Adaptive Runtime Support for Fault Tolerance

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Presentation Outline

- Object-based decomposition
  - General benefits with Charm++ and AMPI
  - Useful features for Fault Tolerance
- Fault Tolerance in Charm++ and AMPI
  - Checkpoint/Restart
  - Message Logging
- Future directions

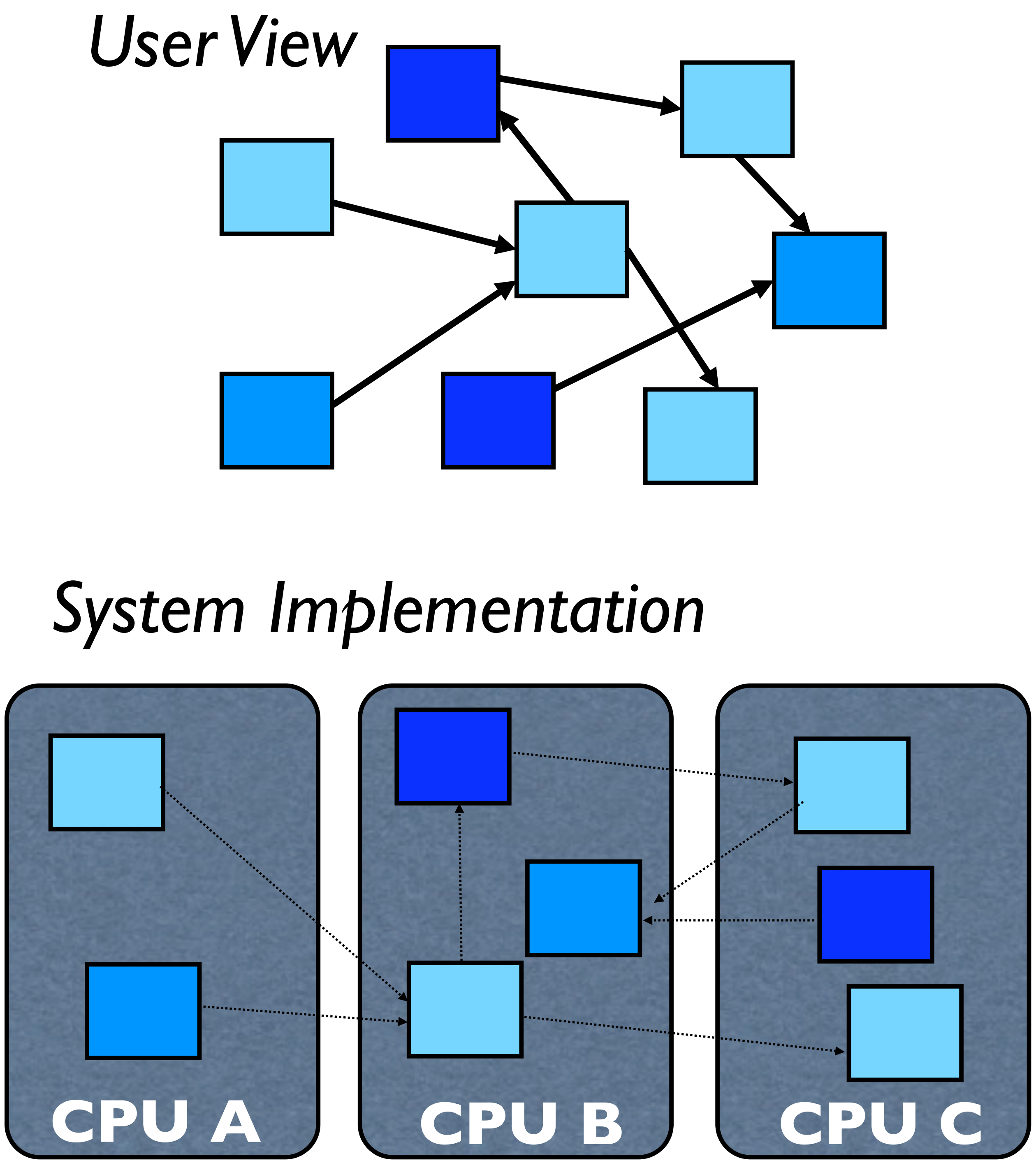
Object-based over-decomposition

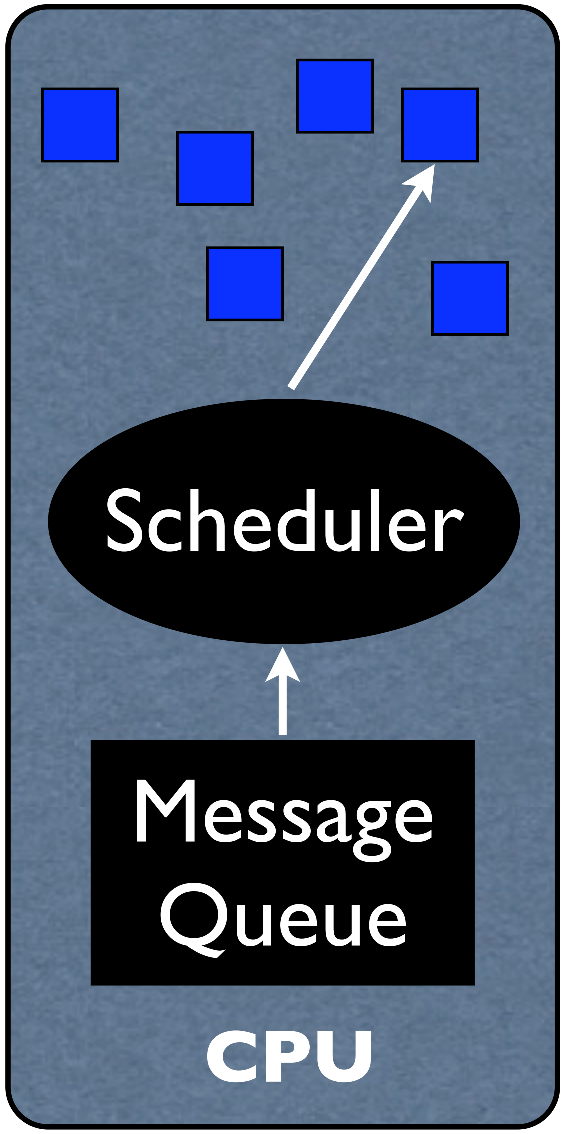
- Objects:
  - Locality of data references (performance)
  - A parallel object can access only its own data
  - Asynchronous method invocation
- Over-decomposition:
  - Decompose computation into objects
  - Work units, data-units, composites
  - Let an intelligent RTS assign objects to processors

Charm++

- Multiple "indexed collections" of C++ objects
  - Multidimensional
  - Dense or sparse
- Object-based Virtualization leads to *Message Driven Execution*
- Permits to overlap communication with computation
- Programmer expresses communication between objects with no reference to processors

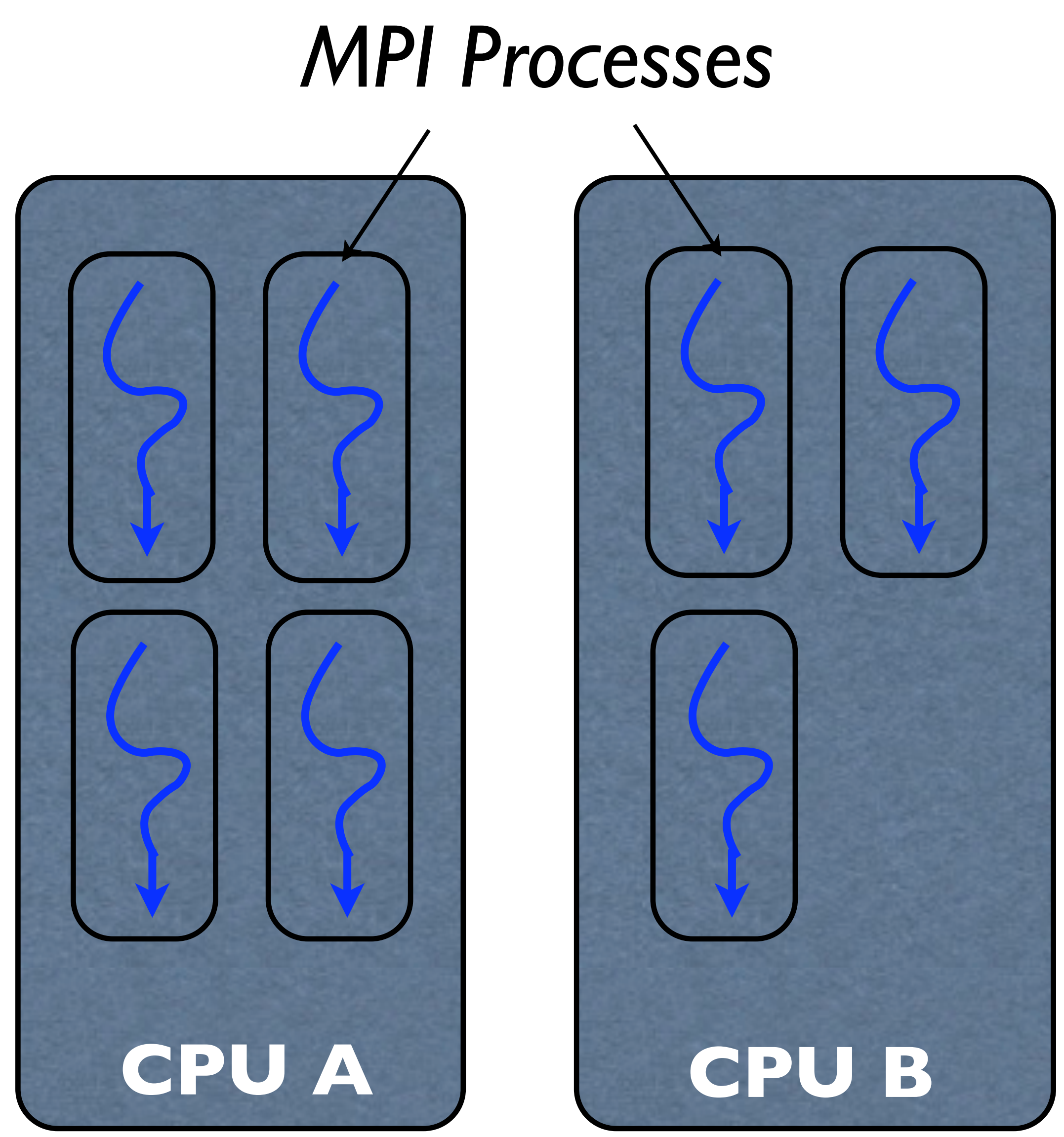
Charm++ (cont.)


