Doctoral Defense

Debugging Large Scale Applications with Virtualization

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Committee

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Outline

- Introduction
  - Motivations
- Debugging on Large Machines
  - Unsupervised Execution
- Virtualized Debugging
  - Separation of Entities
- Processor Extraction
- Provisional Message Delivery
- Conclusions

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Motivations

- Debugging is a fundamental part of software development
- Parallel programs have all the sequential bugs:
  - Memory corruption
  - Incorrect results
  - ....

Motivations (2)

- Parallel programs have new types of bugs:
  - Data races / multicore (heavily studied in literature)
  - Communication mistakes
  - Synchronization mistakes / Message races
- To complicate things further:
  - Non-determinism
  - Problems may show up only at large scale

Problems at Large Scale

- Problems may not appear at small scale
  - Races between messages
    - Latencies in the underlying hardware
  - Incorrect messaging
  - Data decomposition
- Important to handle large scale applications

Challenges to Large Scale Debugging

- Infeasible
  - Debugger needs to handle many processors
  - Human can be overwhelmed by information
  - Machine not available
  - Long waiting time in queue
- Expensive
  - Large machine allocations consume a lot of computational resources

Techniques used in this thesis

- Tight RTS integration
- Unsupervised execution
- Virtualized debug
- Processor extraction
- Provisional delivery

Thesis Goals

- New techniques to help debugging large scale parallel programs
  - Tight integration with runtime system
  - Processor virtualization
- Applying these techniques to message driven parallel programs

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Traditional Debugging

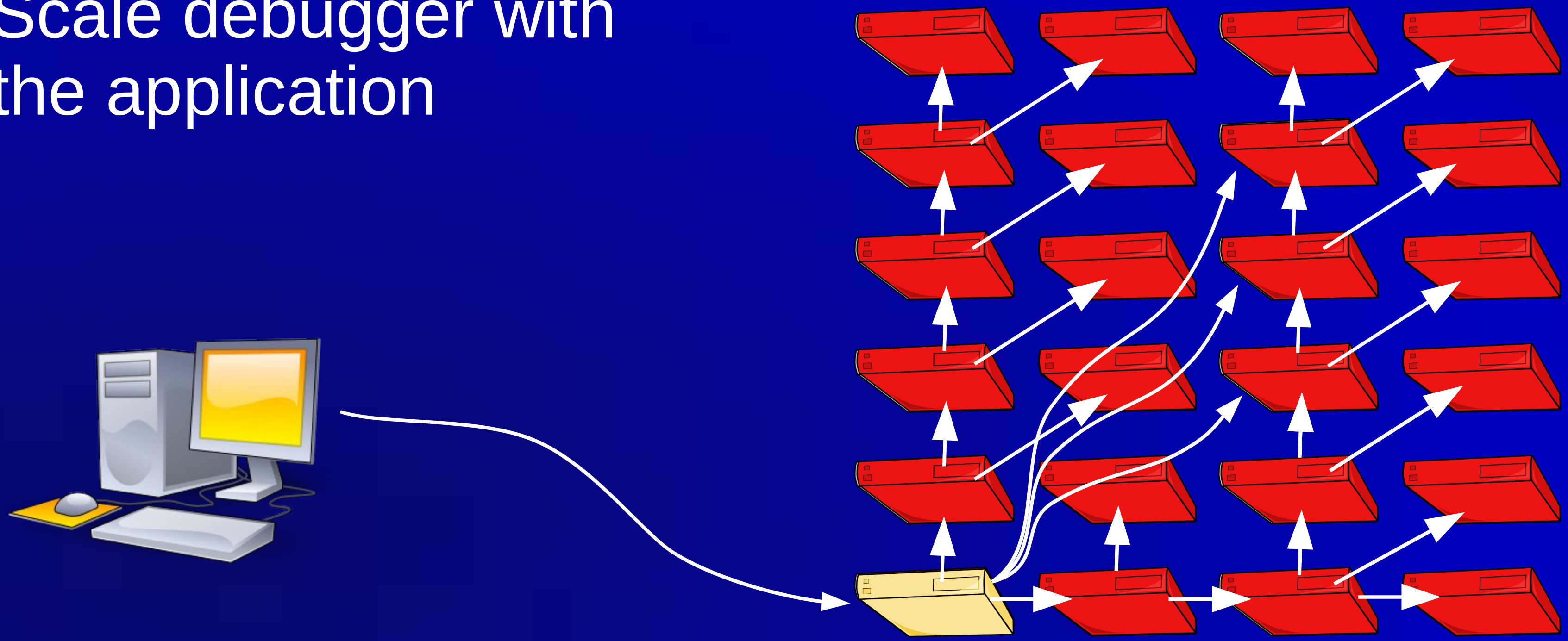
- TotalView, Allinea, Eclipse
  - The user manages all the processors directly
- STAT (Stack Trace Analysis Tool) using MRNET
- ATP (Abnormal Termination Processing)
- Relative debugging (requires working program)

External processes that supervise the application

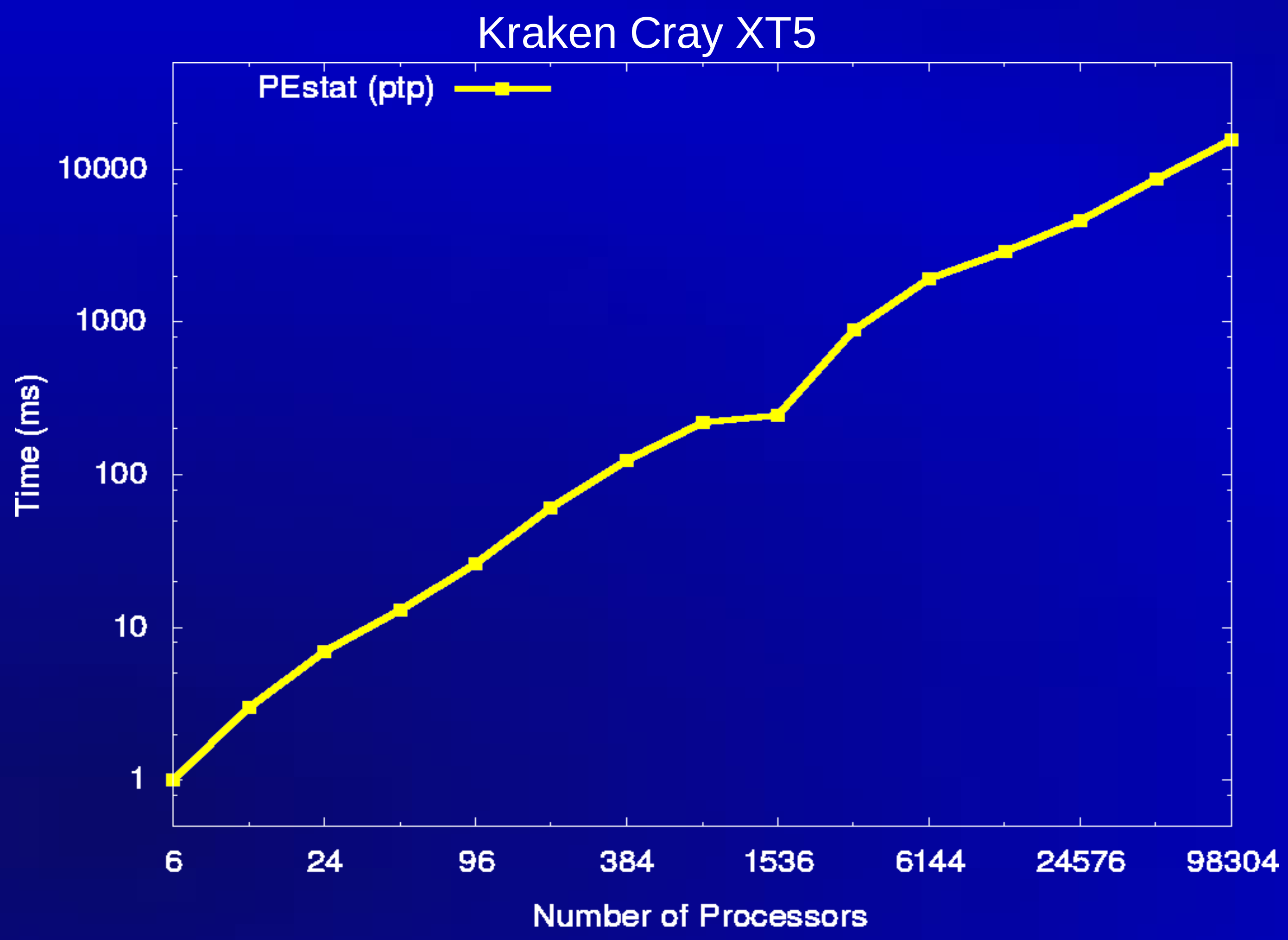
- Information access
- Scalability challenge

