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Time Warp Simulation on Multi-core Processors and Clusters

Douglas A. Weber
Masters Thesis Defense
Advisor: Professor Philip A. Wilsey

University of Cincinnati

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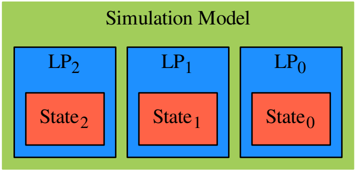
Discrete Event Simulation

- Three main components
  - State variables
  - Simulation clock
  - Pending event set

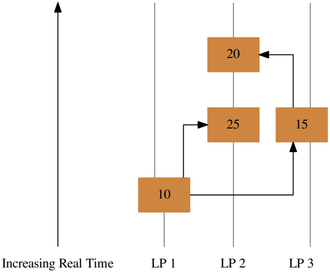
- Unprocessed events stored in pending event set
- Events processed in time stamp order
- Simulation clock and state variables updated only when event occurs

Parallel Discrete Event Simulation

- Model system as a set of Logical Processes (LPs)
- Events exchanged between LPs

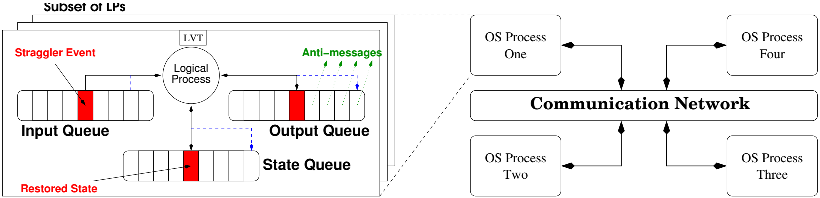


Possible Causality Violations



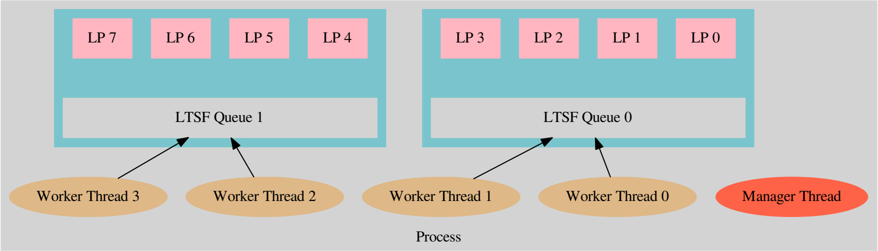
- Events can be received *and* processed out of order
- Two solutions
  - Conservative
  - Optimistic

Optimistic Mechanism



- Rollback Mechanism
  - State Restoration, Anti-Messages
- Local Virtual Time (LVT) & Global Virtual Time (GVT)
- Fossil Collection

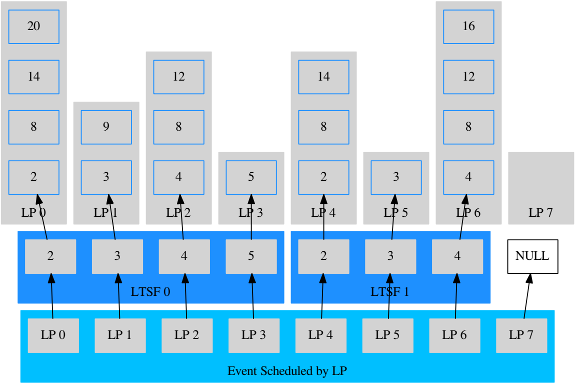
WARPED2 Process



- Worker Threads and Manager Thread
- LTSF Queues/Worker Thread: Contention vs Rollbacks
- LP Partitioning

Worker Threads

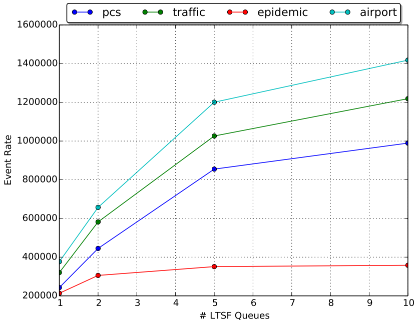
while *termination not detected* **do**
- *e* ← `getNextEvent()`
- *lp* ← receiver of *e*
- **if** *e* < *last processed event for lp* **then**
  - rollback *lp*
- **if** *e is an anti-message* **then**
  - cancel event with *e*
  - schedule new event for *lp*
  - **continue**
- process event *e*
- save state of *lp*
- send new events
- move *e* to processed queue
- replace scheduled event for *lp*