User View
System Implementation
CPU A
CPU B
CPU C


Scheduler
Message Queue
CPU

AMPI

- Each MPI process is implemented as a user-level thread (virtual processor)
- Threads are light-weight, and migratable!
(<1 microsecond contex tswitch time, potentially >100k threads per core)
- Each thread is embedded in a Charm++ object (chare)



Fault Tolerance

- Common Features:
  - Based on dynamic runtime capabilities
  - Use of object-migration
  - Can be used in concert with load-balancing schemes
  - Independence on the number of processors
- Four Approaches Available:
  - Disk-based checkpoint/restart
  - In-memory double checkpoint/restart
  - Proactive object migration
  - Message-logging

Disk-Based Checkpoint/ Restart

- Similar to traditional checkpoint/restart; "migration" to disk
- Implemented by a blocking coordinated checkpoint: MPI_Checkpoint(DIRNAME)

+ Simple scheme, effective for common cases

+ Virtualization enables restart with any number of processors

- Checkpointing and data reload operations may be slow

- Work between last checkpoint and failure is lost

- Job needs to be resubmitted and restarted

Double In-Memory Checkpoint/Restart

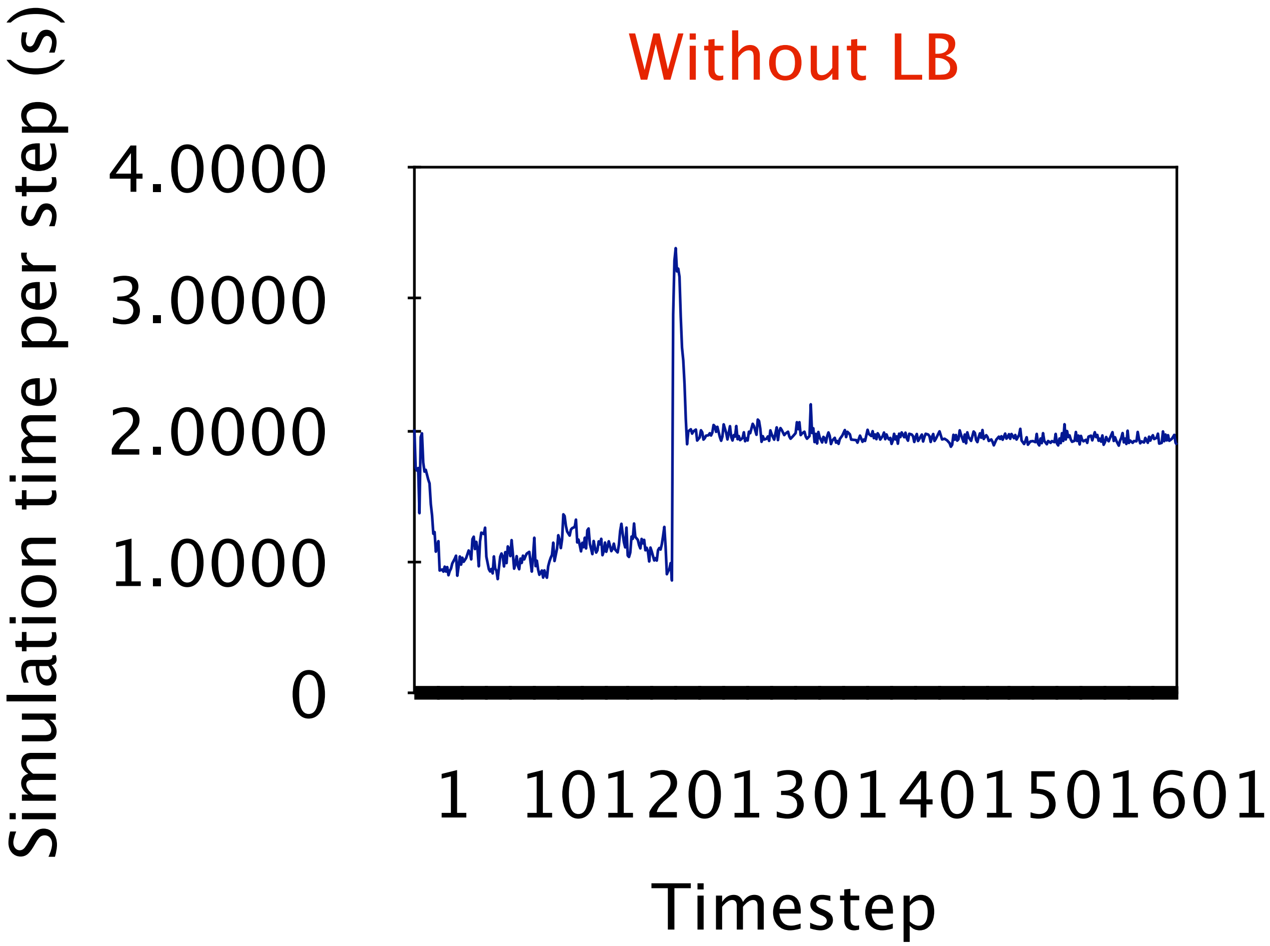
- Avoid overhead of disk access for keeping saved data (allow user to define what makes up the state data)
- Implementation in Charm++/AMPI:
  - Coordinated checkpoint (SYNCFT)
  - Each object maintains two checkpoints:
    - on local processor's memory
    - on remote *buddy* processor's memory

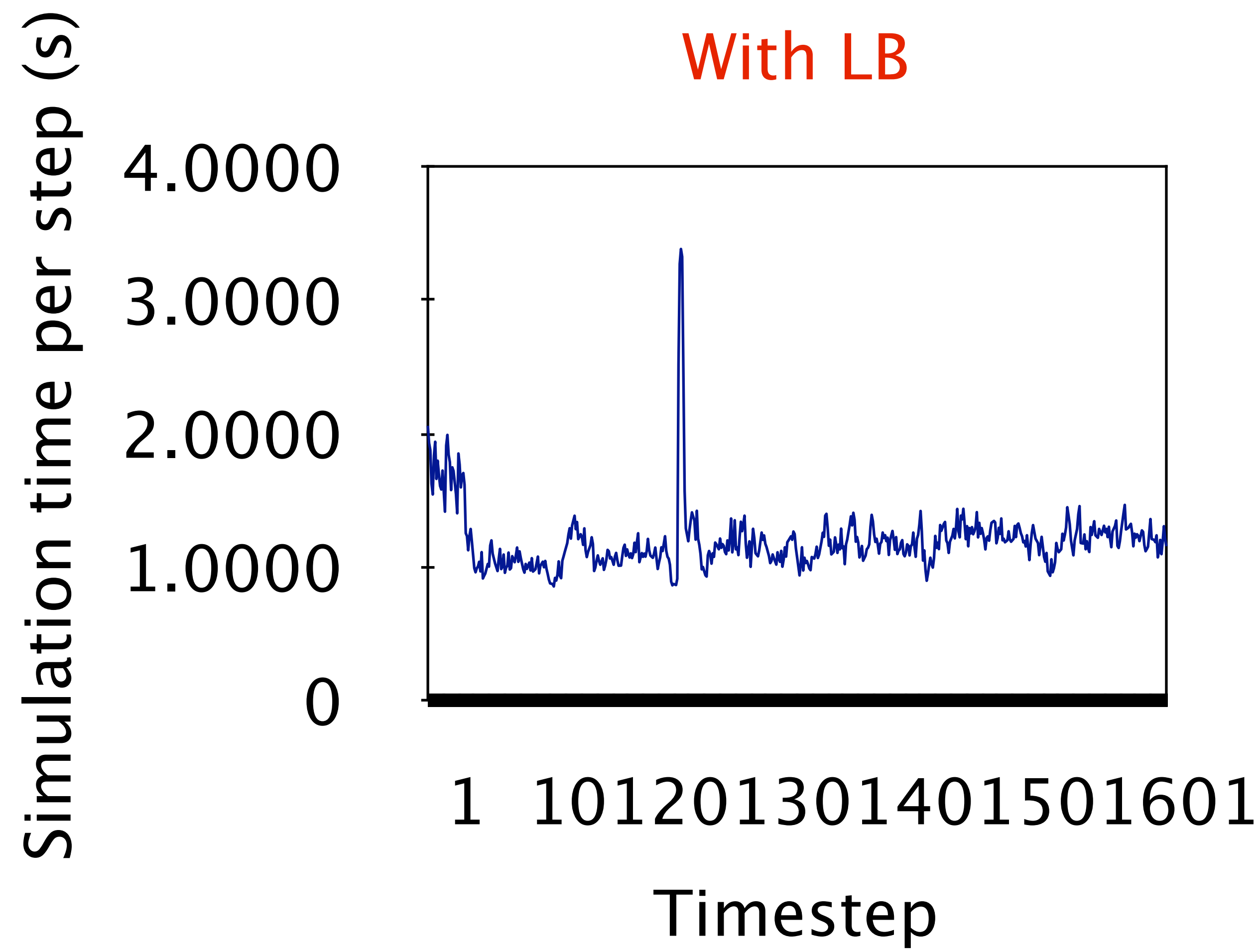
Double In-Memory Checkpoint/Restart (cont.)

