Scalable Fault Tolerance Schemes using Adaptive Runtime Support

Laxmikant (Sanjay) Kale

http://charm.cs.uiuc.edu

Parallel Programming Laboratory

Department of Computer Science

University of Illinois at Urbana Champaign

ILLINOIS

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

PARALLEL PROGRAMMING LAB

DEPT. OF COMPUTER SCIENCE, UNIVERSITY OF ILLINOIS

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Presentation Outline

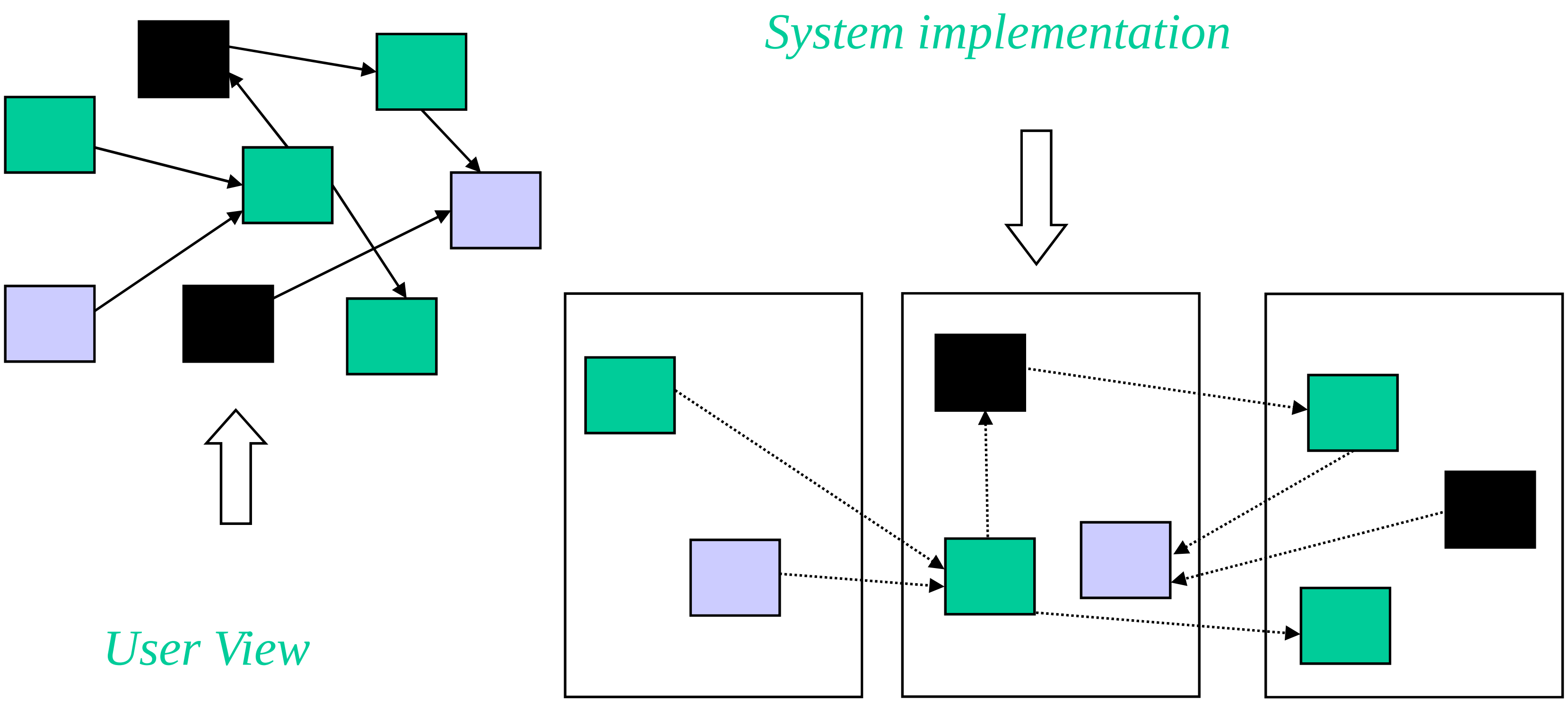
- What is object based decomposition
  - Its embodiment in Charm++ and AMPI
  - Its general benefits
  - Its features that are useful for fault tolerance schemes
- Our Fault Tolerance work in Charm++ and AMPI
  - Disk-based checkpoint/restart
  - In-memory double checkpoint/restart
  - Proactive object-migration
  - Message-logging

Object based over-decomposition

- Programmers decompose computation into objects
  - Work units, data-units, composites
  - Decomposition independent of number of processors
  - Typically, many more objects than processors
- Intelligent runtime system assigns objects to processors
- RTS can change this assignment (mapping) during execution

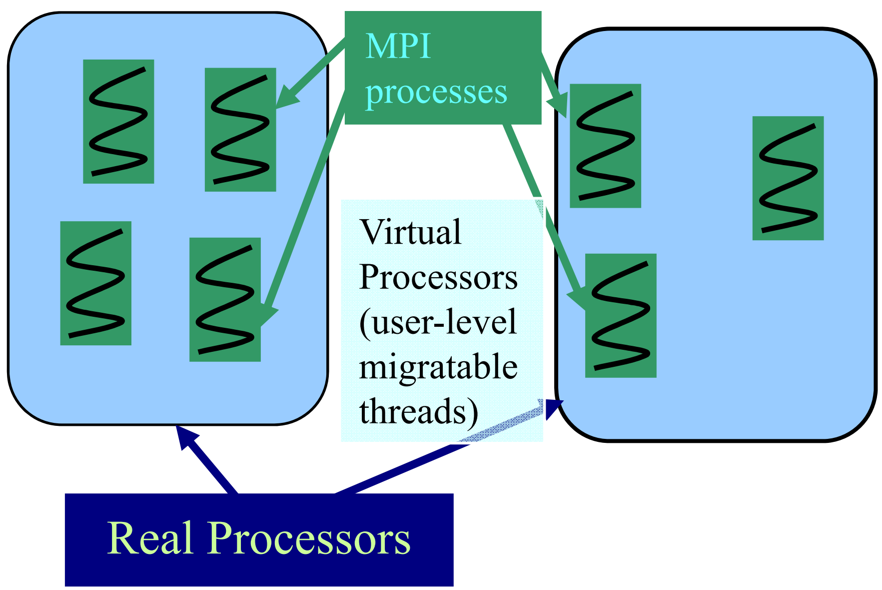
Object-based over-decomposition: Charm++

- Multiple "indexed collections" of C++ objects
- Indices can be multi-dimensional and/or sparse
- Programmer expresses communication between objects
  - with no reference to processors



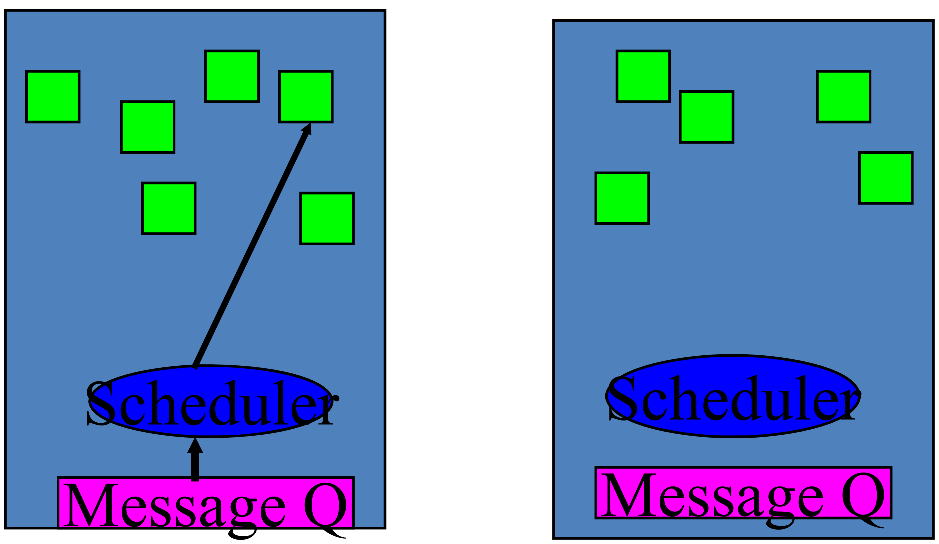
Object-based over-decomposition: AMPI

- Each MPI process is implemented as a <u>user-level</u> thread
- Threads are light-weight, and migratable!
  - <1 microsecond context switch time, potentially >100k threads per core
- Each thread is embedded in a charm+ object (chare)



Some Properties of this approach Relevant to Fault Tolerance

- Object-based Virtualization leads to *Message Driven Execution*



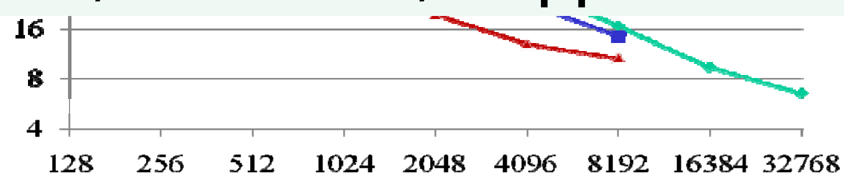
- Dynamic load balancing by migrating objects
- No dependence on processor number:
  - E.g. 3D cube of objects, can be mapped to a non-cube number of processors