Tight Integration with Runtime System

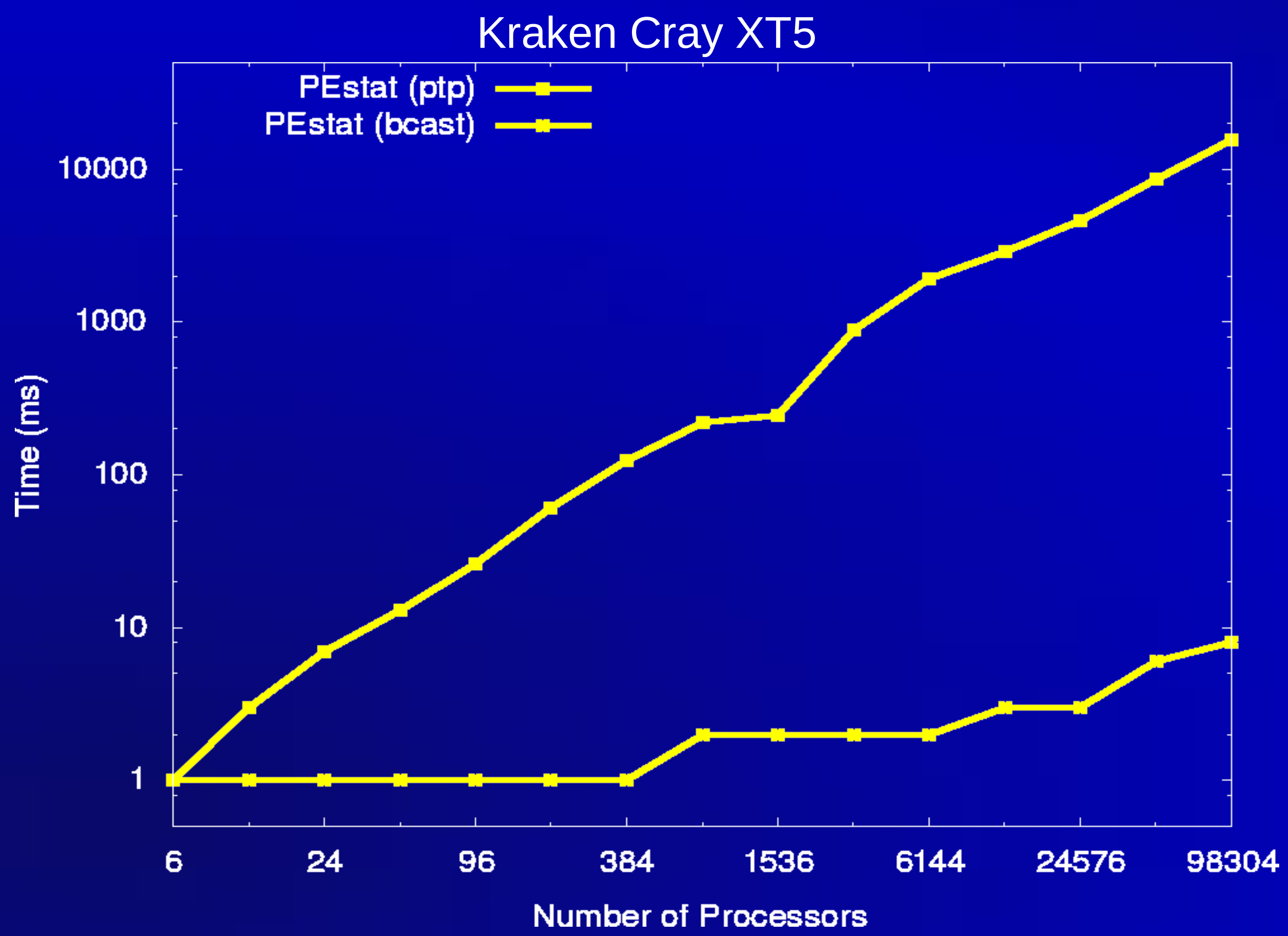
- We use the same communication infrastructure that the application uses to scale
  - Scale debugger with the application



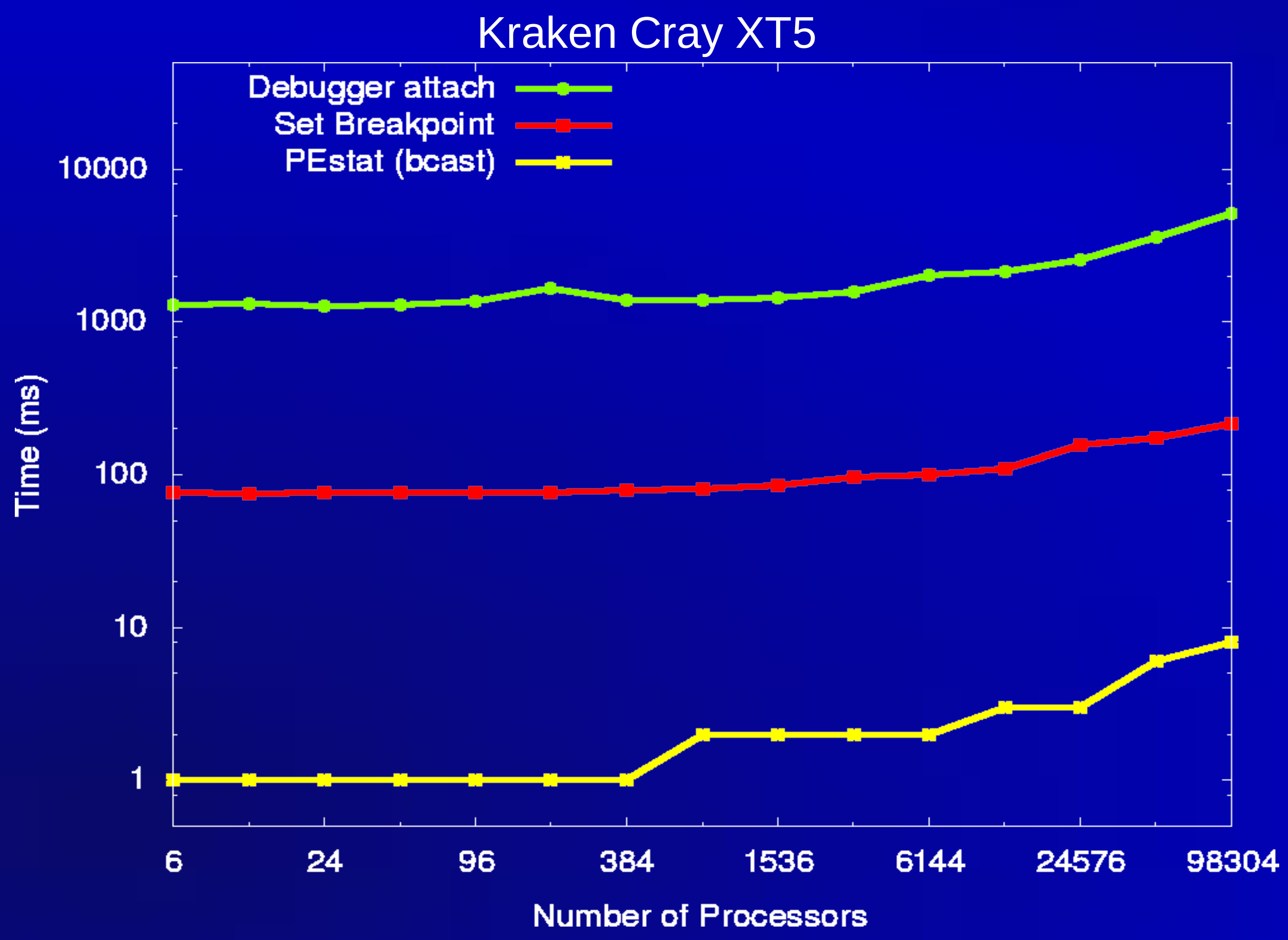
Scalability (1)



Scalability (2)



Scalability (3)



