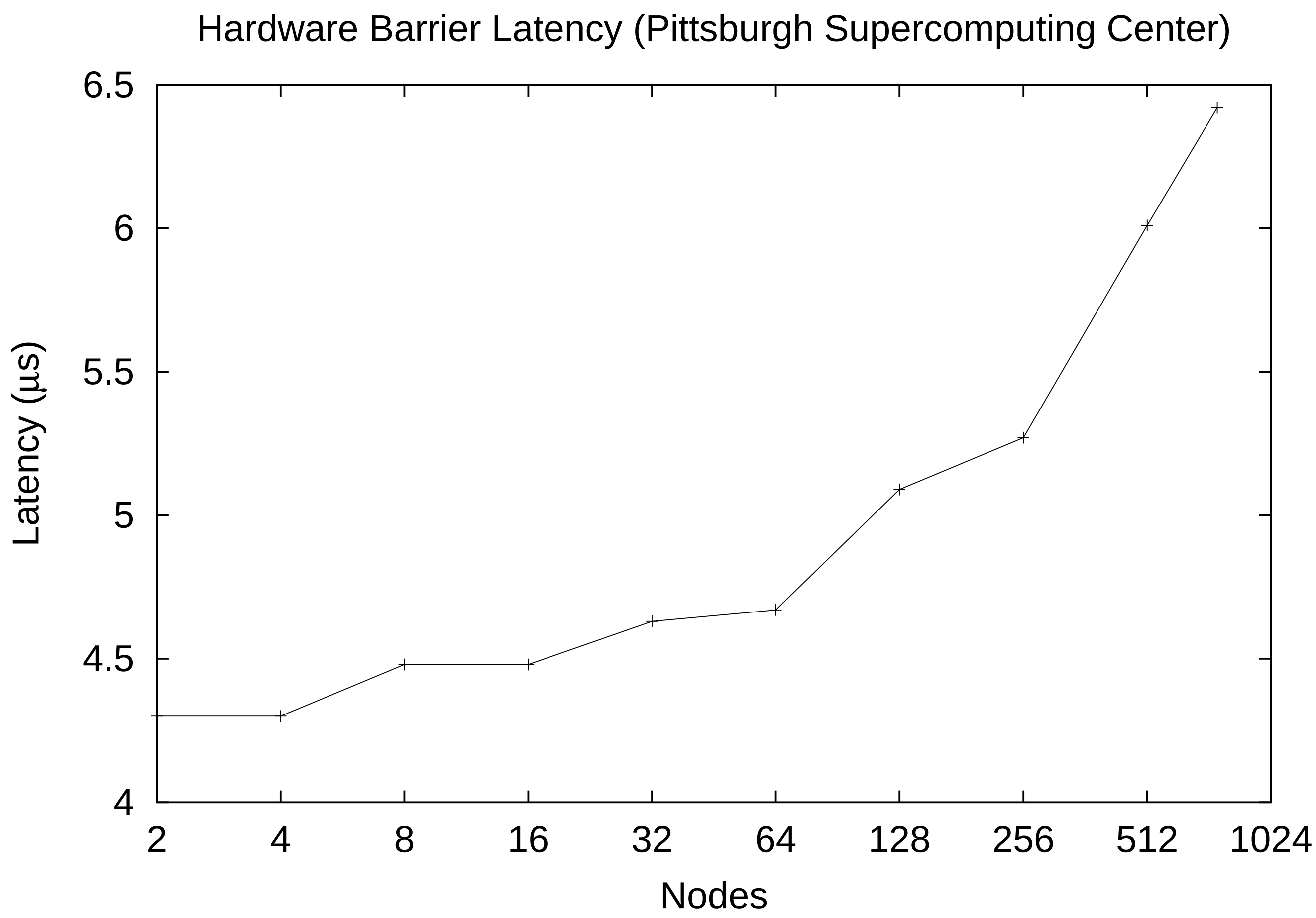
Context-switch scalability



Launch Times on a Loaded System



Quadrics interconnect scalability - barrier



Comparison References

STORM compared to:

- GLUnix [Ghormley 98]
- BProc [Hendriks 02]
- SCore-D [Hori 98]
- Cplant [Brightwell 99]
- RMS [Frachtenberg 01]
- NFS / `rsh` (PBS)