Charm++/AMPI are well established systems

- The Charm++ 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



Fault Tolerance in Charm++ & AMPI

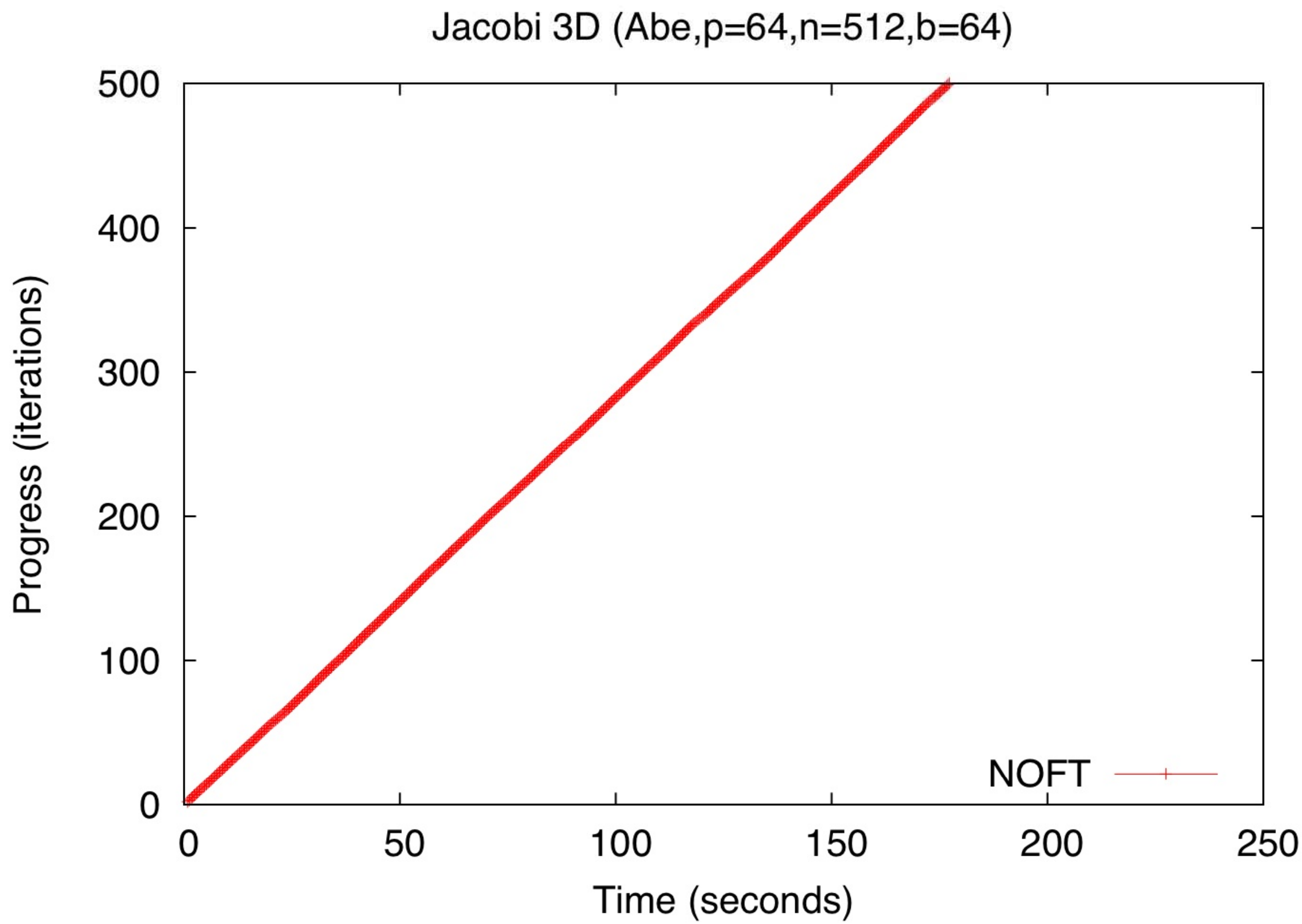
- Four Approaches Available:
  a) Disk-based checkpoint/restart
  b) In-memory double checkpoint/restart
  c) Proactive object migration
  d) Message-logging: scalable rollback, parallel restart
- Common Features:
  - Based on dynamic runtime capabilities
  - Use of object-migration
  - Can be used in concert with load-balancing schemes

Disk-Based Checkpoint/Restart

- Basic Idea:
  - Similar to traditional checkpoint/restart; "migration" to disk
- Implementation in Charm++/AMPI:
  - Blocking coordinated checkpoint: `MPI_Checkpoint(DIRNAME)`
- Pros:
  - Simple scheme, effective for common cases
  - Virtualization enables restart with any number of processors
- Cons:
  - Checkpointing and data reload operations may be slow
  - Work between last checkpoint and failure is lost
  - Job needs to be resubmitted and restarted

SyncFT: In-Memory double Checkpoint/Restart

- Basic Idea:
  - 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
  - Each object maintains two checkpoints:
    - on local processor's memory
    - on remote *buddy* processor's memory
  - A *dummy* process is created to replace crashed process
  - New process starts recovery on another processor
    - use buddy's checkpoint to recreate state of failing processor
    - perform load balance after restart



Jacobi 3D (Abe,p=64,n=512,b=64)
Progress (iterations)
Time (seconds)
NOFT
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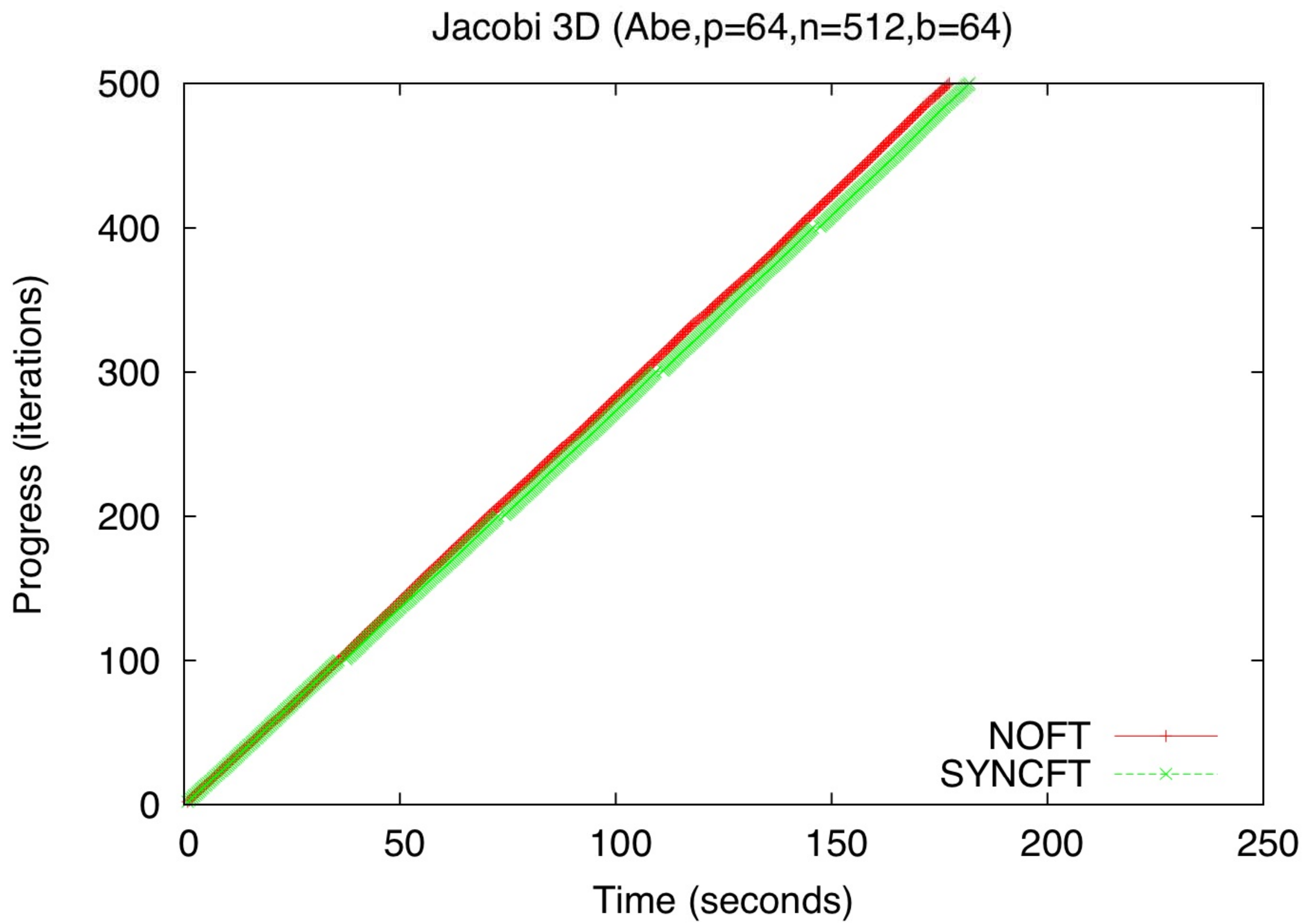
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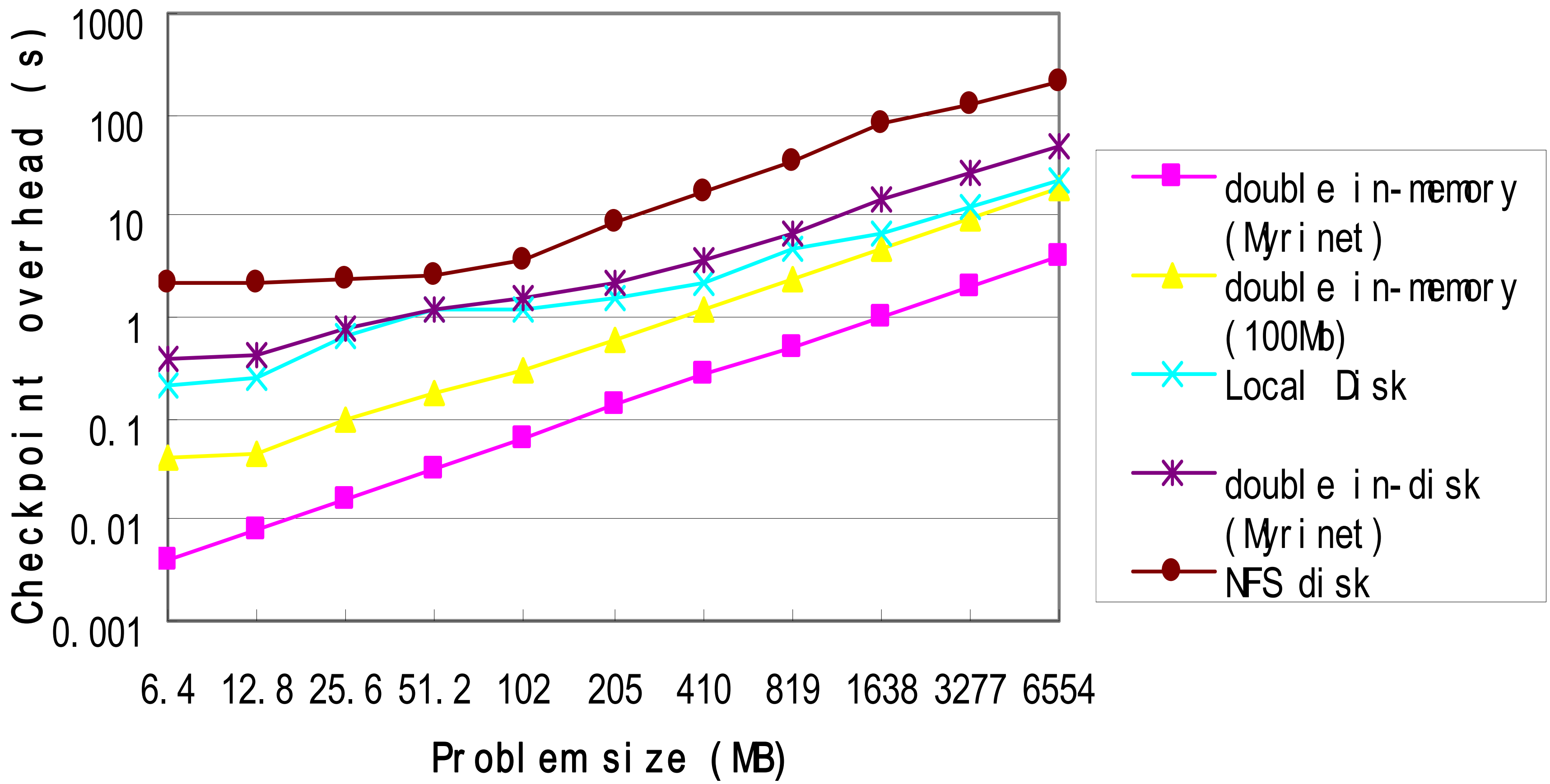
SYNCFT