Autoinspection

- The programmer should not manually handle all the processors
  - Unsupervised execution
  - Notification to the user from interesting processors
    - User-defined
      - Breakpoints
      - Assertion failure
    - System-defined
      - Abort / signals
      - Memory corruption
  - *Discussed in the prelim (Thesis Chapter 3)*

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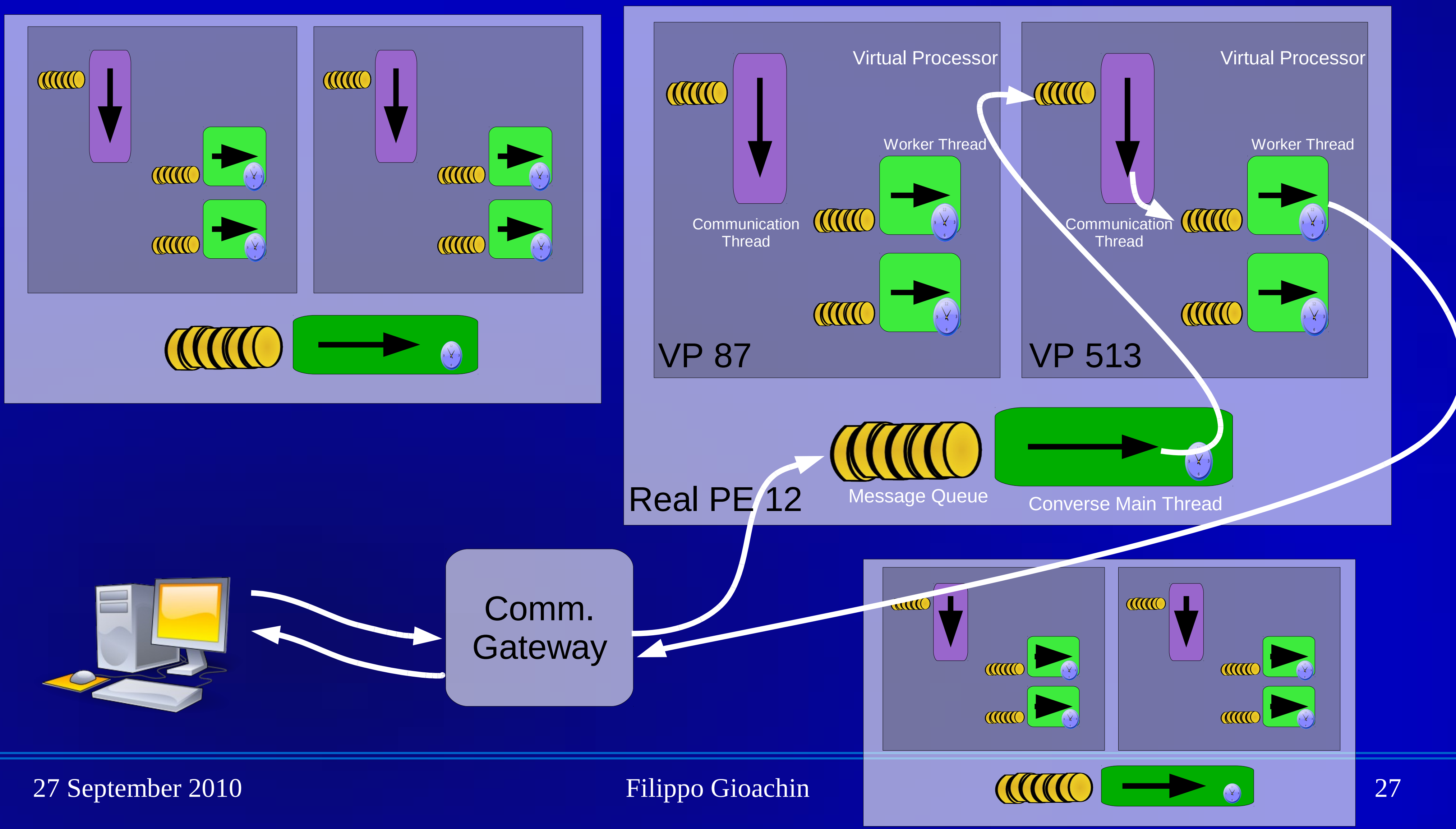
Virtualized Emulation

- Use emulation techniques to provide virtual processors to display to the user
  - Use BigSim emulation tool
    - Cannot assume correctness of program
  - Debugger needs to communicate with application
  - Single address space

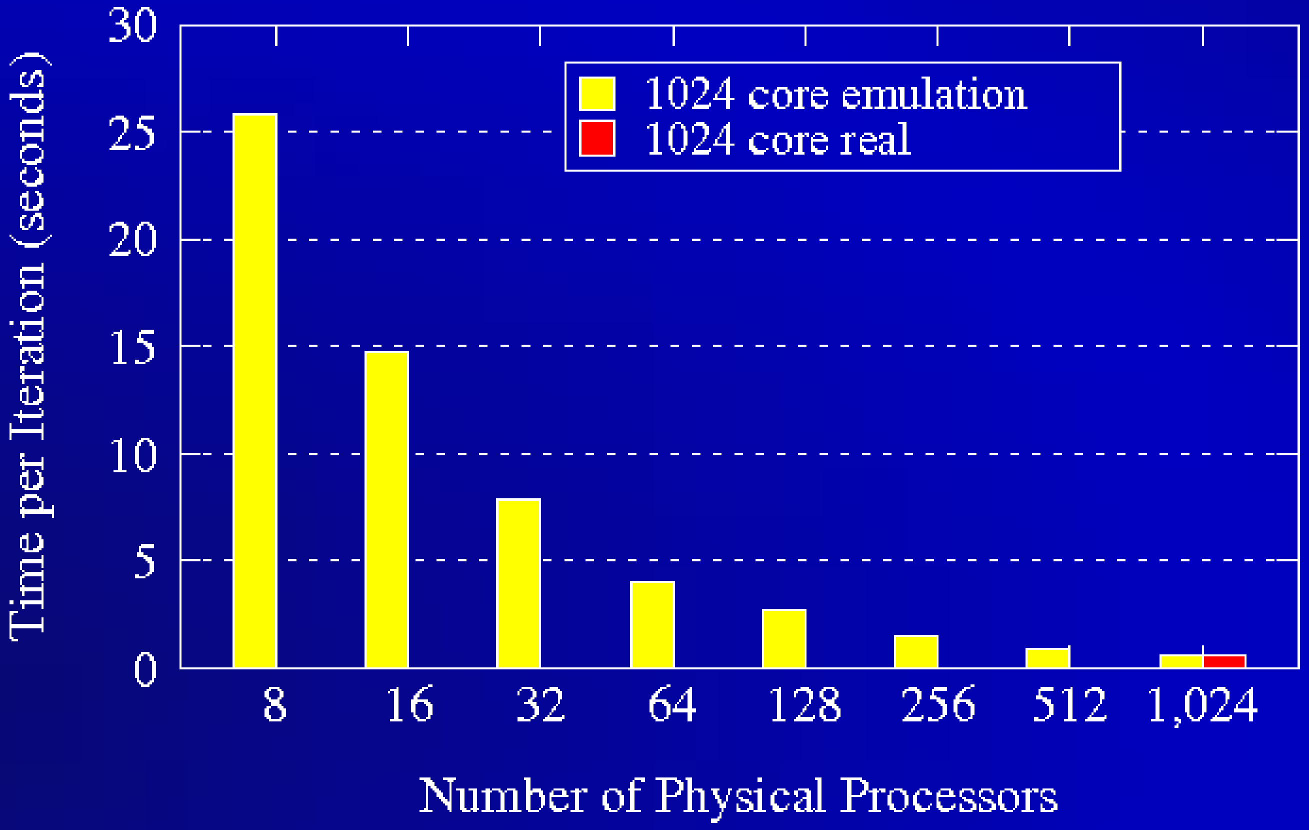
* F. Gioachin, G. Zheng, L.V. Kalé: "Debugging Large Scale Applications in a Virtualized Environment" *to appear in the Proceedings of the 23rd International Workshop on Languages and Compilers for Parallel Computing (LCPC2010)*