- A *dummy* process is created to replace crashed process
- New process starts recovery on other processors
  - use buddy's checkpoint to recreate state of failing processor
  - perform load balance after restart

Recovery Performance

- Molecular Dynamics LeanMD code, 92K atoms, P=128
  - Load Balancing (LB) effect after failure:





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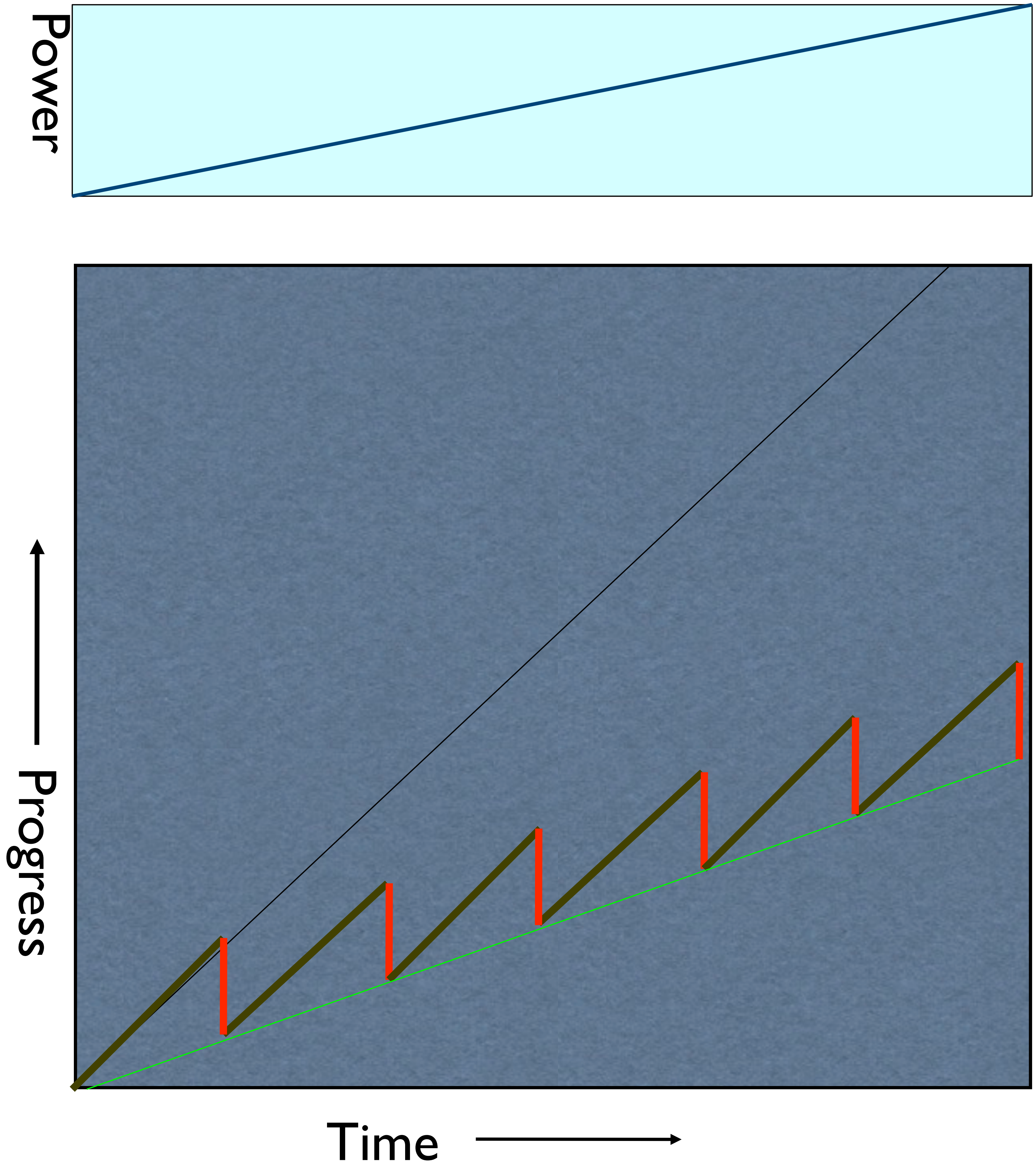
Summary (SYNCFT)

+ Faster checkpointing than disk-based
+ Reading of saved data also faster
+ Only one processor fetches checkpoint across network
- Memory overhead may be high
- All processors are rolled back, despite individual failure
- All the work since last checkpoint is redone by every processor

Message-Logging

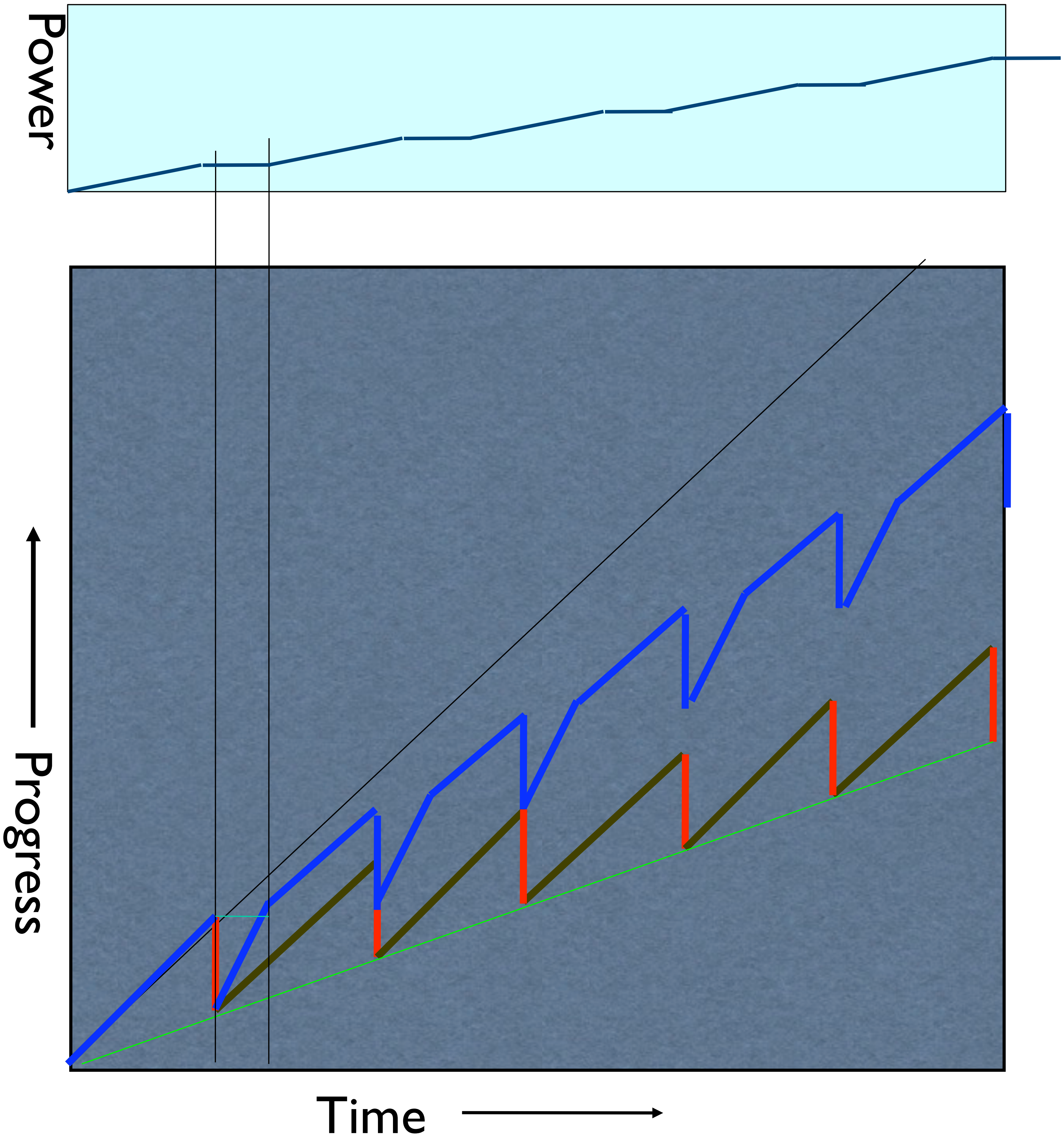
- Basic Idea: messages are stored by sender during execution
  - Periodic checkpoints still maintained
  - After a crash, reprocess "recent" messages to regain state
- Implementation in Charm++/AMPI:
  - New receptions occur in the same order
  - No need to roll back all the processors!
  - Restart can be parallelized
  - Virtualization helps fault-free case as well



Normal Checkpoint-Resart method

Progress is slowed down with failures

Power consumption is continuous



Our Checkpoint-Restart method

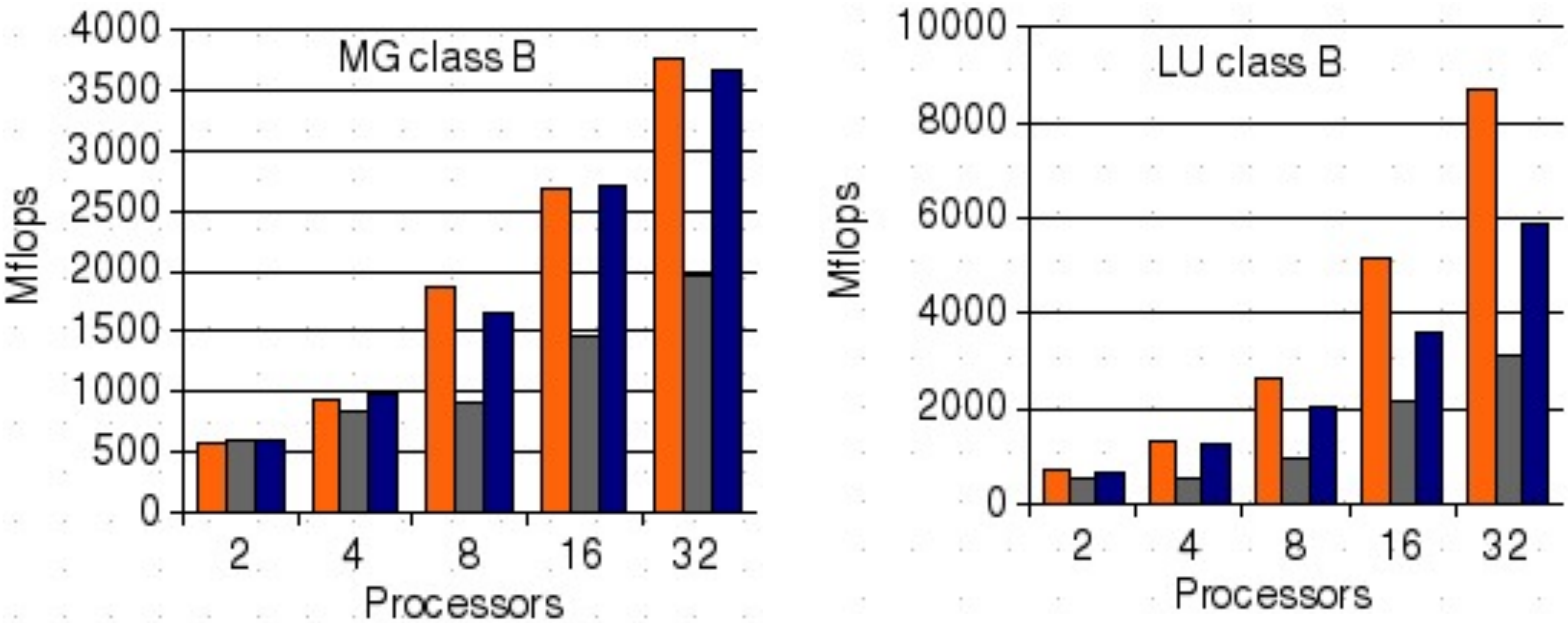
(Message logging + Object-based virtualization)