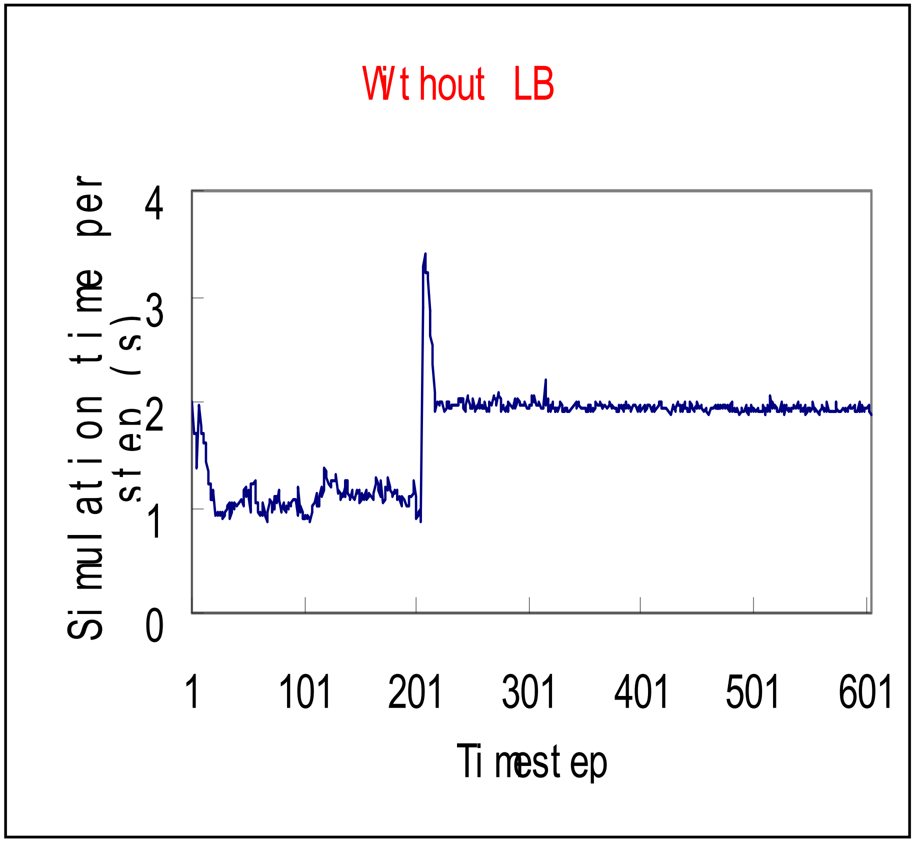
In-Memory Double Checkpoint/Restart (cont.)

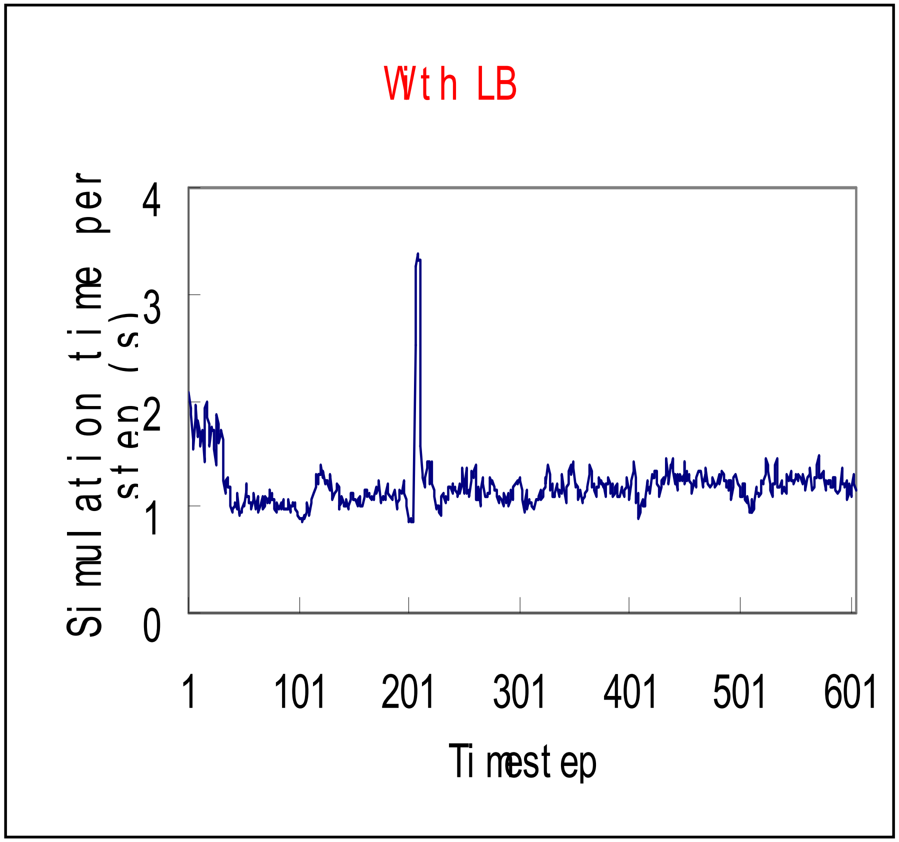
- Comparison to disk-based checkpointing:



In-Memory Double Checkpoint/Restart (cont.)