Communication under Emulated Environment



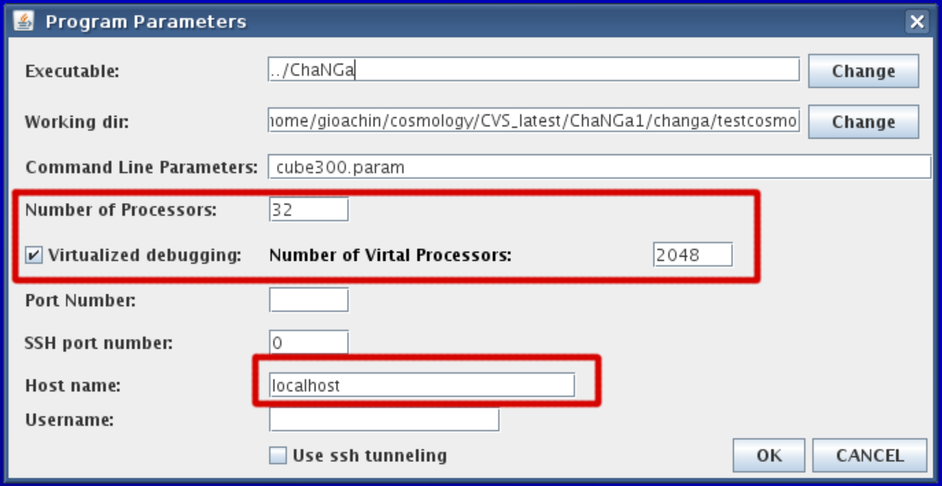
Resource Consumption: Jacobi (on NCSA's BluePrint)

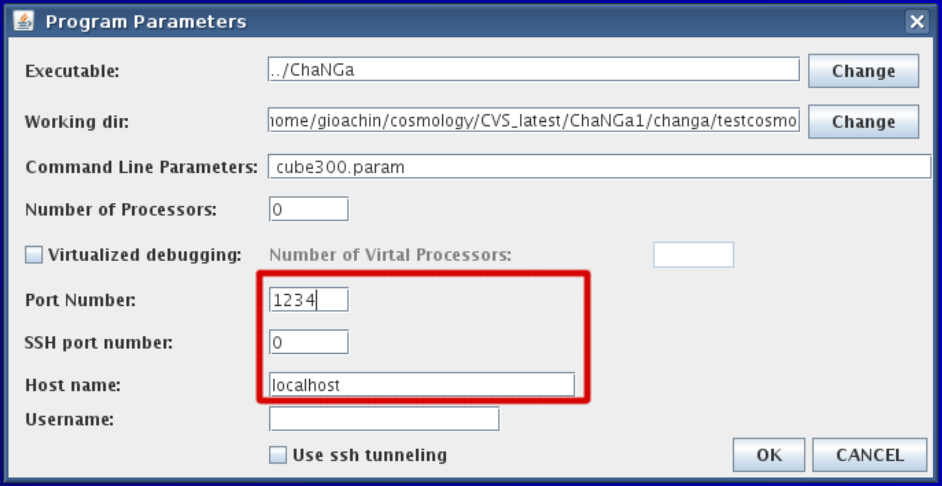
- User thinks for one minute about what to do:
  - 8 processors
    - 86 sec.
    - ~0.2 SU
  - 1024 procs
    - 60.5 sec.
    - ~17 SU