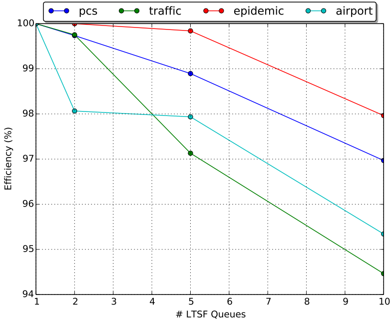


- Unprocessed and Processed Queues
- Scheduling to LTSF
- Rollbacks

Sharing LTSF Queues

Intel® Xeon® X5675 (6 cores/10 worker threads)





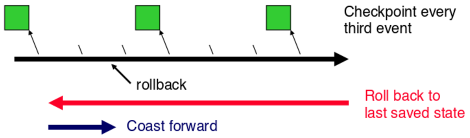
$$EventRate = \frac{CommitedEvents}{Runtime}$$

$$Efficiency = \frac{CommittedEvents}{ProcessedEvents} * 100\%$$

Reducing contention more important than reducing rollbacks

Periodic State Saving: Overview

Save state only once every *N* events



- Not all states available to roll back to
- Must "Coast Forward" to reproduce state
- Increases time to rollback
- Decrease time to save states and reduce memory footprint

Periodic State Saving: SMP Machine

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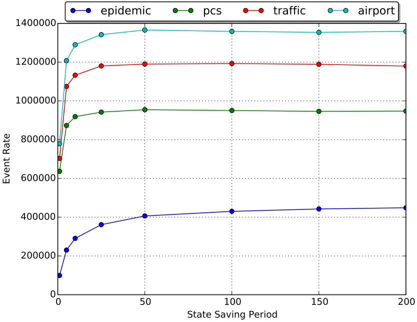
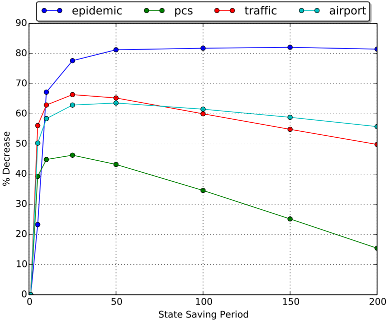
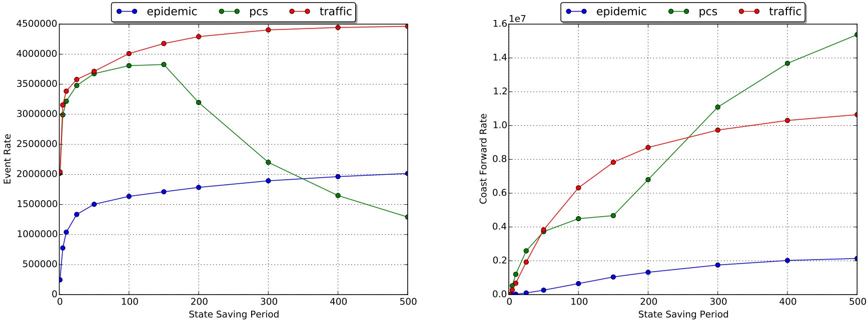
Intel® Xeon® X5675 (6 cores/10 worker threads)





Periodic State Saving: Cluster

Intel® Xeon® E5410 (8 nodes)