Faster recovery

Power consumption is lower during recovery

Fault-free Performance

- Test: NAS benchmarks, MG/LU
  - Versions: AMPI, AMPI+FT, AMPI+FT+multipleVPs



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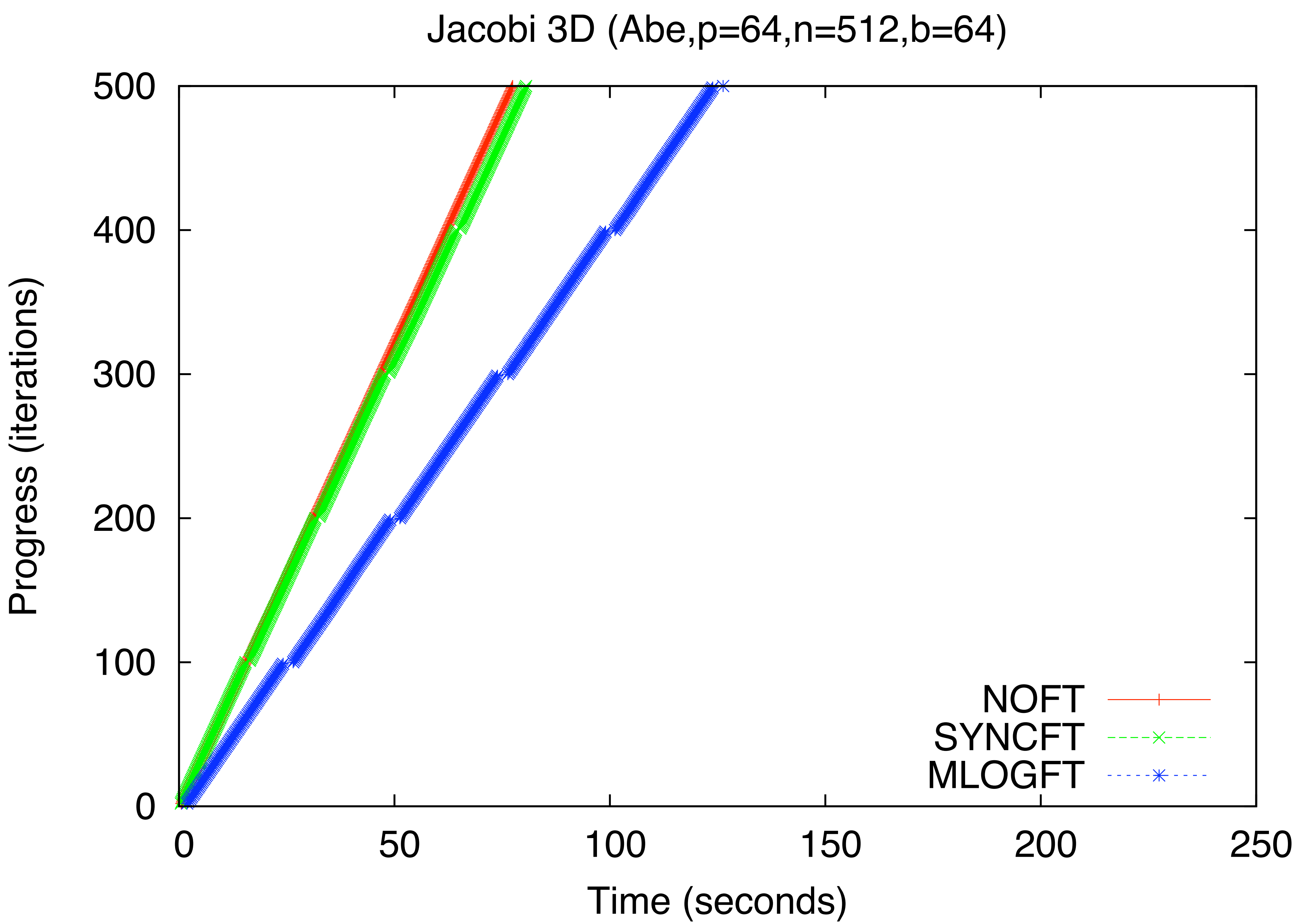
Bad scenario



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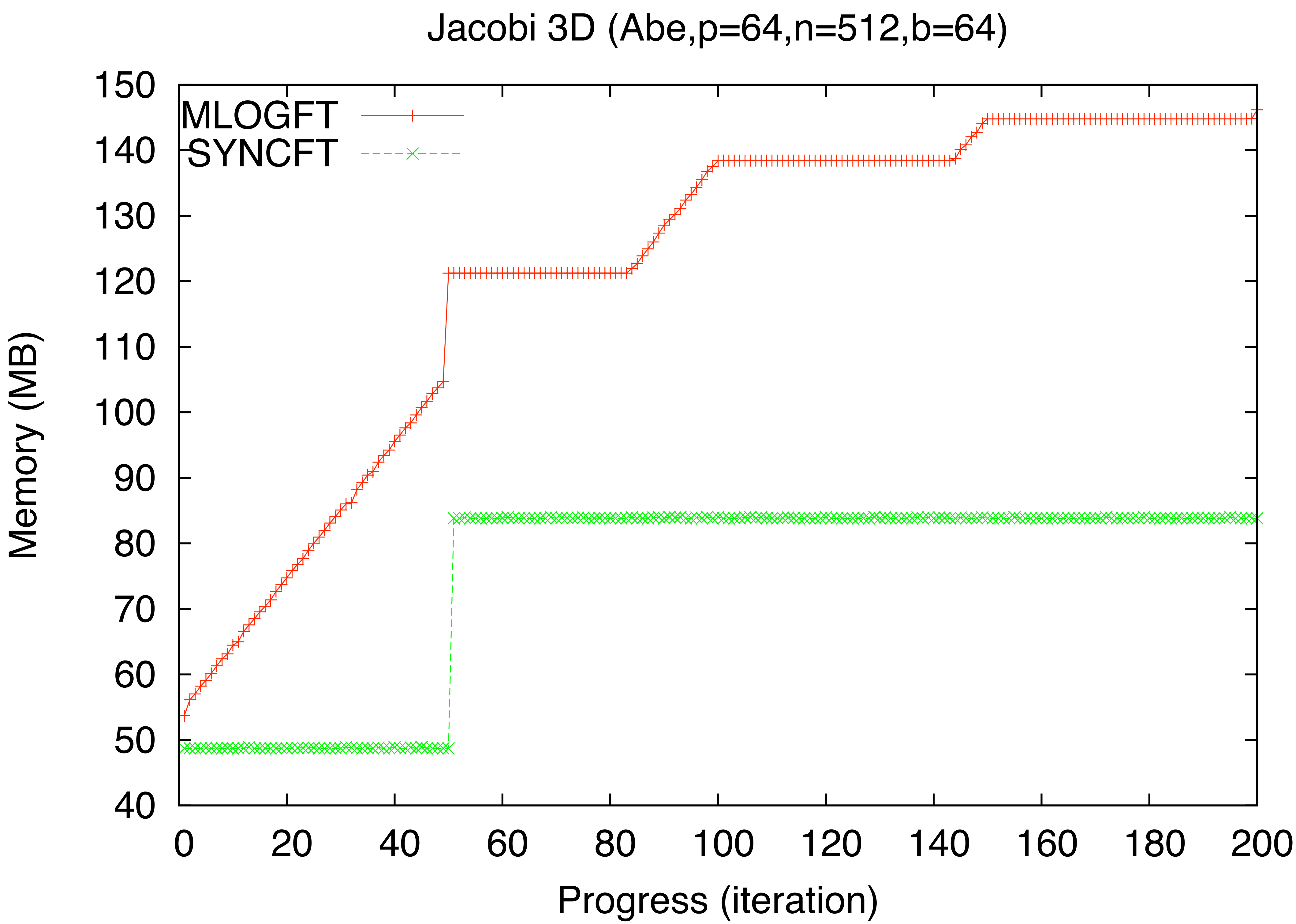
Memory Consumption



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Summary (MLOGFT)