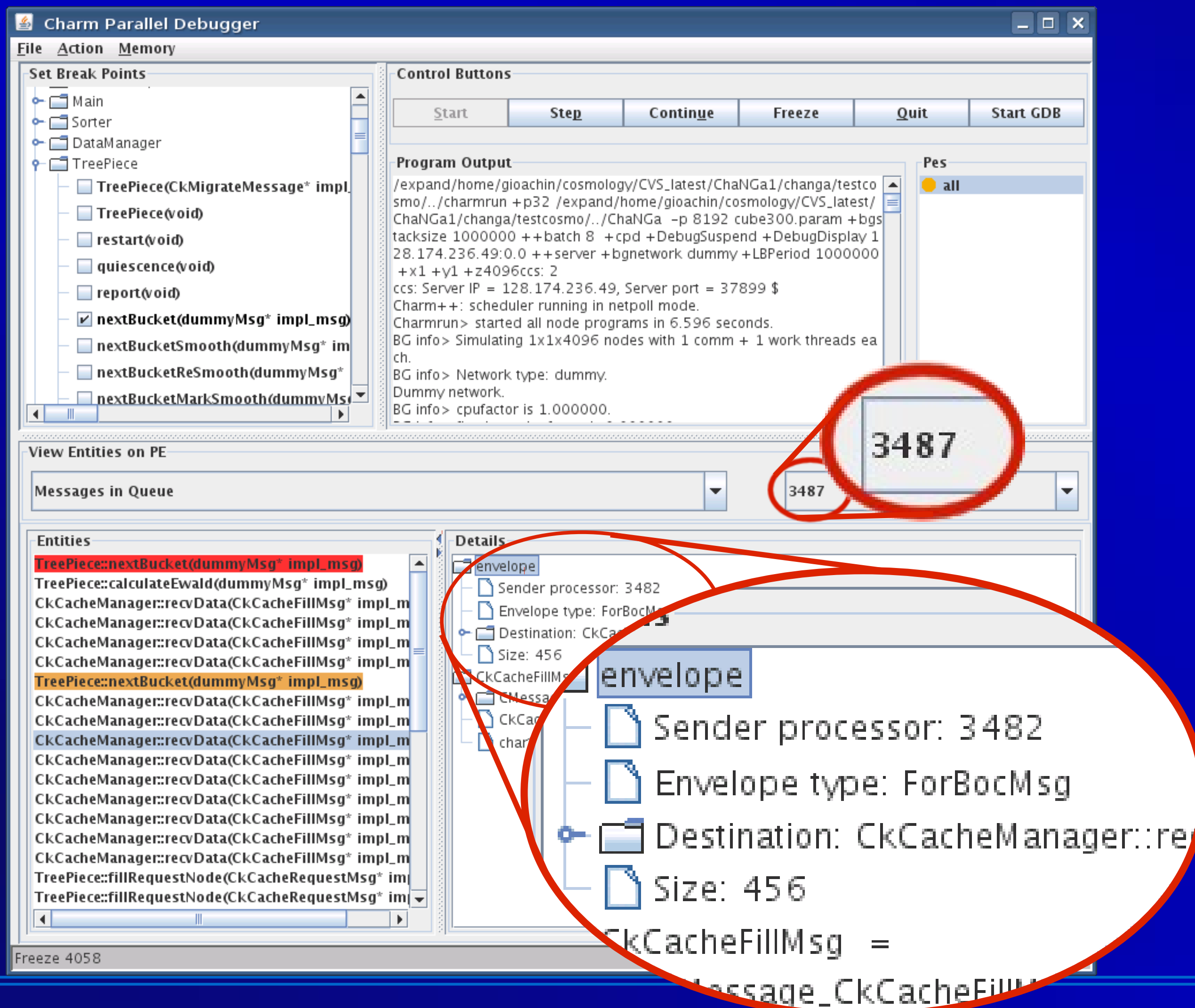
Demo

Usage: Starting





Usage: Debugging

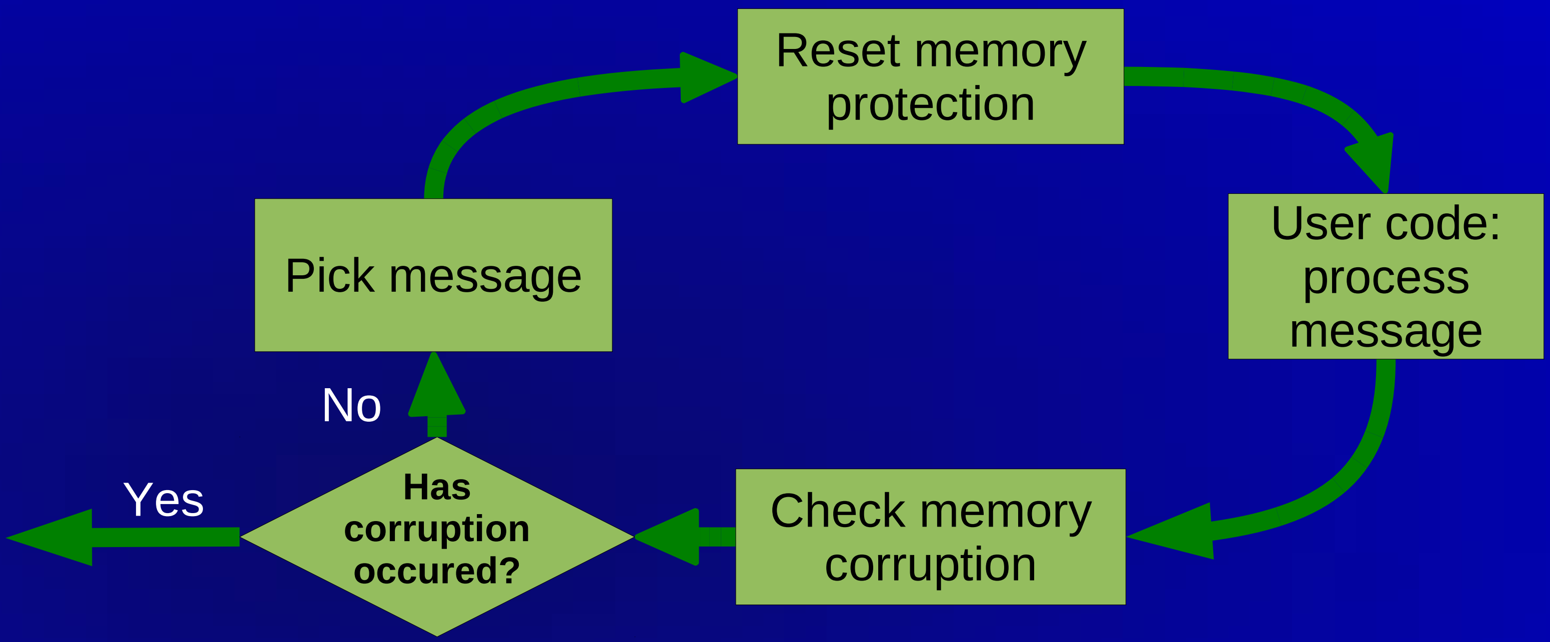


Separation of Virtual Entities

- Single address space shared by different entities
  - Virtual processors for emulation
  - Multiple chares in Charm++
  - Multiple user-level threads
- One entity can overwrite memory of another entity
  - Dangling pointers (memory reallocated)
  - Pointers passed between entities
  - Spurious writes (e.g. buffer overflow)

Memory Corruption Detection

- Protect memory such that spurious writes can be detected
- Exploit the scheduler in message driven systems



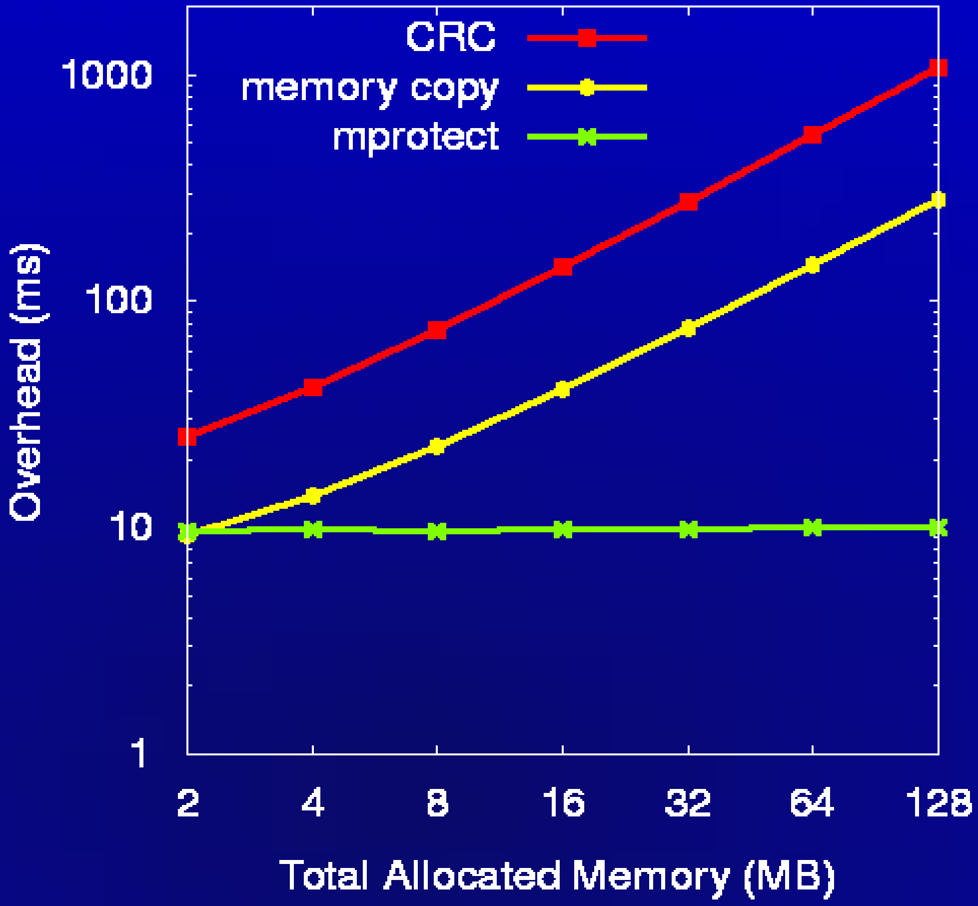
* F. Gioachin, L.V. Kalé: "Memory Tagging in Charm++" *in Proceedings of the 6th Workshop on Parallel and Distributed Systems: Testing, Analysis, and Debugging (PADTAD '08)*

Protection Mechanisms

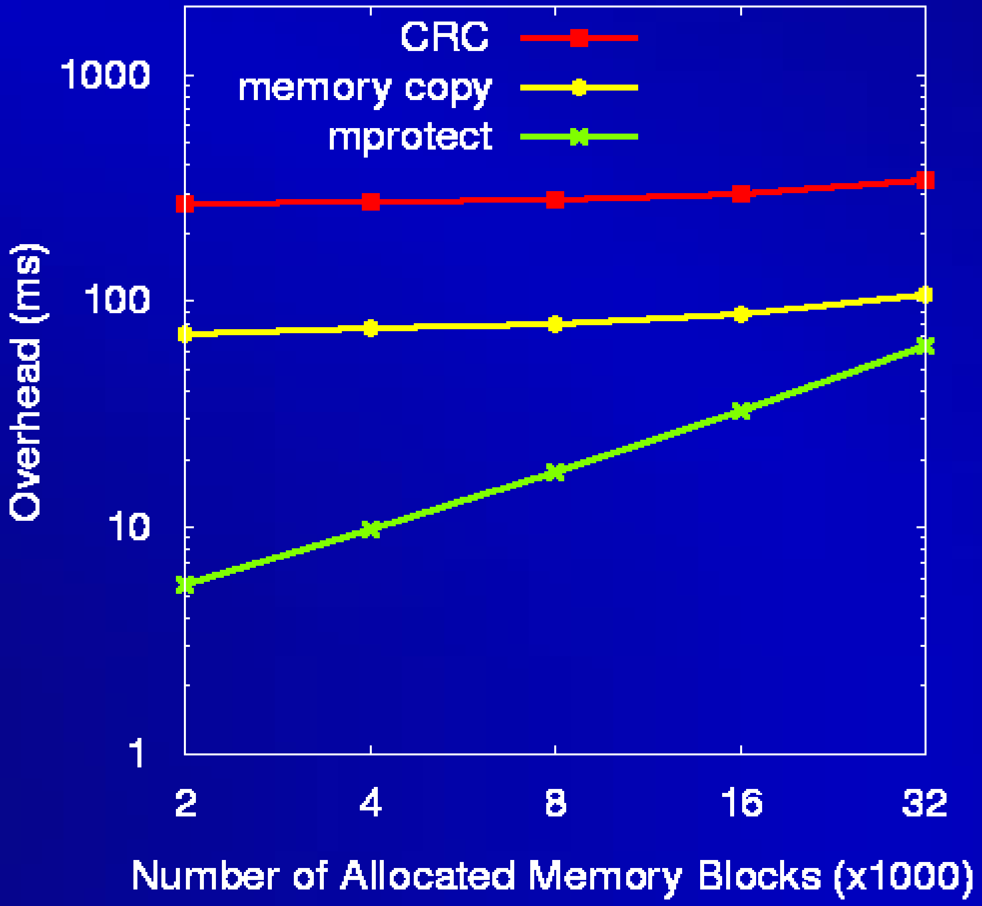
- Checksum: Cyclic Redundancy Check (CRC)
  - Compute CRC-32 for all the memory in the system. Recompute upon entry method return
- Memory copy
  - Copy all the memory in a system in a separate area. Compare upon entry method return
- mprotect
  - Allocate memory with mmap and mark read-only with mprotect. Receive signal upon corruption