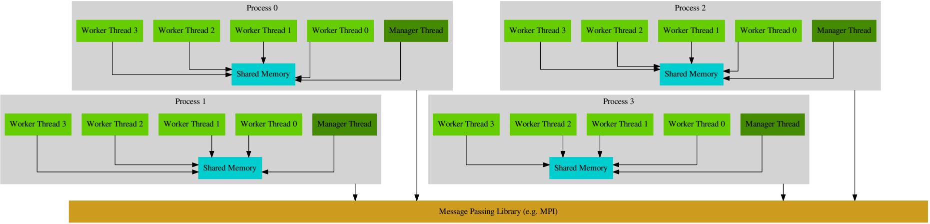


$$CoastForwardRate = \frac{CoastForwardEvents}{Rollbacks} * RollbackRate$$

Communication Model

Shared Memory vs Message Passing

- Sending Events, GVT, Termination

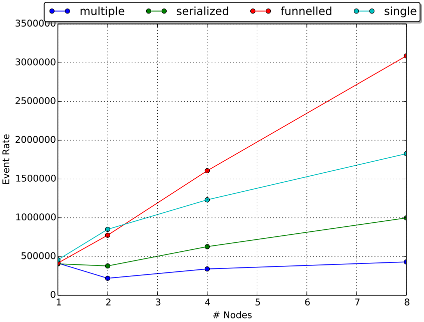


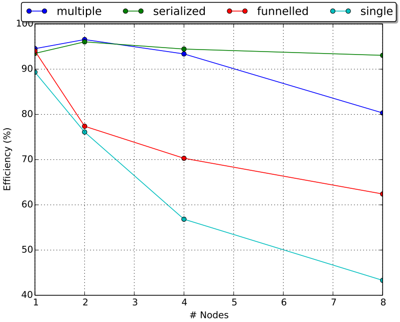
Thread Message Passing Models

- Single threaded
- Funnelled
- Serialized
- Multiple

Intel® Xeon® E5410 (8 nodes)

- Single: 1 thread (combining worker/manager threads)
- Others: 7 worker threads and manager thread





- Funneled/Single: Minimal Synchronization, High Latency
- Serialized/Multiple: Lots of Synchronization , Low Latency
- Performance will vary with model and partitioning.

Message Aggregation

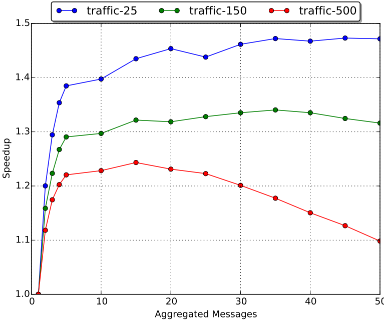
- Wait for N messages with same **destination process** and send together

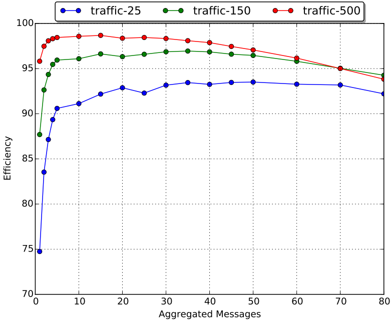
Num Msgs 4 bytes	Length 0 (L[0]) 4 bytes	Length 1 (L[1]) 4 bytes	Length 2 (L[2]) 4 bytes	...	Message 0 L[0]	Message 1 L[1]	Message 2 L[2]	...

- Pros
  - Single buffer allocated for multiple messages
  - Latency shared by multiple messages (TCP/IP/Ethernet/...)
  - Events destined for same LP may be sent together

- Cons
  - May increase event latency and increase receiver rollbacks

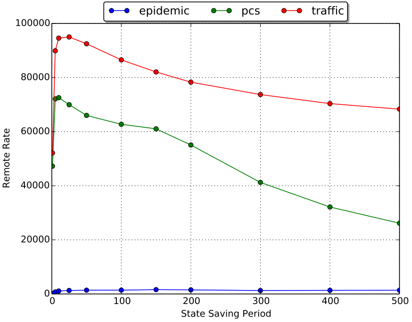
Message Aggregation: Traffic Model

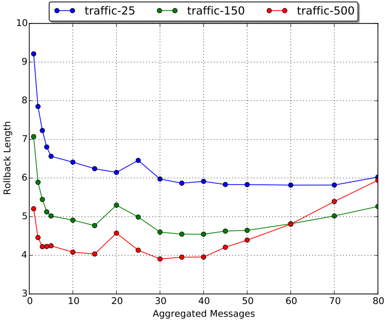




- Best with small number of aggregated events
- Different behavior with different state saving periods