+ No need to roll back non-failing processors

+ Restart can be accelerated by spreading work to be redone

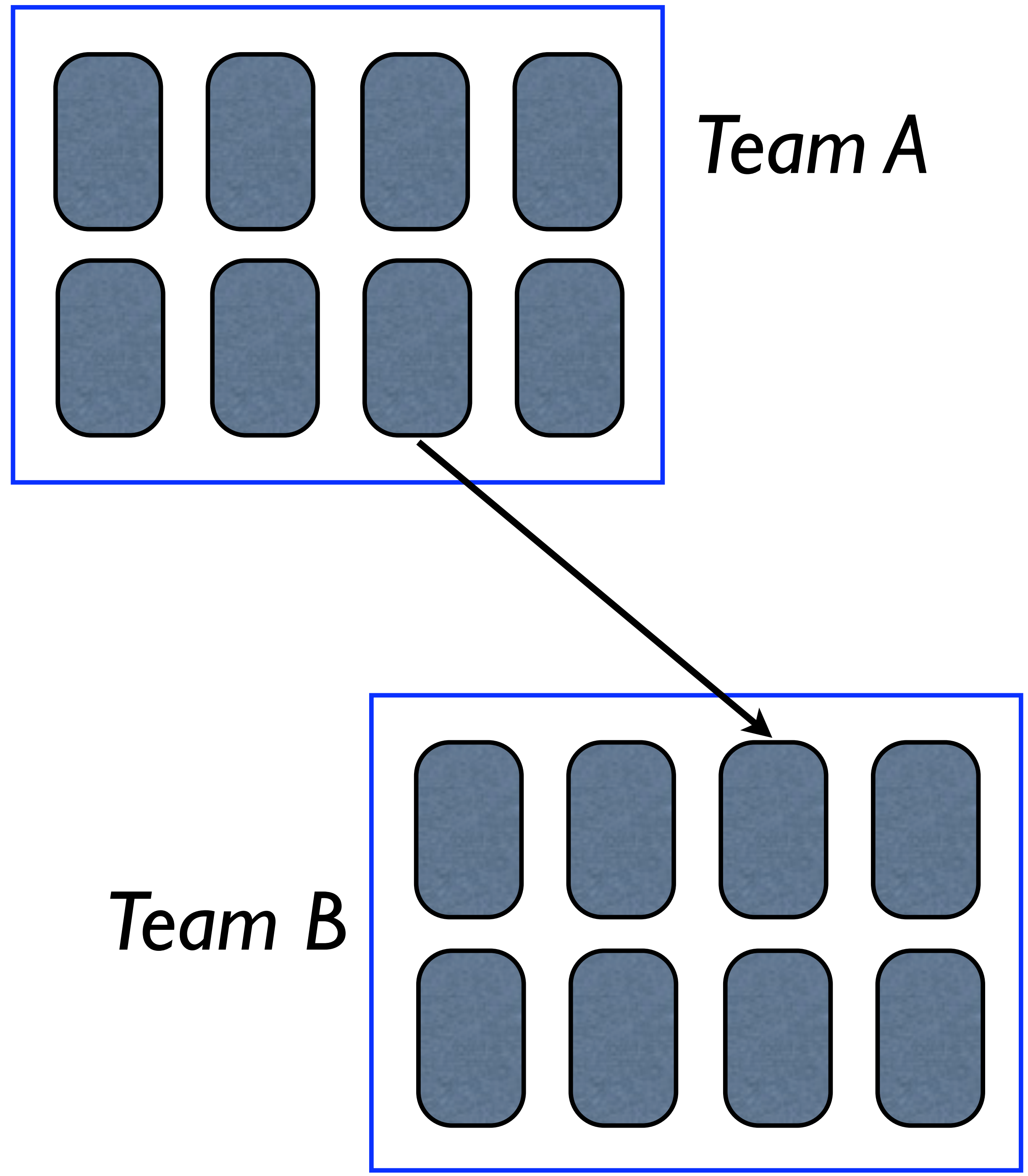
+ No need of stable storage

- Protocol overhead is present even in fault-free scenario

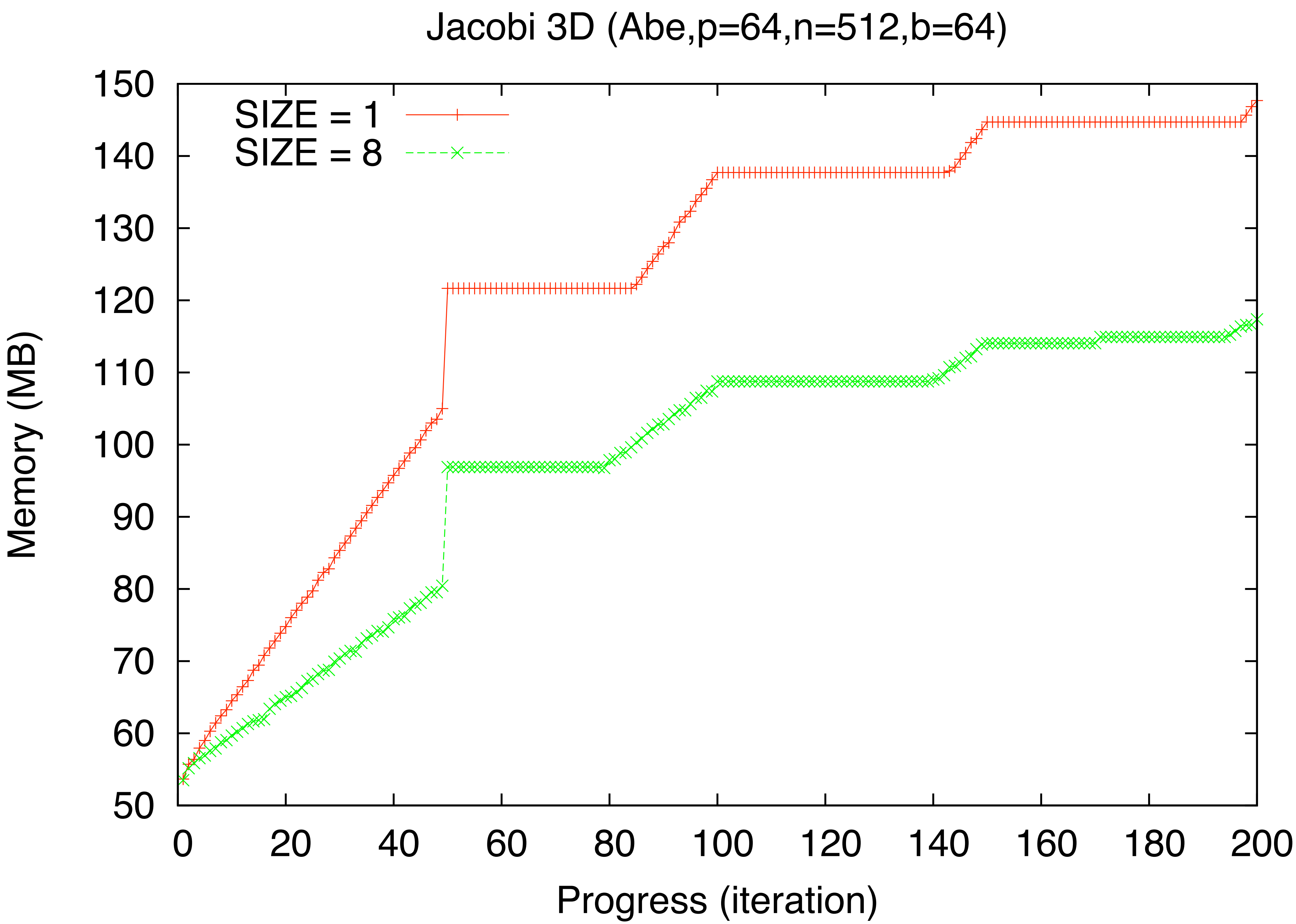
- Increase in latency may be an issue for fine-grained applications

Team-based Message Logging

- Group processors in *teams* and avoid logging intra-team messages
- Each team recovers as a unit
- Compromise between *memory demand* and *recovery time*
- Load balancer in charge of assigning objects to processors
- Cores per node = natural team size



Allocated Memory



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Proactive Object Migration

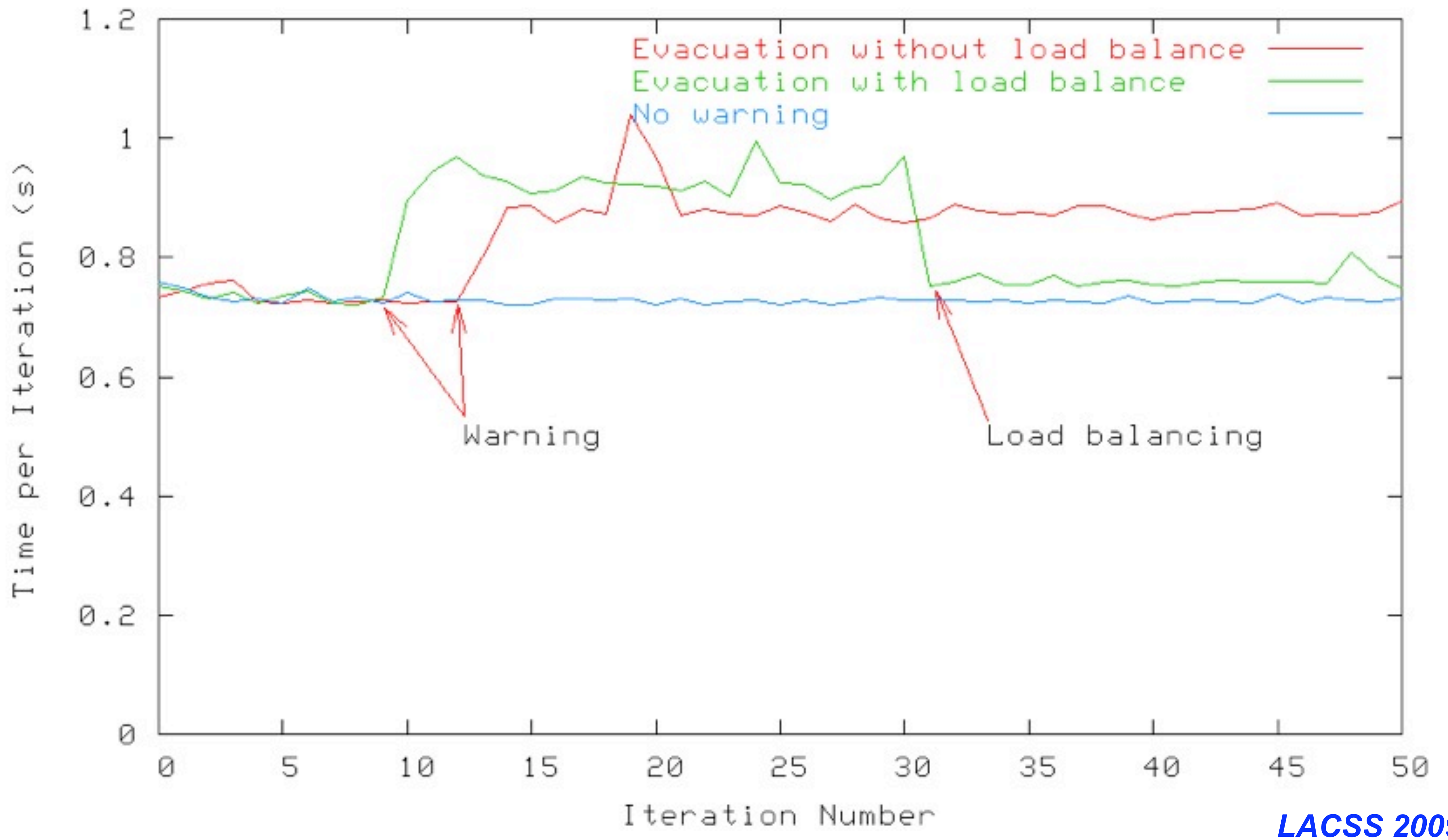
- Basic Idea: use knowledge about impending faults
  - Migrate objects away from processors that may fail soon
  - Fall back to checkpoint/restart when faults not predicted
- Implementation in Charm++/AMPI:
  - Each object has a unique index
  - Each object is mapped to a *home* processor
    - objects need not reside on home processor
    - home processor knows how to reach the object

Proactive Object Migration (cont.)