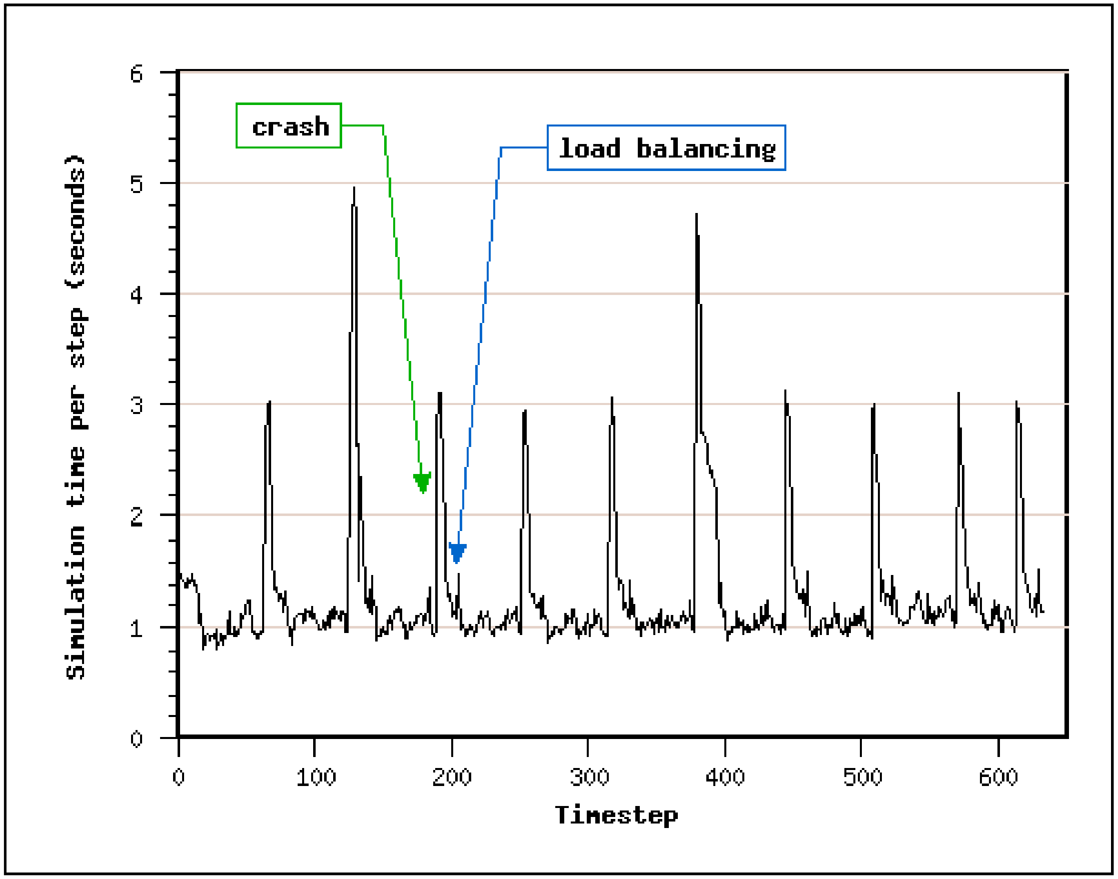
- Recovery Performance:
  - Molecular Dynamics LeanMD code, 92K atoms, P=128
  - Load Balancing (LB) effect after failure:





In-Memory Double Checkpoint/Restart (cont.)

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



In-Memory Double Checkpoint/Restart (cont.)

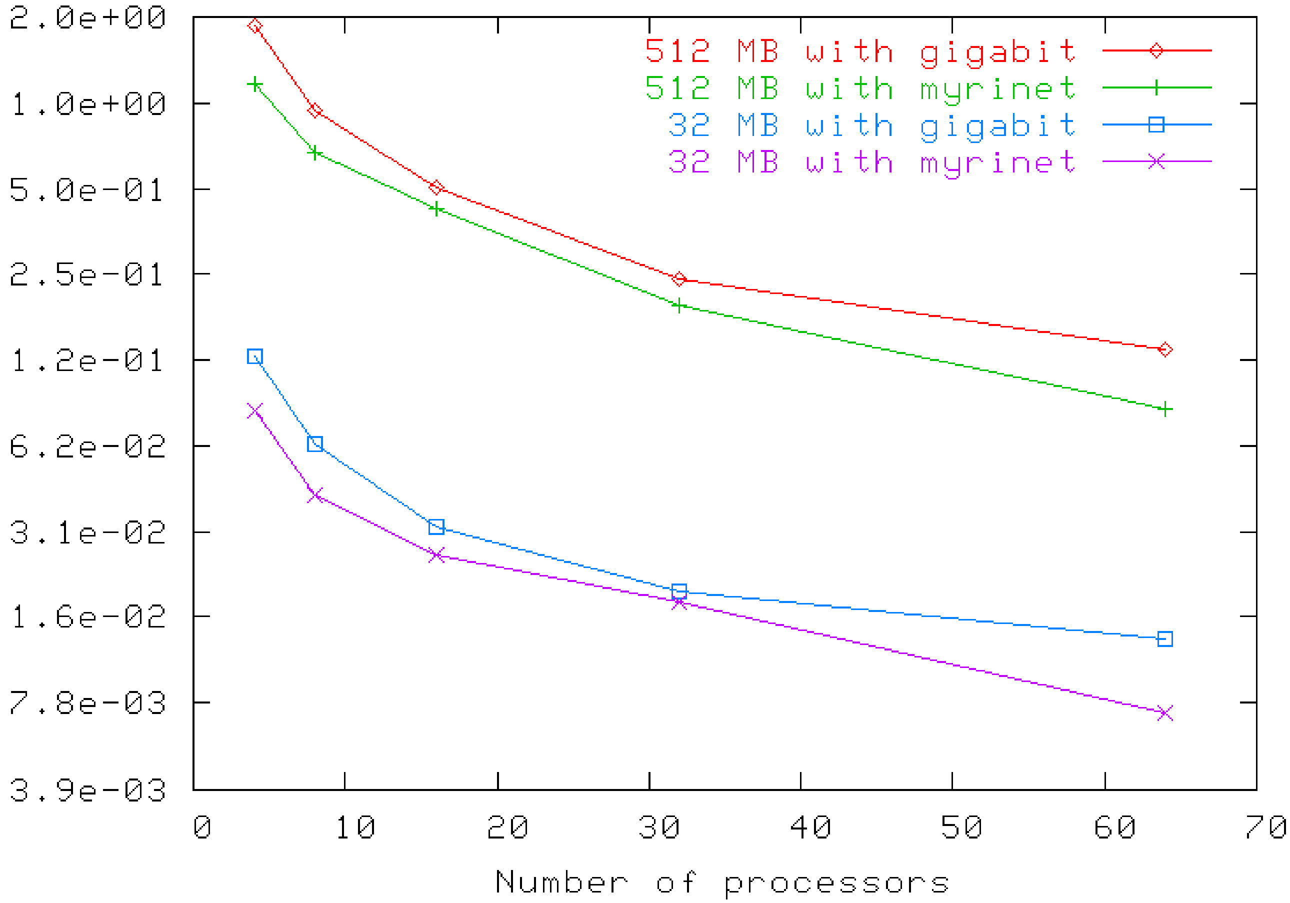
- Pros:
  - Faster checkpointing than disk-based
  - Reading of saved data also faster
  - Only one processor fetches checkpoint across network
- Cons:
  - Memory overhead may be high
  - All processors are rolled back, despite individual failure
  - All the work since last checkpoint is redone by every processor
- Publications:
  - Zheng, Huang & Kale: ACM-SIGOPS, April 2006
  - Zheng, Shi & Kale: IEEE-Cluster'2004, Sep.2004

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

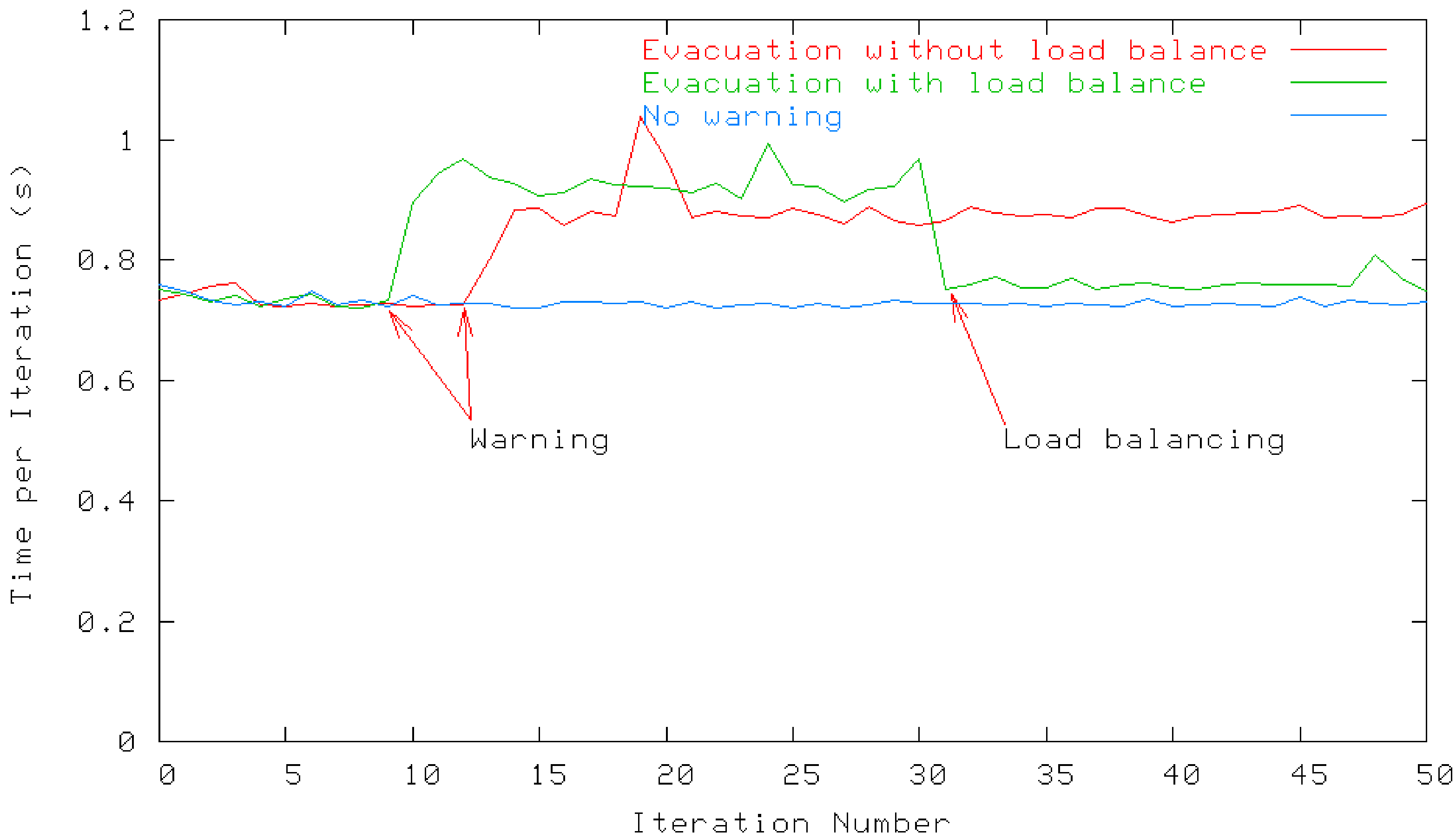
Proactive Object Migration (cont.)