Message Aggregation: More Observations



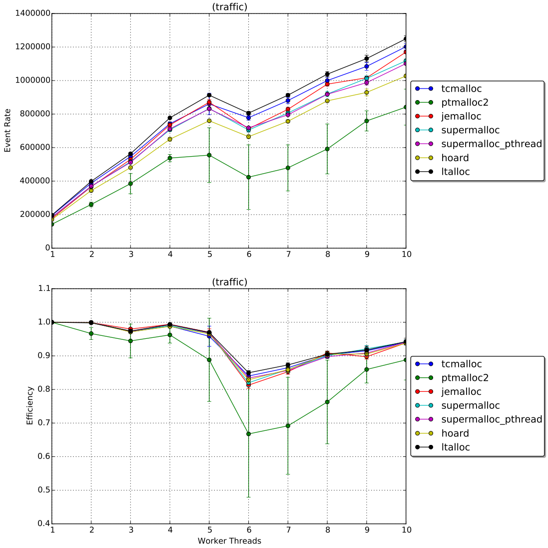


- Faster rate of remote events better
- Can lower rollback length?

$$AverageRollbackLength = RolledBackEvents / Rollbacks$$

Memory Allocation: Traffic Model

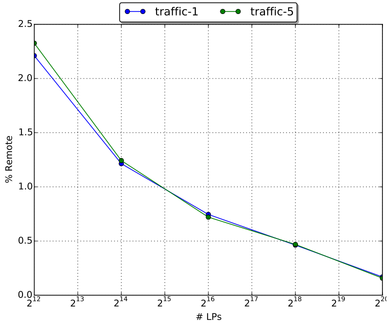
Intel® Xeon® X5675 (6 cores/up to 12 threads)

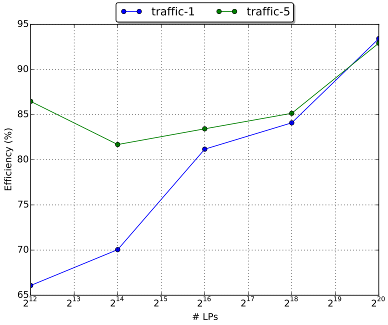


- Imbalance at 6 worker threads
- ptmalloc2 (the default in GLIBC) is inefficient and unpredictable

Scaling Simulation Models: Advantages

Intel® Xeon® E5410 (8 nodes/7 worker threads)

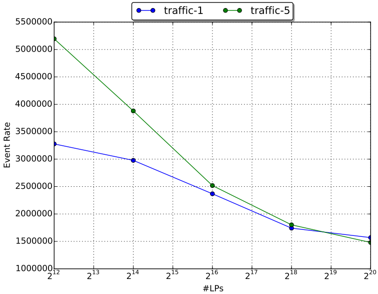


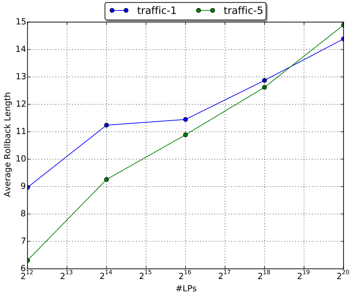


- Coarser Granularity
- Higher Efficiency

Scaling Simulation Models: Disadvantages

Intel® Xeon® E5410 (8 nodes/7 worker threads)





- More LPs to fossil collect
- Longer Rollbacks

Conclusions & Future Research

- Conclusions
  - Synchronization should always be avoided
    - Interprocess communication: Higher latency over synchronization
    - 1 LTSF queue per worker thread
  - Avoid communication ... If possible
    - If it cannot be avoided, aggregating messages may help
    - Hard to calculate GVT efficiently
    - Memory consumption: May need flow control
  - Alternative multi-threaded memory allocators better than GLIBC default
- Future Research
  - Optimistic Fossil Collection
  - Scaling up