- Upon getting a warning, evacuate the processor
  - reassign mapping of objects to new home processors
  - send objects away, to their home processors

MPI Application Performance

- Sweep3d code, 150x150x150 dataset, P=32, 1 warning
- 5-point stencil code in Charm++, IA-32 cluster



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Summary (Proactive)

+ No overhead in fault-free scenario
+ Evacuation time scales well, only depends on data and network
+ No need to roll back when predicted fault happens
- Effectiveness depends on fault predictability mechanism
- Some faults may happen without advance warning

Obstacles to FT on Existing Machines

- Current systems too strict and inflexible
  - Entire application is killed when one process dies
  - Most MPI implementations behave like this
  - True in other scenarios as well (e.g. IBM's POE+LAPI)
- Typical situation today
  - System software (OS, scheduler) controls the whole machine
  - Job is aborted when something goes bad
  - No option for application to continue running after faults, even for applications that could proceed!
    - But Charm++ net version can handle faults today, and other Charm++ versions can follow a similar scheme

Obstacles to FT on Existing Machines

- Desired scenario
  - System software optionally allows job to proceed beyond faults
  - It must be a community effort: includes vendor participation !
- Broader Need:
  - Scheduler that allows flexible, bi-directional communication between jobs and scheduler
  - Scheduler may notify job to shrink or expand, and job adapts accordingly
  - Job may ask scheduler for more resources when needed, or return partial resources no longer needed

Current PPL Research Directions

- Multiple concurrent failures
- Message-Logging Scheme
  - Decrease latency overhead and memory overhead
  - Stronger coupling to load-balancing
  - Newer schemes to reduce message-logging overhead
    - Team-based: a set of cores are sent back to their checkpoint (Greg Bronevetsky)
    - Implementation of other protocols (Franck Capello)

But, we are not experts in FT

- The message-driven objects model provides many benefits for fault tolerance schemes
  - Not just our schemes, but your schemes too
  - Multiple objects per processor: latencies of protocols can be hidden
  - Parallel recovery by leveraging "multiple objects per processor"
  - Can combine benefits by using system level or BLCR schemes specialized to take advantage of objects (or user-level threads)

Conclusions

- We have interesting fault tolerance schemes (read about them)
- We have an approach to parallel programming
  - That has benefits in the era of complex machines, and sophisticated applications
  - That is used by real apps
  - That provides beneficial features for FT schemes
  - That is available via the web
  - SO: please think about developing new FT schemes of your own for this model
- More info, papers, software: http://charm.cs.uiuc.edu

Acknowledgements

- Dep. of Energy – FastOS Program
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  - Collaborators: ORNL (Terry Jones) & IBM (Jose Moreira)
- Fullbright Scholarship
  - Interim support between Colony phases
- NSF/NCSA
  - Deployment efforts specific for Blue Waters
- Machine allocations
  - TeraGrid MRAC – NCSA, TACC, ORNL
  - Argonne Nat. Lab – BG/P

Thank you!

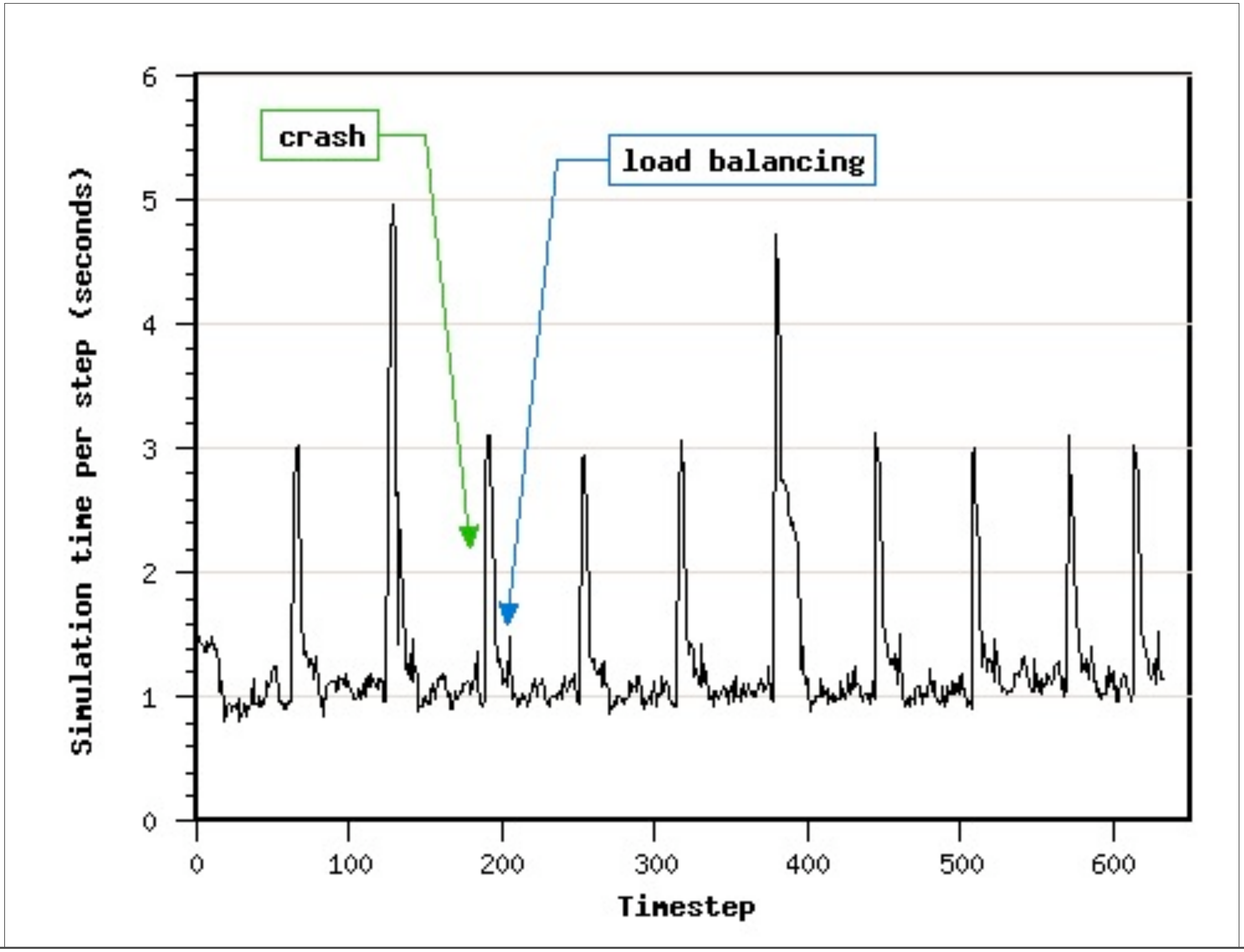
Overflow slides

Well Established Systems

- The Charm++/AMPI model has succeeded in CSE/HPC (because resource management,...)
- 15% of cycles at NCSA, 20% at PSC, were used on Charm++ apps, in a one year period
- So, work on fault tolerance for Charm++ and AMPI is directly useful to real apps
- Also, with AMPI, it applies to MPI applications

Application Performance

- Molecular Dynamics LeanMD code, 92K atoms, P=128
  - Checkpointing every 10 timesteps; 10 crashes inserted:



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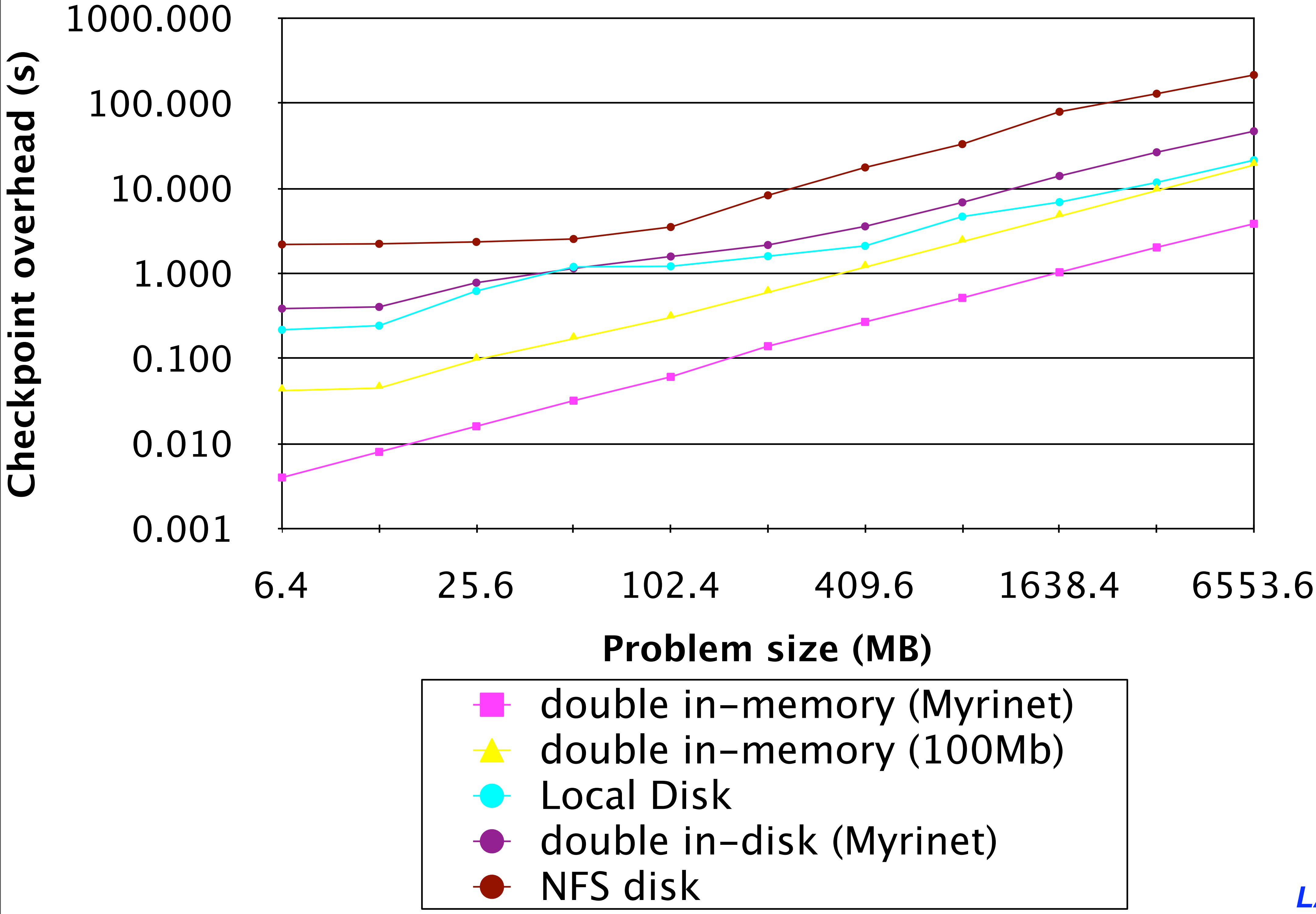
Memory vs Disk