- Evacuation time as a function of #processors:
  - 5-point stencil code in Charm++, IA-32 cluster



Proactive Object Migration (cont.)

- Performance of an MPI application
  - Sweep3d code, 150x150x150 dataset, P=32, 1 warning



Proactive Object Migration (cont.)

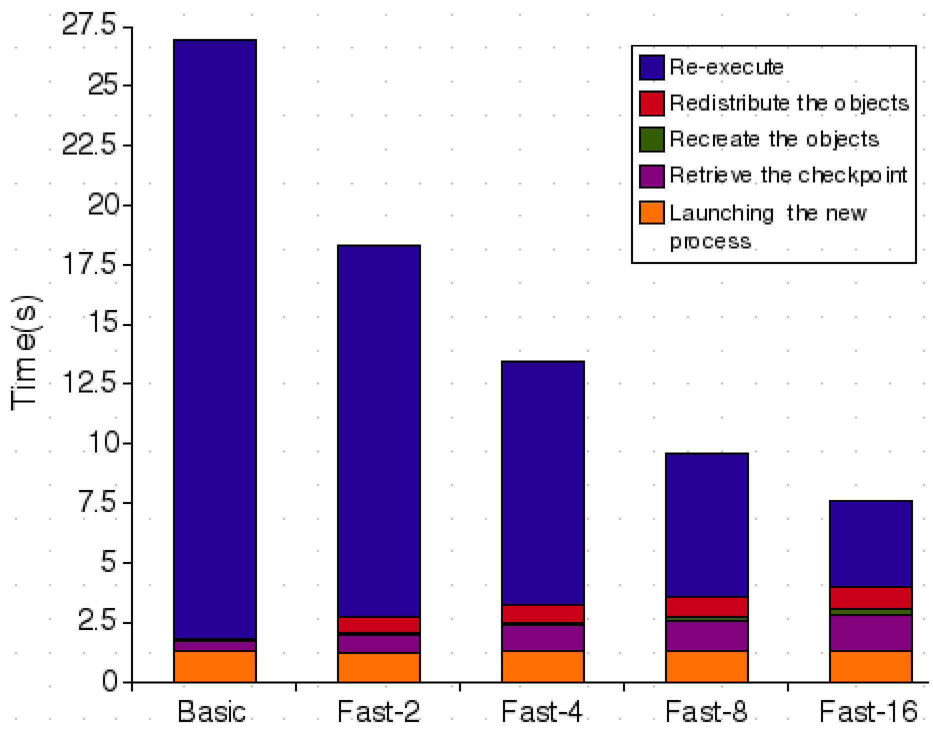
- Pros:
  - No overhead in fault-free scenario
  - Evacuation time scales well, only depends on data and network
  - No need to roll back when predicted fault happens
- Cons:
  - Effectiveness depends on fault predictability mechanism
  - Some faults may happen without advance warning
- Publications:
  - Chakravorty, Mendes & Kale: HiPC, Dec.2006
  - Chakravorty, Mendes, Kale et al: ACM-SIGOPS, April 2006

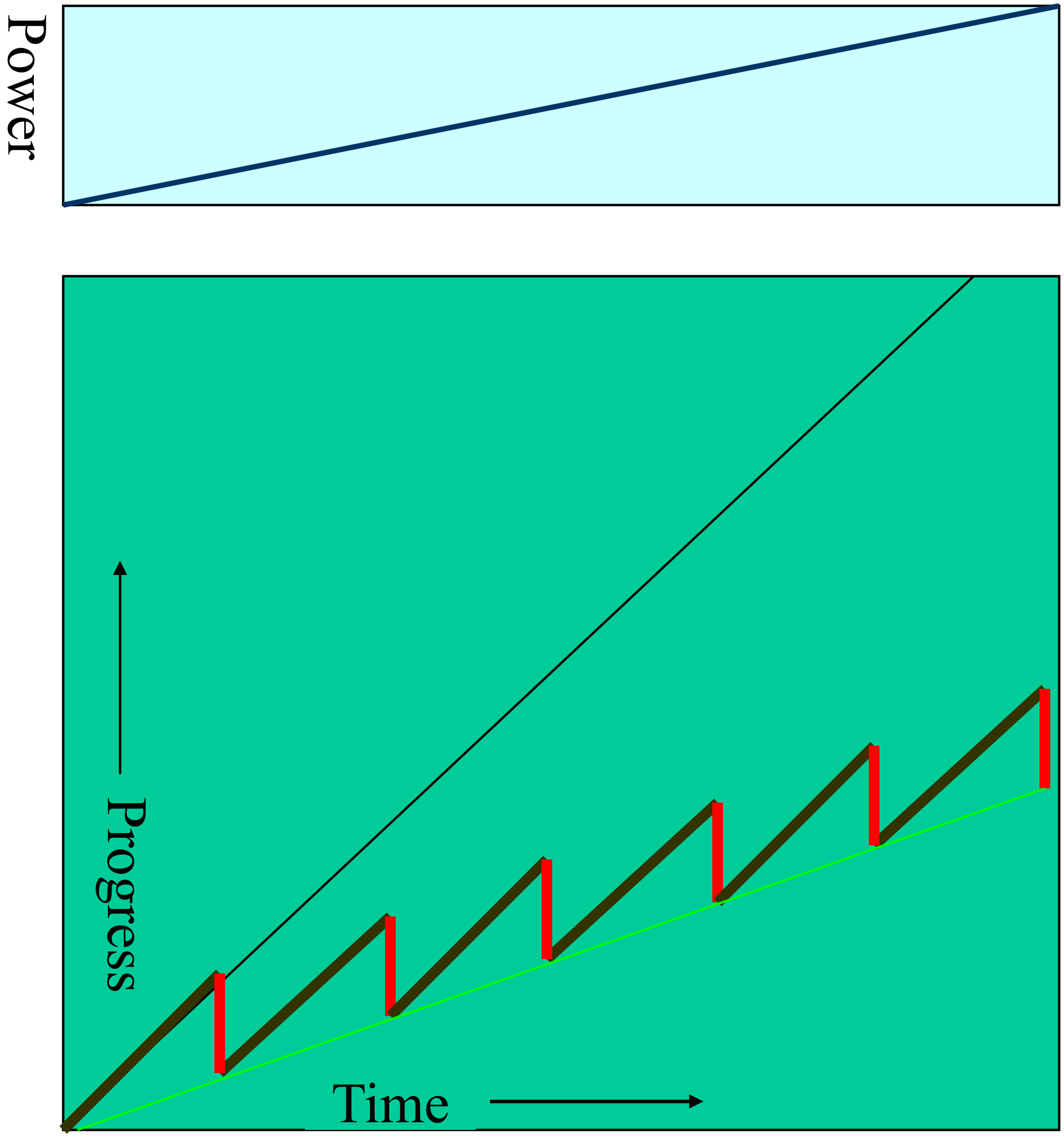
Message-Logging

- 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:
  - Since the state depends on the order of messages received, the protocol ensures that the new receptions occur in the same order
  - Upon failure, roll back is “localized” around failing point: no need to roll back all the processors!
  - With virtualization, work in one processor is divided across multiple virtual processors; **thus, restart can be parallelized**
  - Virtualization helps fault-free case as well

Message-Logging (cont.)

- Fast restart performance:
  - Test: 7-point 3D-stencil in MPI, P=32, $2 \leq VP \leq 16$
  - Checkpoint taken every 30s, failure inserted at t=27s