Performance Aspect

4,000 allocated blocks



32 MB of allocated memory



Related Work

- Memory protection
  - Studied for concurrent threads (Data Races)
    - Intel Thread Checker
    - RecPlay
      - Not applicable with only one execution thread
  - TotalView
    - User can mimic the protection manually

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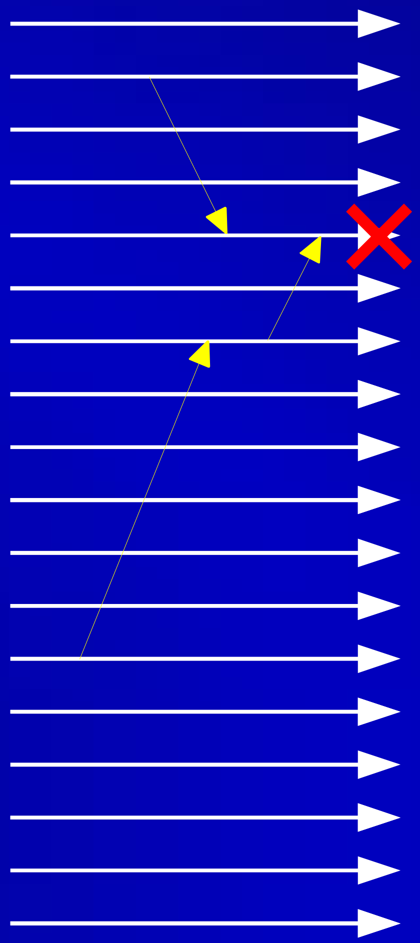
Do we need all the processors?

- The problem manifests itself on a single processor
- The cause can span multiple processors (causally related)
  - The subset is generally much smaller than the whole system
- Select the interesting processors and ignore the others



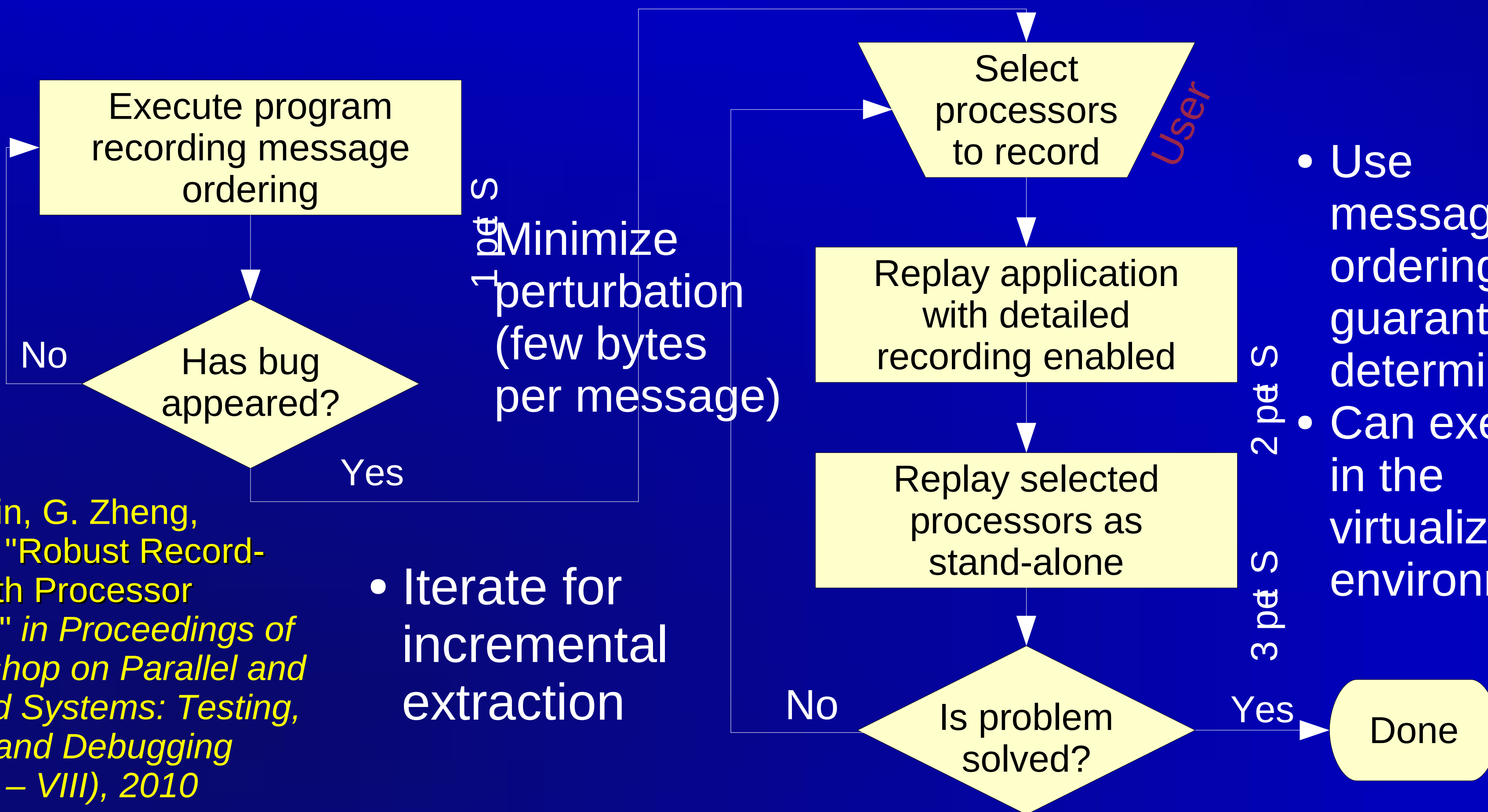
Extracting Processors: Challenges

- Record all data processed by each processor
  - Huge volume of data stored
  - High interference with application (probe effect)
    - The bug may not appear
  - Existing: RecPlay, TotalView
  - Work on reduction in space requirements
    - Online analysis of necessary data
    - Processors grouping
    - Record only some processors?

Fighting non-determinism

- Record all data processed by each processor
  - Huge volume of data stored
  - High interference with application (probe effect)
    - The bug may not appear
- Record only message ordering
  - Must re-execute using the whole machine
  - Based on piecewise deterministic assumption

Three-step Procedure for Processor Extraction



- Minimize perturbation (few bytes per message)

- Use message ordering to guarantee determinism
- Can execute in the virtualized environment

- Iterate for incremental extraction

* F. Gioachin, G. Zheng, L.V. Kalé: "Robust Record-Replay with Processor Extraction" *in Proceedings of the Workshop on Parallel and Distributed Systems: Testing, Analysis, and Debugging (PADTAD – VIII), 2010*