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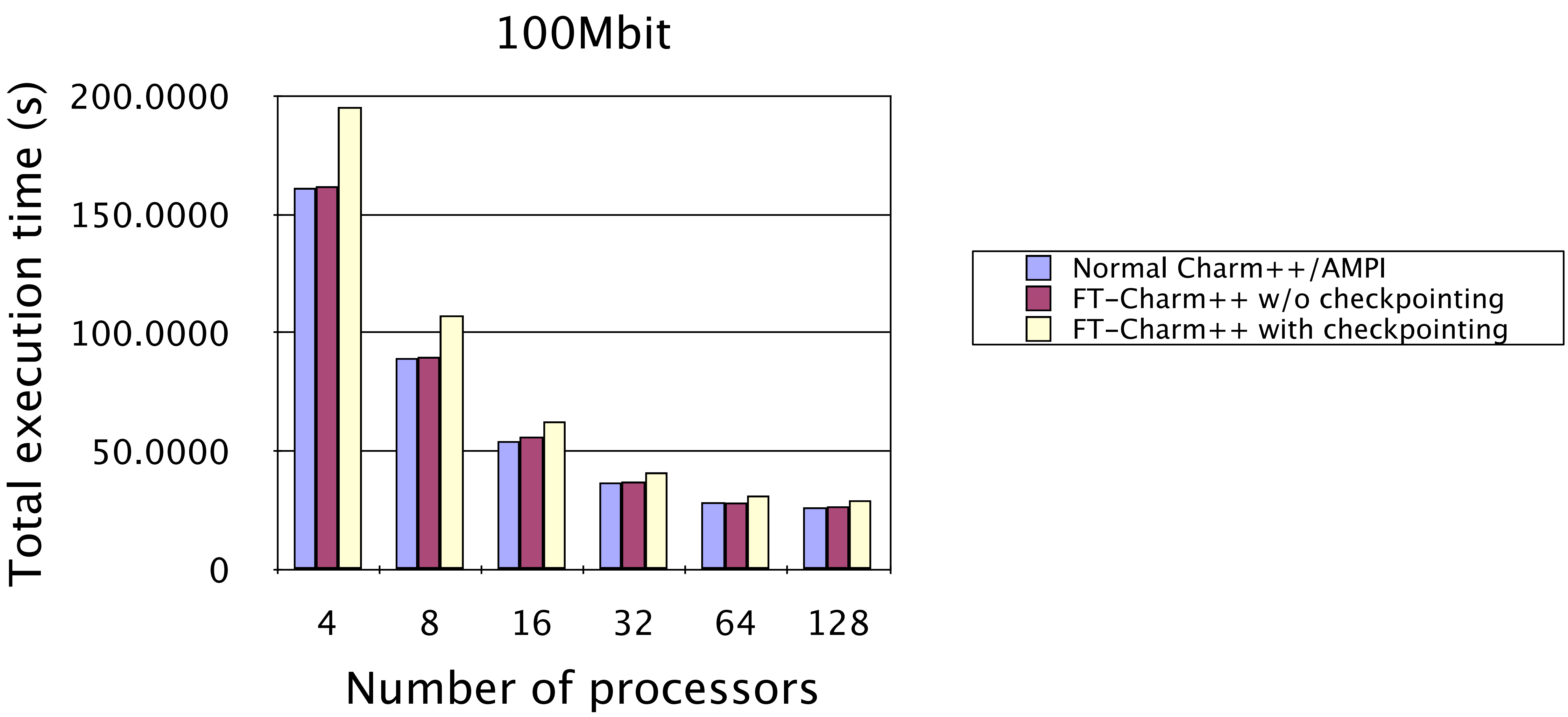
Checkpoint Overhead

- 3D-Jacobi code in AMPI, 200 MB data, IA-32 cluster
  - Execution of 100 iterations, 8 checkpoints taken



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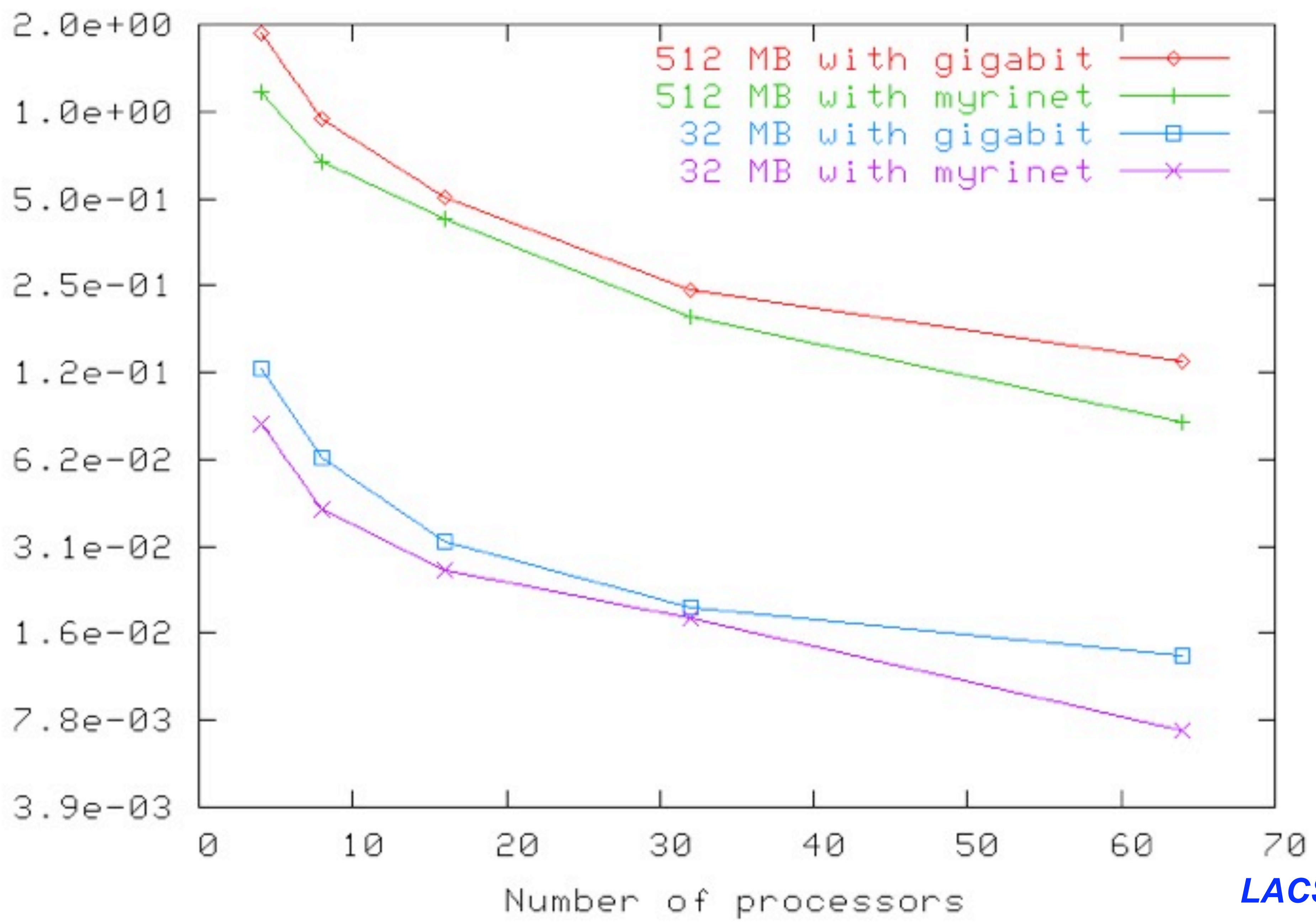
Evacuation Time vs Number of Processors