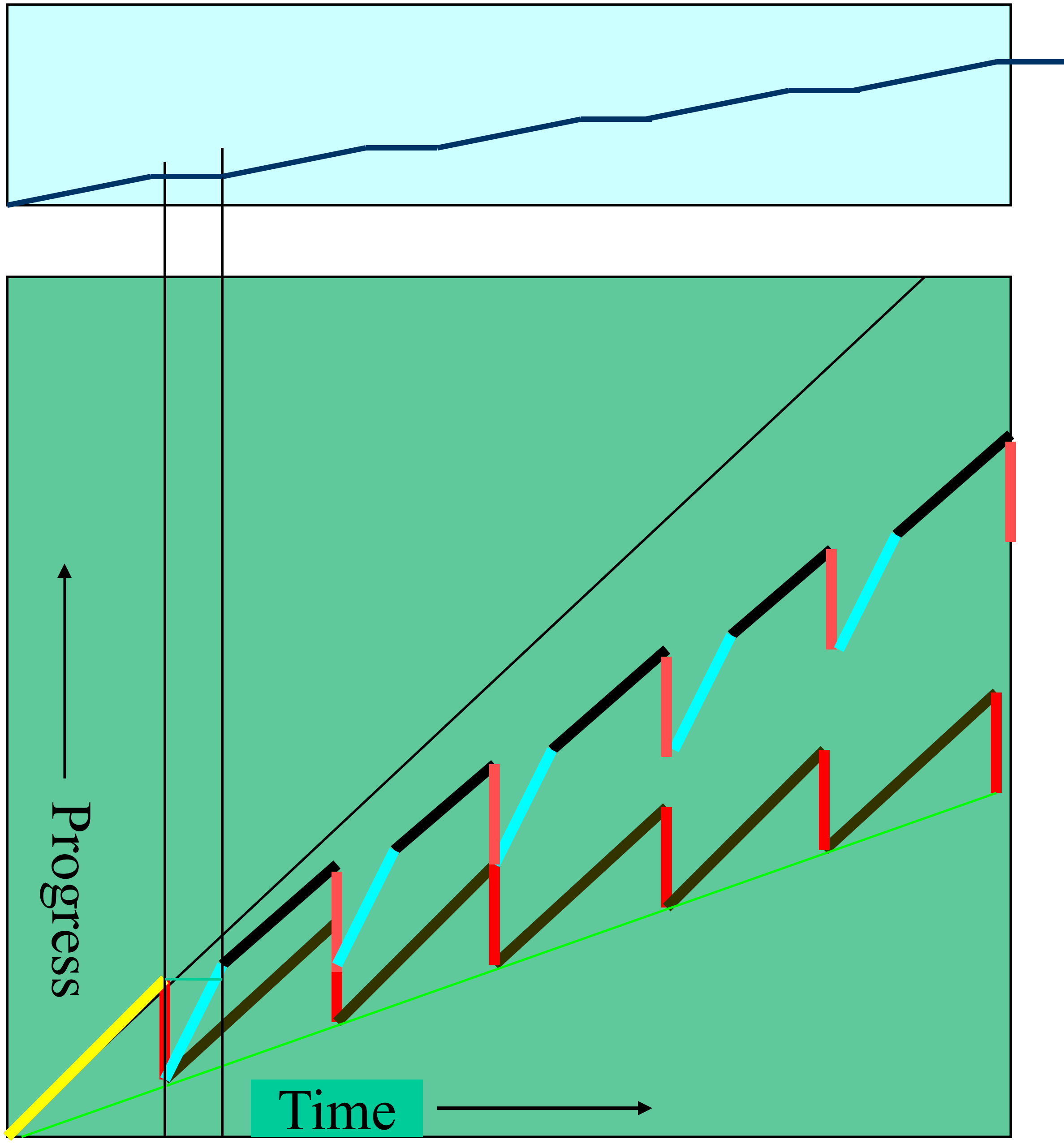




Normal Checkpoint-Resart method

Progress is slowed down with failures

Power consumption is continuous



Our Checkpoint-Resart method

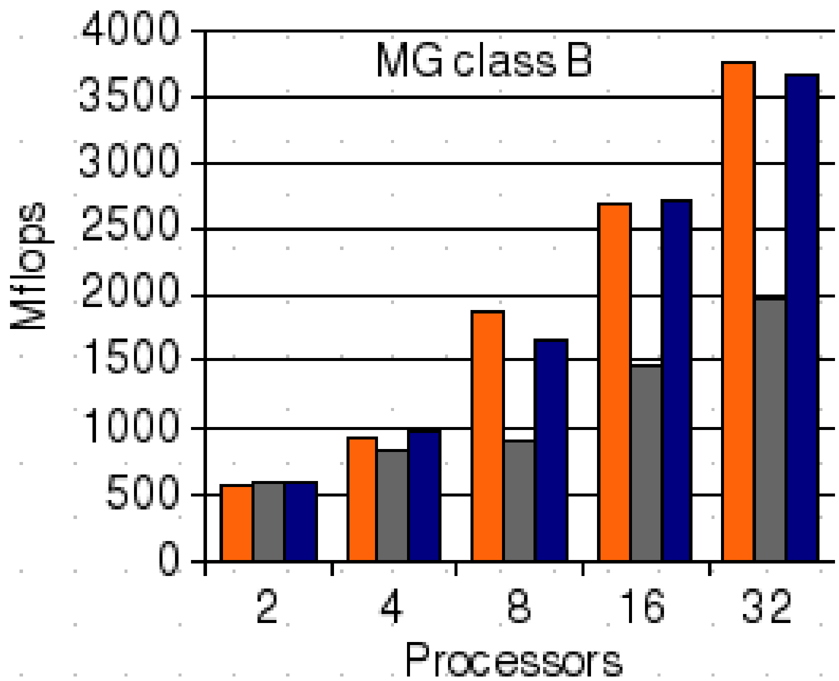
(Message logging + Object-based virtualization)

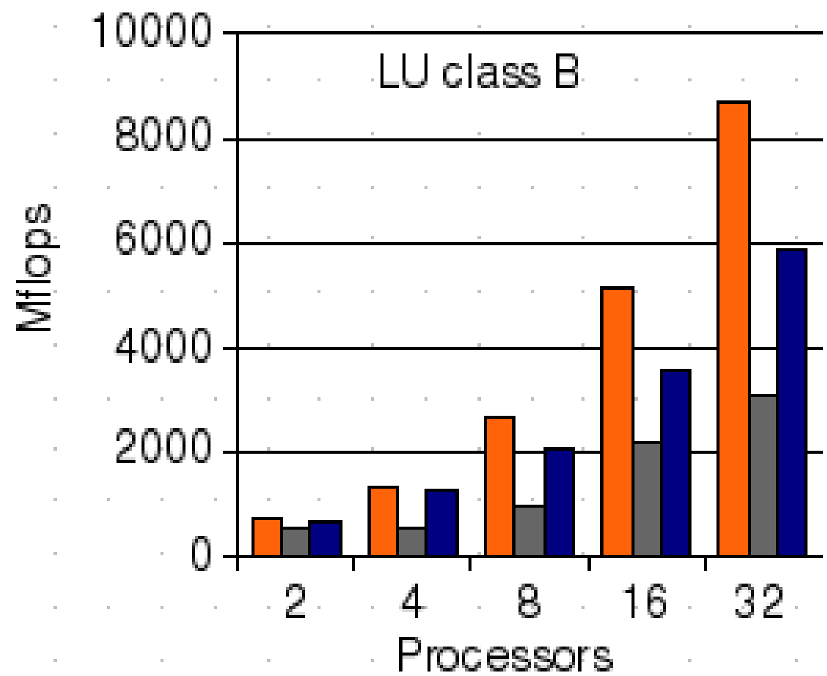
Progress is faster with failures

Power consumption is lower during recovery

Message-Logging (cont.)

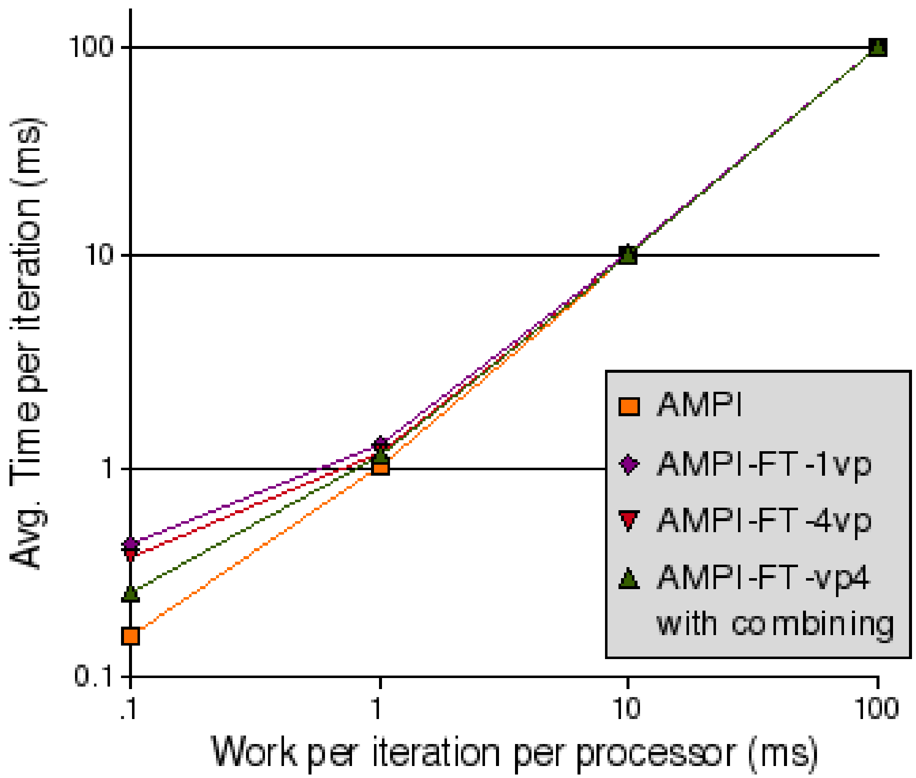
- Fault-free performance:
  - Is ok with large-grain, but significant los with fine-grained
  - Test: NAS benchmarks, MG/LU
  - Versions: AMPI, AMPI+FT, AMPI+FT+multipleVPs