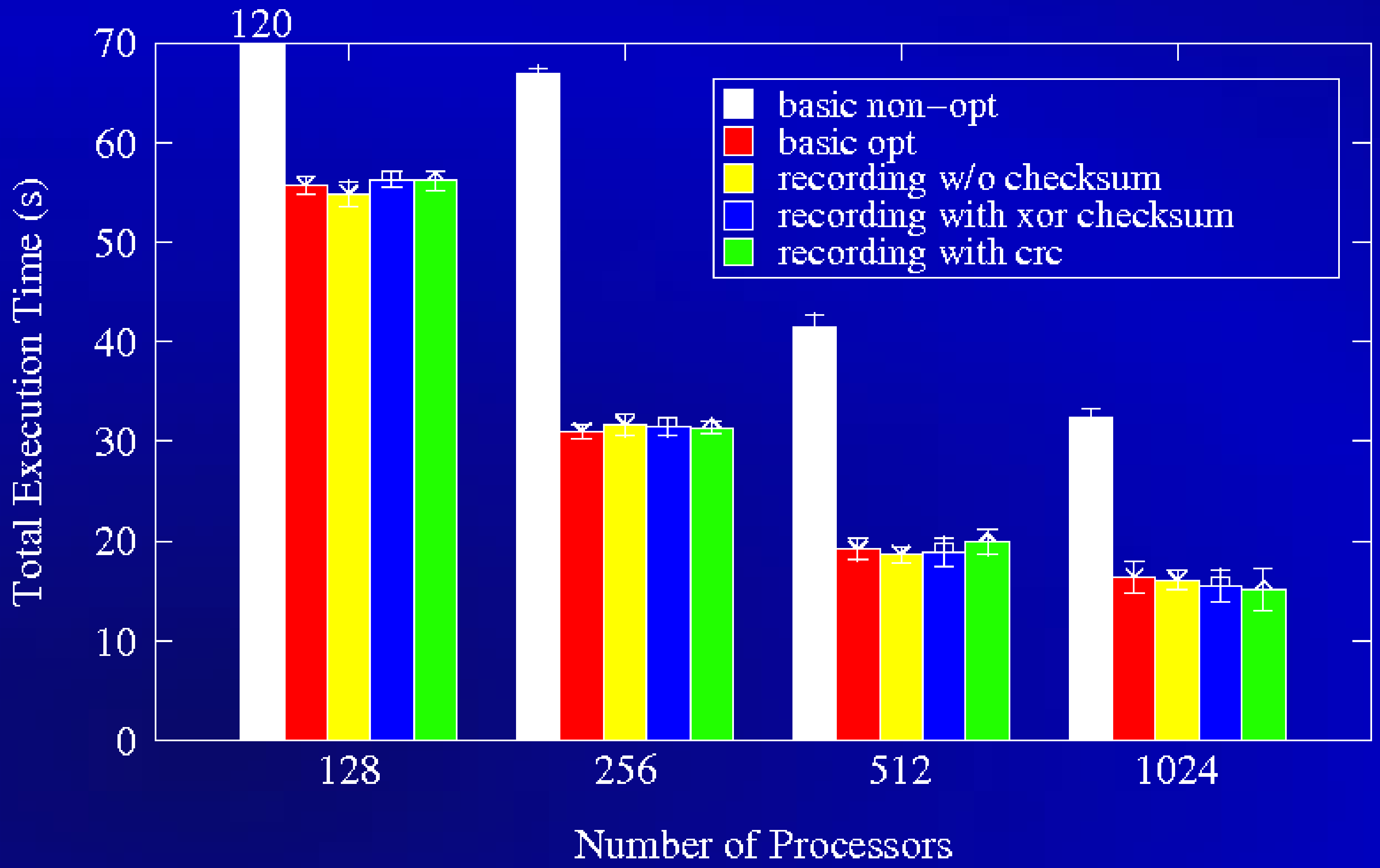
What if the piecewise deterministic assumption is not met?

- Make sure to detect it, and notify the user

If all messages during replay are identical to those during record, we can assume the application is deterministic

- Methods to detect failure:
  - Message size and destination
  - Checksum of the whole message (XOR, CRC32)

ChaNGa
(dwf1.2048 on NCSA's BluePrint)



Debugging Case Study

- Message race during particle exchange
  - Was fixed with tedious print statements
    - Printf often made the bug disappear

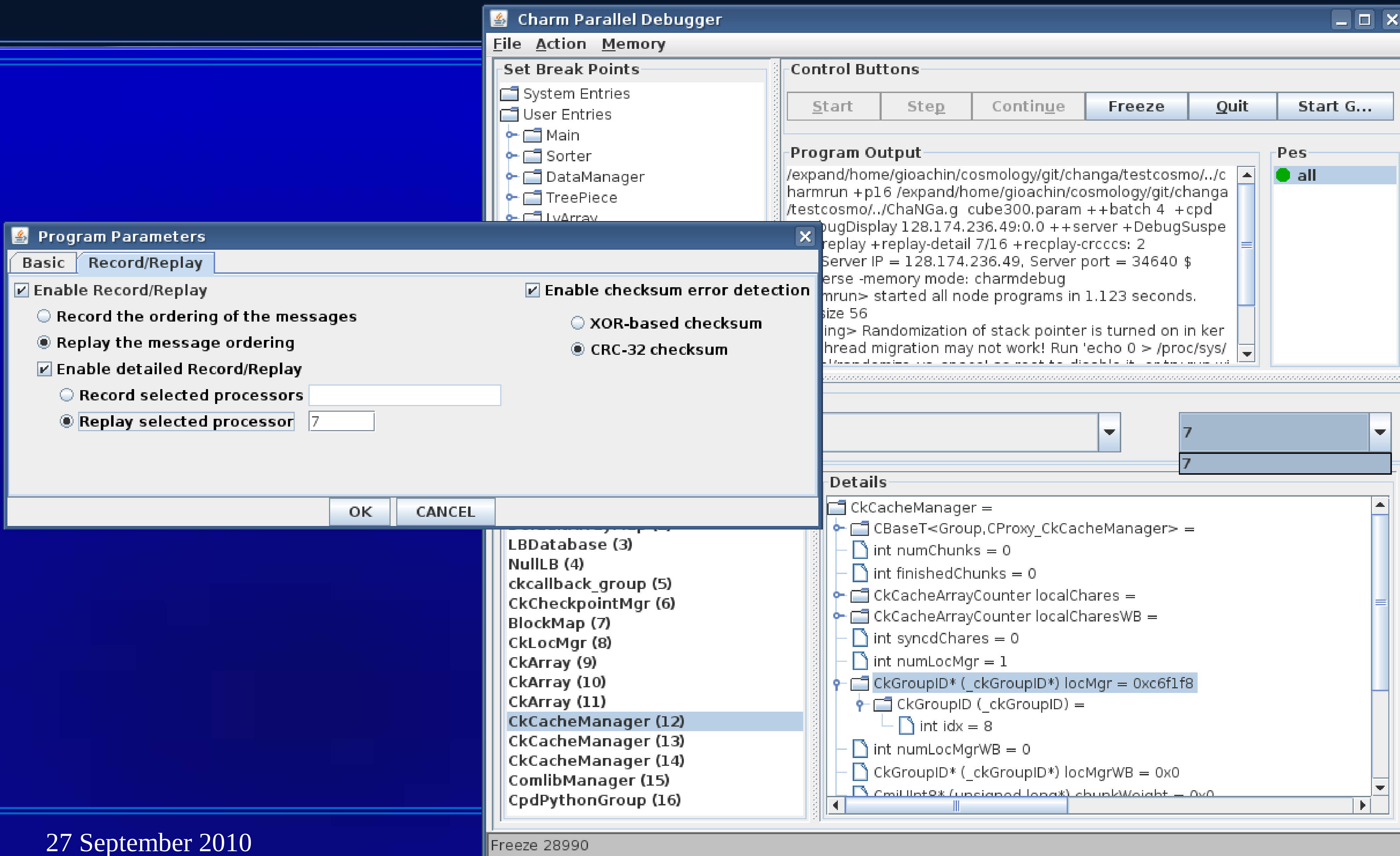
```
../charmrun +p16 ../ChaNGa cube300.param +record
        +recplay-crc

../charmrun +p16 ../ChaNGa cube300.param +replay
        +recplay-crc +record-detail 7

gdb ../ChaNGa
>> run cube300.param +replay-detail 7/16
```

Demo

Record-replay with CharmDebug



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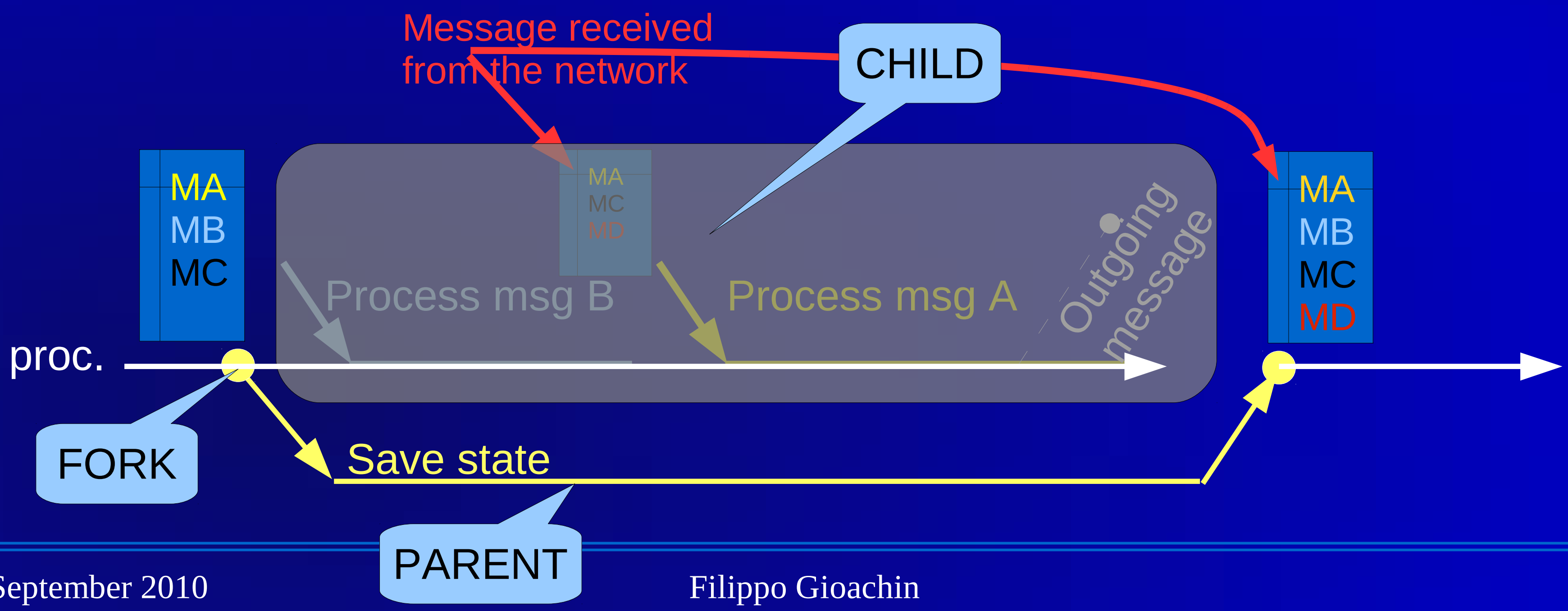
Provisional Message Delivery