- 5-point stencil code in Charm++, IA-32 cluster



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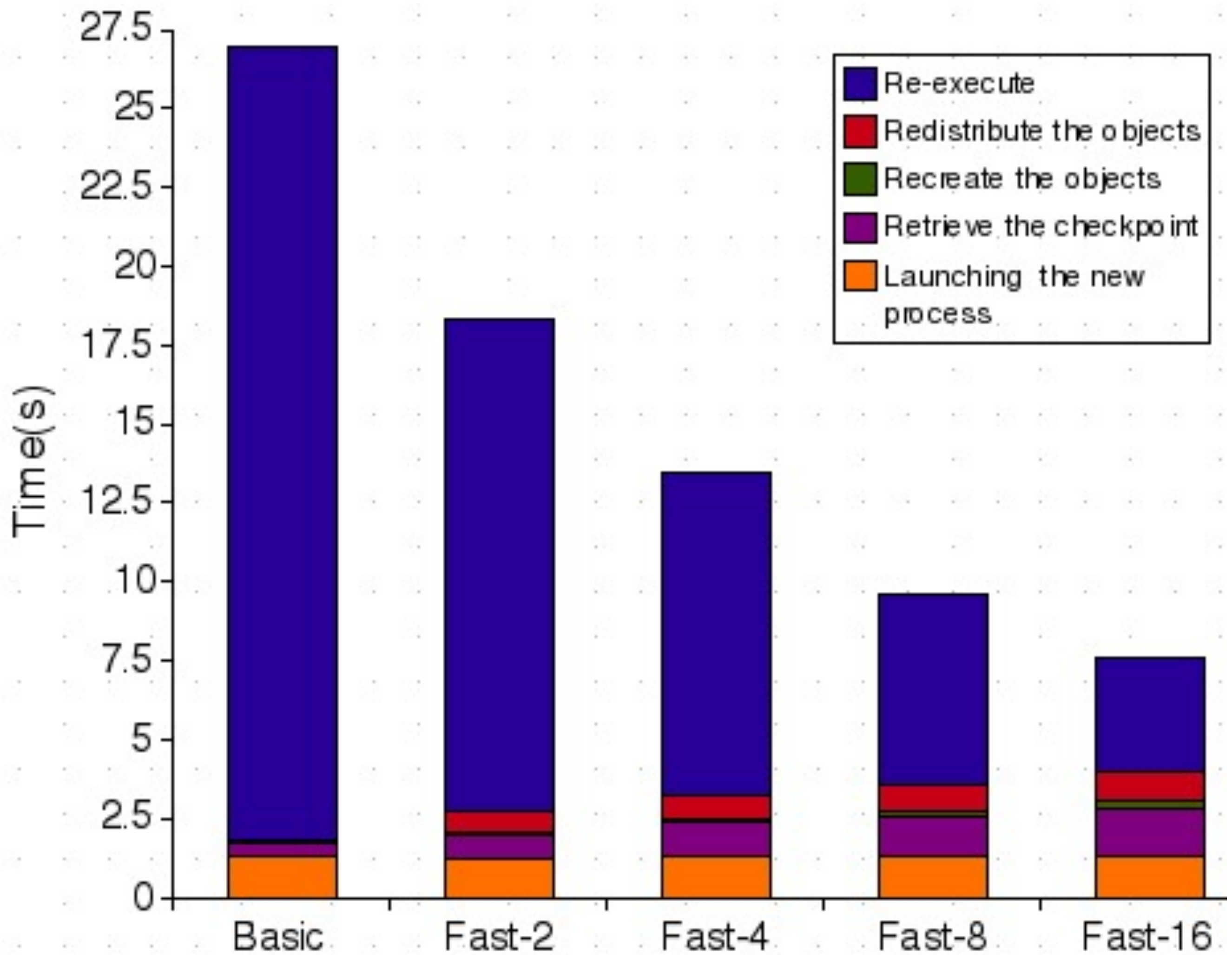
Fast restart performance

- Test: 7-point 3D-stencil in MPI, P=32, 2 ≤ VP ≤ 16
- Checkpoint taken every 30s, failure inserted at t=27s



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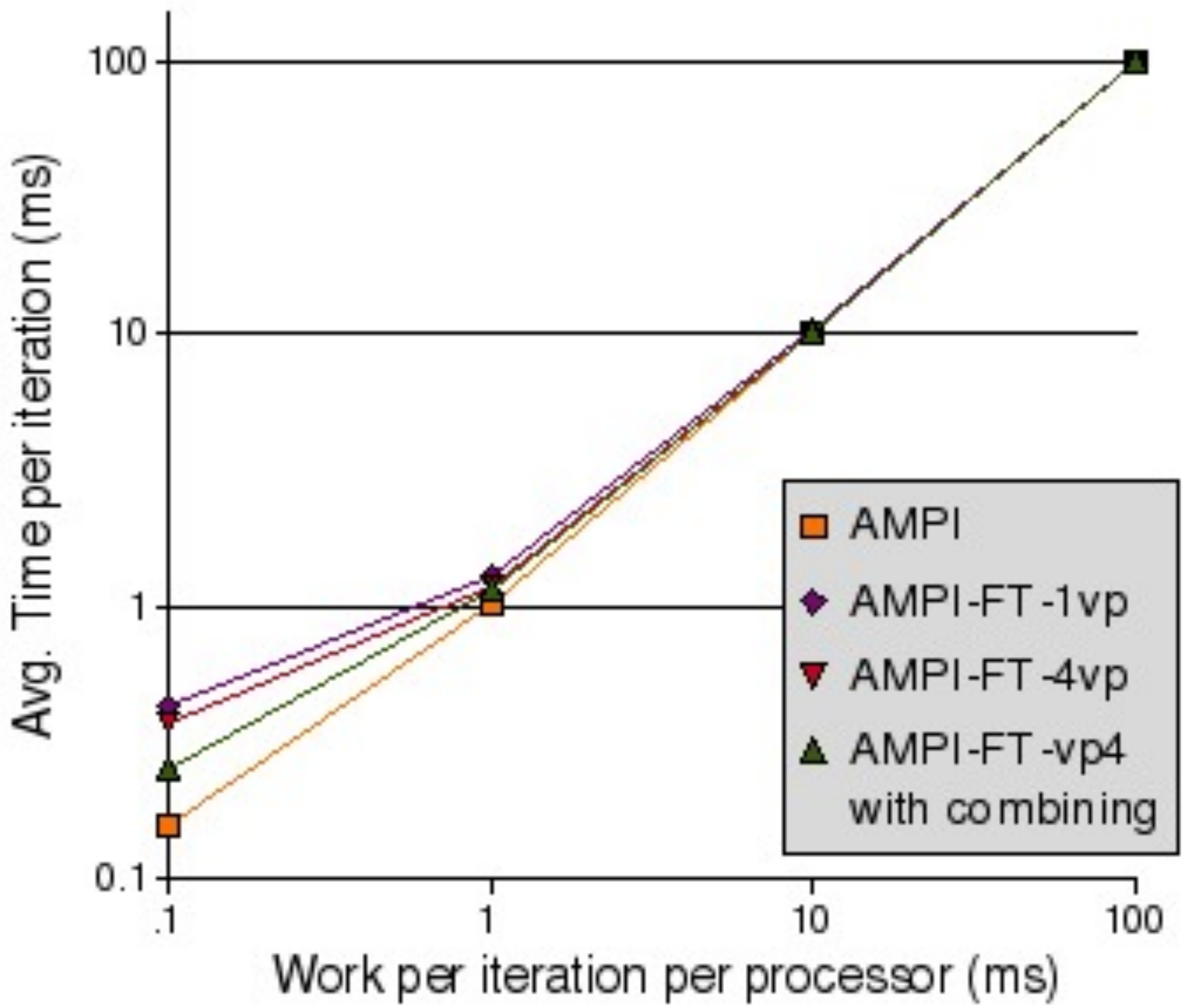
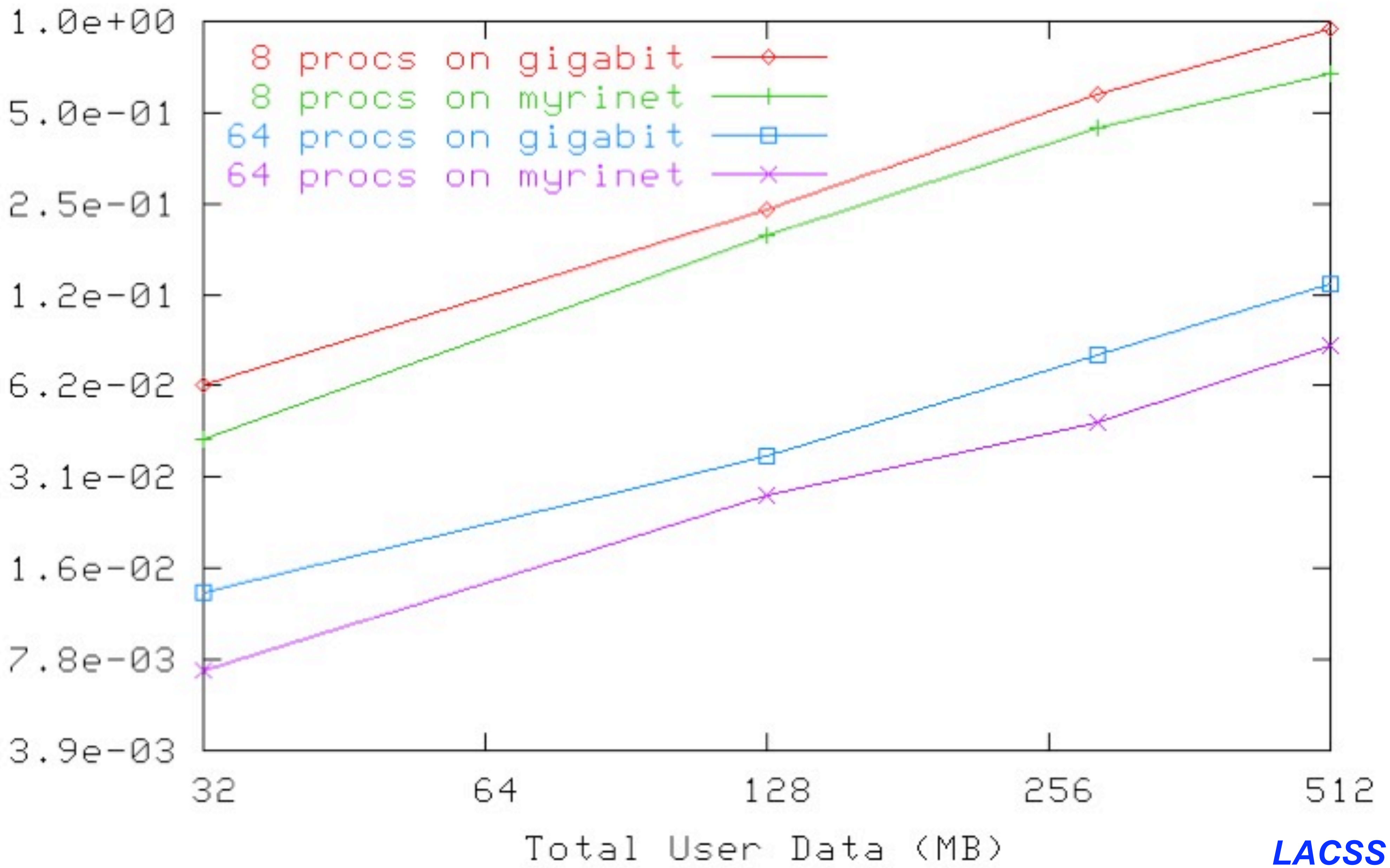
Protocol Optimization

- Combine protocol messages: reduces overhead and contention
- Test: synthetic compute/communicate benchmark



Evacuation Time vs Data Size

- 5-point stencil code in Charm++, IA-32 cluster



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