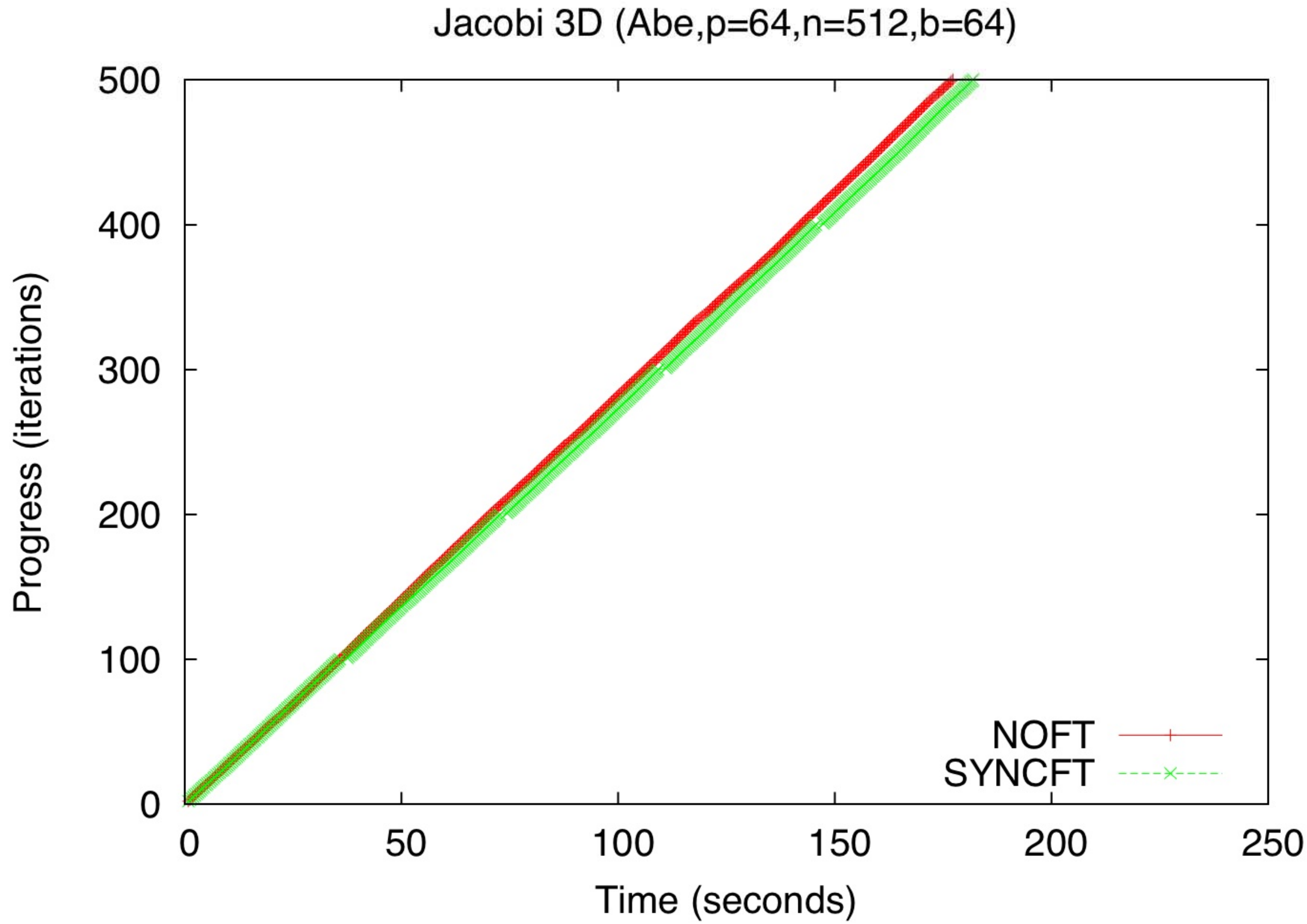




Message-Logging (cont.)

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

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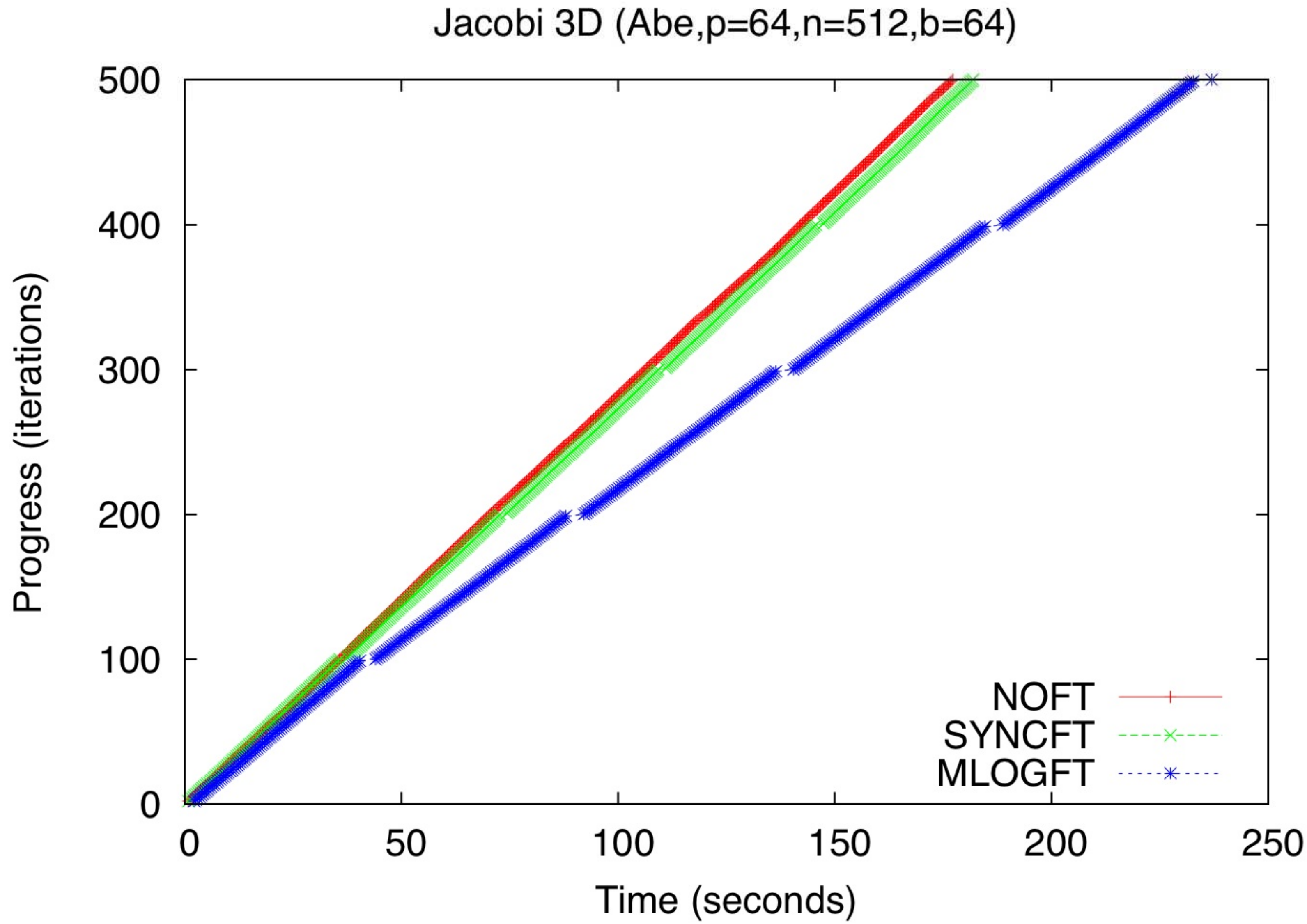