- Instead of replaying the same message ordering, replay a different one
  - Can force the bug to appear on a smaller scale
  - Automatic or manual
- Manual: programmers may have an idea where the problem lies
  - A specific message may confirm or refute the idea
  - Need a way to test without restarting the application
    - Important for bugs that appear after long time

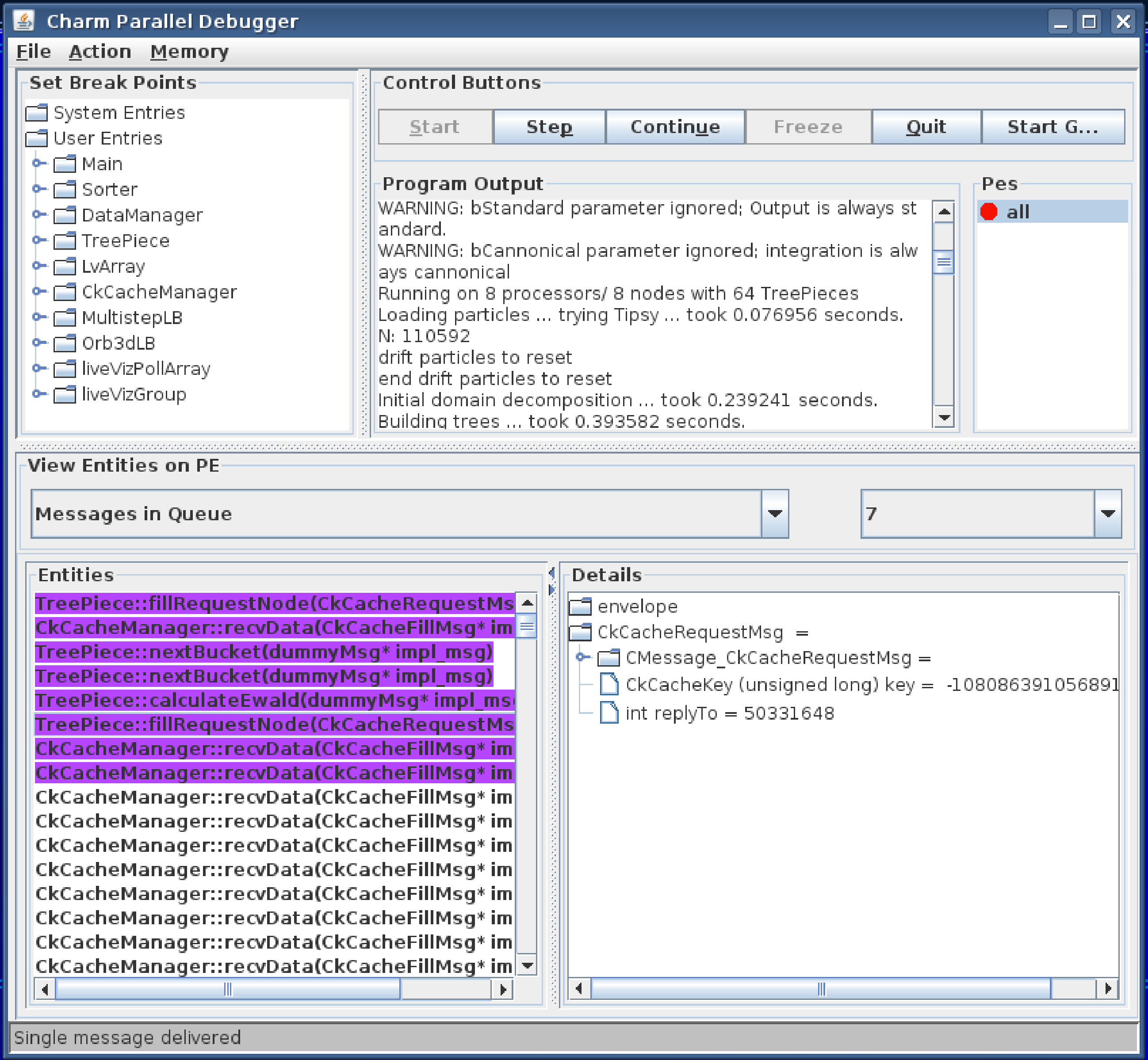
Testing Execution Paths

- Save state of the running application
  - Deliver the message
  - Rollback to try another path (live)



Demo

Provisional Delivery: Example



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Thesis Contributions

- Techniques to handle thousands of processors efficiently
  - Unsupervised execution with notification upon event
- Reducing the resources required for debugging of large scale applications
  - Virtualized debugging
  - Processor extraction
  - Provisional message delivery
- Techniques to debug message driven parallel applications

Future Extensions

- Shared memory compliance
- Race detector
  - Automated testing of message delivery to discover message races
- Replay in isolation of single virtual entities
  - Conditions of validity

Peer Reviewed Papers

- F. Gioachin, G. Zheng, L.V. Kale: ”Robust Non-Intrusive Record-Replay with Processor Extraction”; in Proceedings of the 8th Workshop on Parallel and Distributed Systems: Testing, Analysis, and Debugging (PADTAD 2010)
- F. Gioachin, G. Zheng, L.V. Kale: ”Debugging Large Scale Applications in a Virtualized Environment”; to appear in Proceedings of the 23rd International Workshop on Languages and Compilers for Parallel Computing (LCPC2010)
- F. Gioachin, C.W. Lee, L.V. Kale: ”Scalable Interaction with Parallel Applications”; in Proceedings of TeraGrid'09
- F. Gioachin, L.V. Kale: ”Dynamic High-Level Scripting in Parallel Applications”; in Proceedings of the 23rd IEEE International Parallel and Distributed Processing Symposium (IPDPS 2009)
- F. Gioachin, L.V. Kale: ”Memory Tagging in Charm++”; in Proceedings of the 6th Workshop on Parallel and Distributed Systems: Testing, Analysis, and Debugging (PADTAD '08)
- C. Mei, G. Zheng, F. Gioachin, L.V. Kale: ”Optimizing a Parallel Runtime System for Multicore Clusters: A Case Study”; in Proceedings of Teragrid'10
- P. Jetley, L. Wesolowski, F. Gioachin, L.V. Kale, T.R. Quinn: ”Scaling Hierarchical N-Body Simulations on GPU Clusters”; to appear in Proceedings of the ACM/IEEE Supercomputing Conference 2010 (SC10)
- P. Jetley, F. Gioachin, C. Mendes, L.V. Kale, T.R. Quinn: ”Massively Parallel Cosmological Simulations with ChaNGa”; in Proceedings of IEEE International Parallel and Distributed Processing Symposium 2008
- F. Gioachin, A. Sharma, S. Chakravorty, C. Mendes, L.V. Kale, T.R. Quinn: ”Scalable Cosmological Simulations on Parallel Machines”; in Proceedings of the 7th International Meeting on High Performance Computing for Computational Science (VECPAR 2006). LNCS 4395, pp 476-489, 2007
- F. Gioachin, R. Shankesi, M.J. May, C.A. Gunter, W. Shin: ”Emergency Alerts as RSS Feeds with Interdomain Authorization”; in IARIA International Conference on Internet Monitoring and Protection (ICIMP '07), 2007