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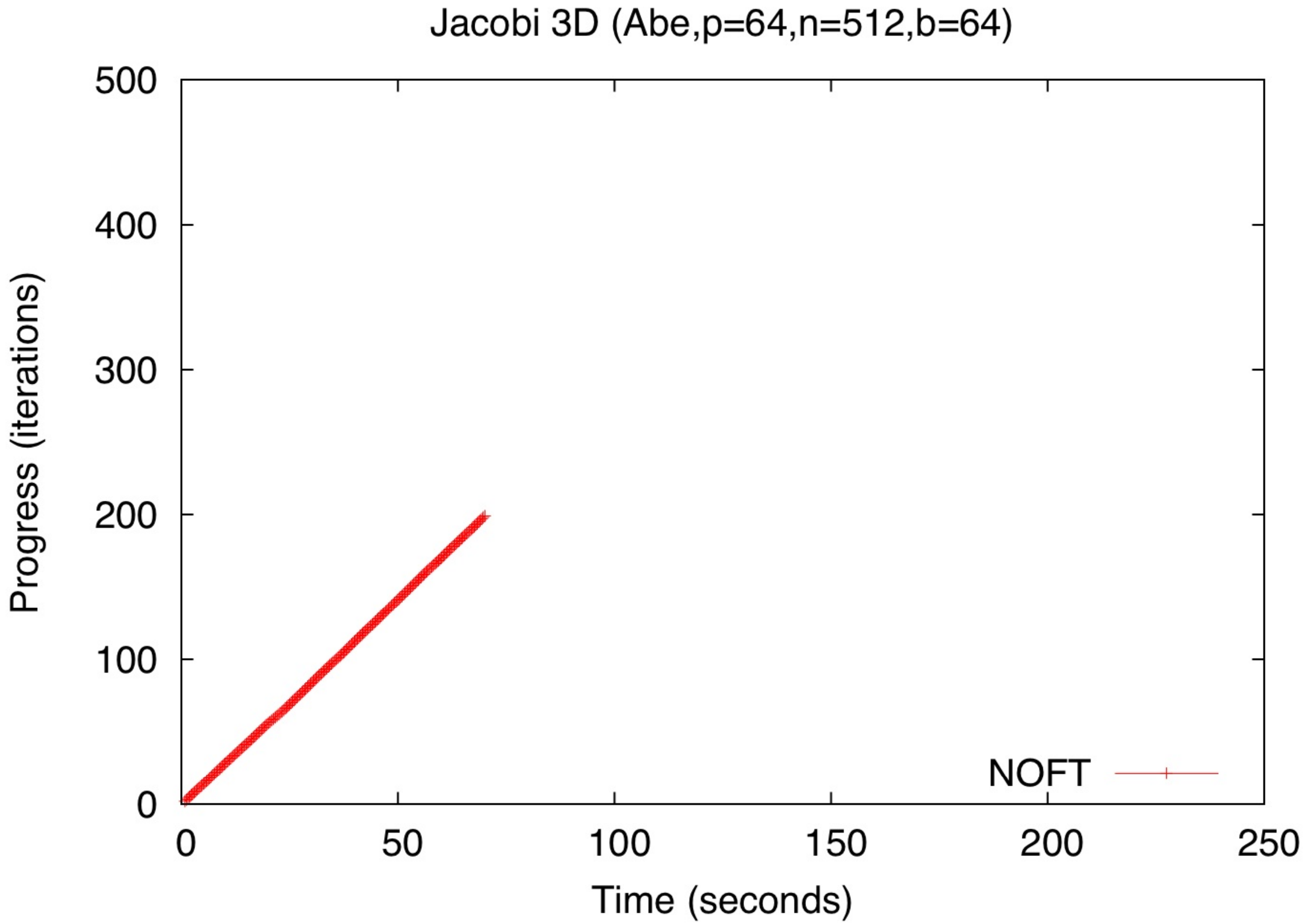
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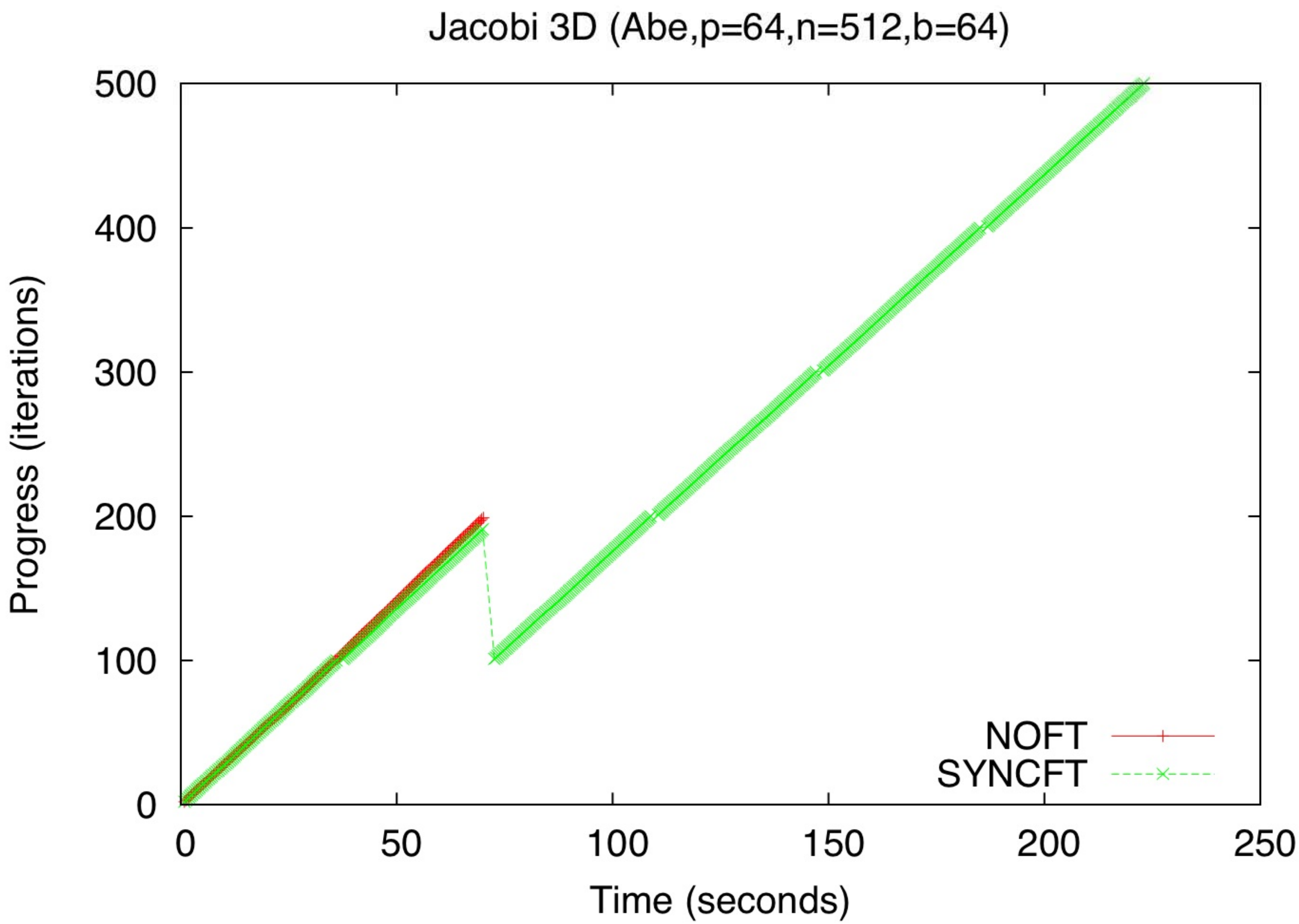
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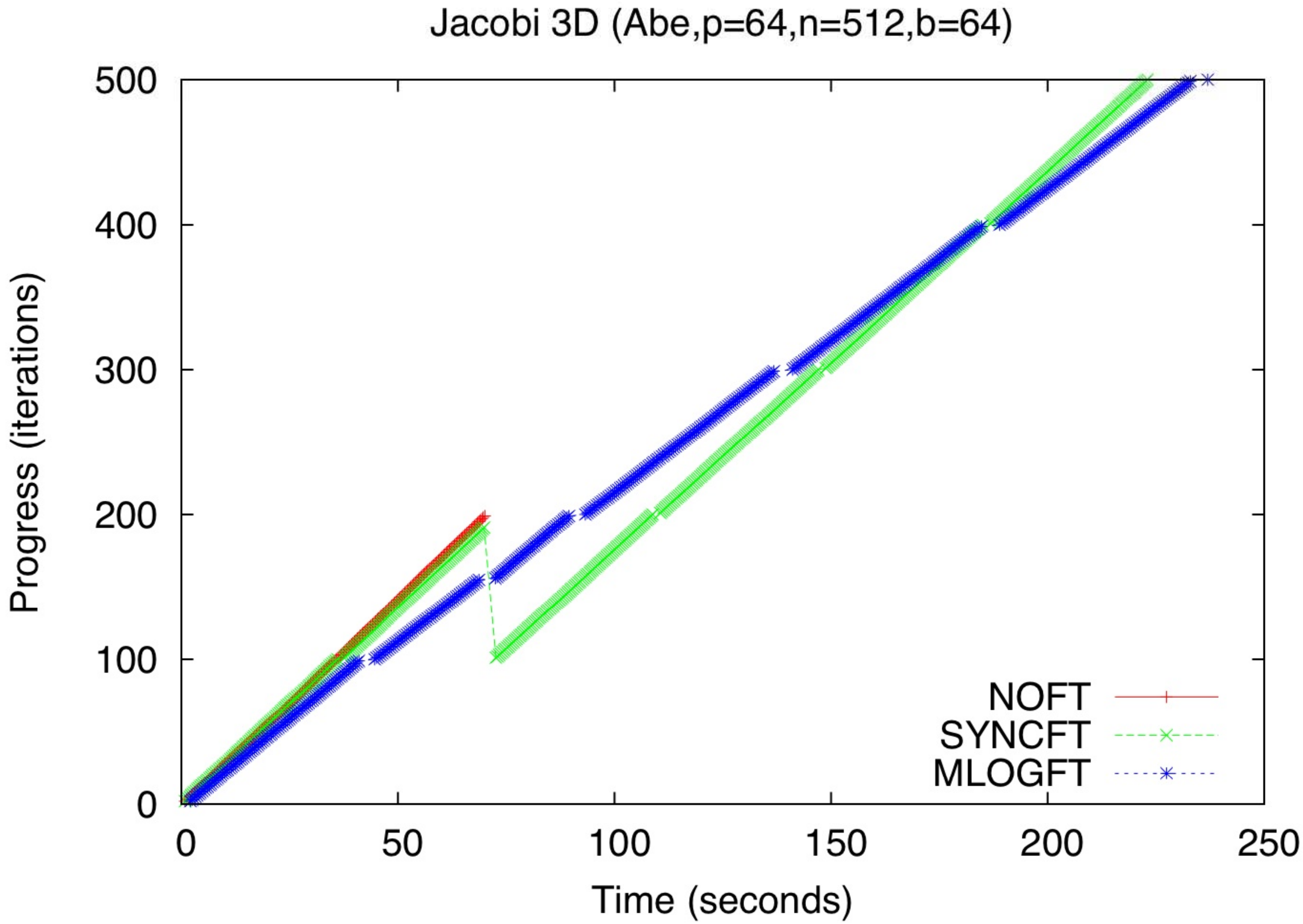
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Message-Logging (cont.)

- Pros:
  - No need to roll back non-failing processors
  - Restart can be accelerated by spreading work to be redone
  - No need of stable storage
- Cons:
  - Protocol overhead is present even in fault-free scenario
  - Increase in latency may be an issue for fine-grained applications
- Publications:
  - Chakravorty: UIUC PhD Thesis, Dec.2007
  - Chakravorty & Kale: IPDPS, April 2007
  - Chakravorty & Kale: FTPDS workshop at IPDPS, April 2004

Current PPL Research Directions

- Message-Logging Scheme
  - Decrease latency overhead in protocol
  - Decrease memory overhead for checkpoints
  - Stronger coupling to load-balancing
  - Newer schemes to reduce message-logging overhead
    - Clustering: a set of cores are sent back to their checkpt
      - Greg Bronevetsky's suggestion
    - Other collaboration with Franck Capello

Some external Gaps

- Scheduler that won't kill a job
  - Broader need: a scheduler that allows flexible bi-directional communication between jobs and scheduler
- Fault prediction
  - Needed if proactive Fault Tolerance is of use
- Local disks!
- Need to better integrate knowledge from distributed systems
  - They have sophisticated techniques, but HPC metrics and context is substantially different

Messages

- 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
- And please pass the word on: we are hiring