Pending Event Set Management in Parallel Discrete Event Simulation

Sounak Gupta
Ph.D. Candidate
Computer Science and Engineering

Committee Chair : Philip A. Wilsey, Ph.D.

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Related Publications (in prep)

- **S. Gupta**, and P. A. Wilsey, "Time Warp Parallel Simulation and the Pending Event Set," *ACM Transactions on Modeling and Computer Simulation* (TOMACS), (in prep).

- **S. Gupta**, J. B. Yang, and P. A. Wilsey, "A Synthetic Simulation Model for Studies of Scalability in Parallel Simulation," *Simulation Modelling Practice and Theory* (SIMPAT), (in prep).

- D. Weber, **S. Gupta**, P. A. Wilsey, N. Abu-Ghazaleh, and D. Ponomarev, "Time Warp Simulation on Multi-core Processors and Clusters," *SCS Transactions on Simulation*, (in prep).

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Related Publications

- **S. Gupta**, and P. A. Wilsey, “Quantitative Driven Optimization of a Time Warp Kernel,” In *Proceedings of the 2017 ACM SIGSIM Conference on Principles of Advanced Discrete Simulation* (SIGSIM-PADS ’17), 27-38.

- **S. Gupta**, and P. A. Wilsey, “Lock-Free Pending Event Set Management in Time Warp,” In *Proceedings of the 2014 ACM SIGSIM/PADS conference on Principles of Advanced Discrete Simulation* (SIGSIM-PADS’14), 15-26.

- T. Dickman, **S. Gupta**, and P. A. Wilsey, “Event pool structures for PDES on many-core Beowulf clusters,” In *Proceedings of the 2013 ACM SIGSIM conference on Principles of Advanced Discrete Simulation* (SIGSIM-PADS ’13), 103-114.

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Publications (other)

- J Xu, BJ Hartley, P Kurup, A Phillips, A Topol, M Xu, C Ononenyi, E Foscue, S Ho, TD Baguley, N Carty, CS Barros, U Mller, **S Gupta**, D Ruderfer, P Sklar, J Rapoport, JA Ellman, C Pittenger, B Aronow, AC Nairn, MW Nestor, PJ Lombroso and KJ Brennand, "Inhibition of STEP 61 ameliorates deficits in mouse and hiPSC-based schizophrenia models," *Molecular Psychiatry* (2016); doi:10.1038/mp.2016.163

- A Topol, JA English, E Flaherty, P Rajarajan, BJ Hartley, **S Gupta**, F Desland, S Zhu, T Goff, L Friedman, J Rapoport, D Felsenfeld, G Cagney, A Mackay-Sim, JN Savas, B Aronow, G Fang, B Zhang, D Cotter and KJ Brennand, "Increased abundance of translation machinery in stem cell-derived neural progenitor cells from four schizophrenia patients," *Translational Psychiatry* (2015) 5, e633; doi:10.1038/tp.2015.118

- **S. Gupta** and G. Paul. "Revisiting Fermat's Factorization for the RSA Modulus," *Computing Research Repository* (CoRR) abs/0910.4179 (2009)

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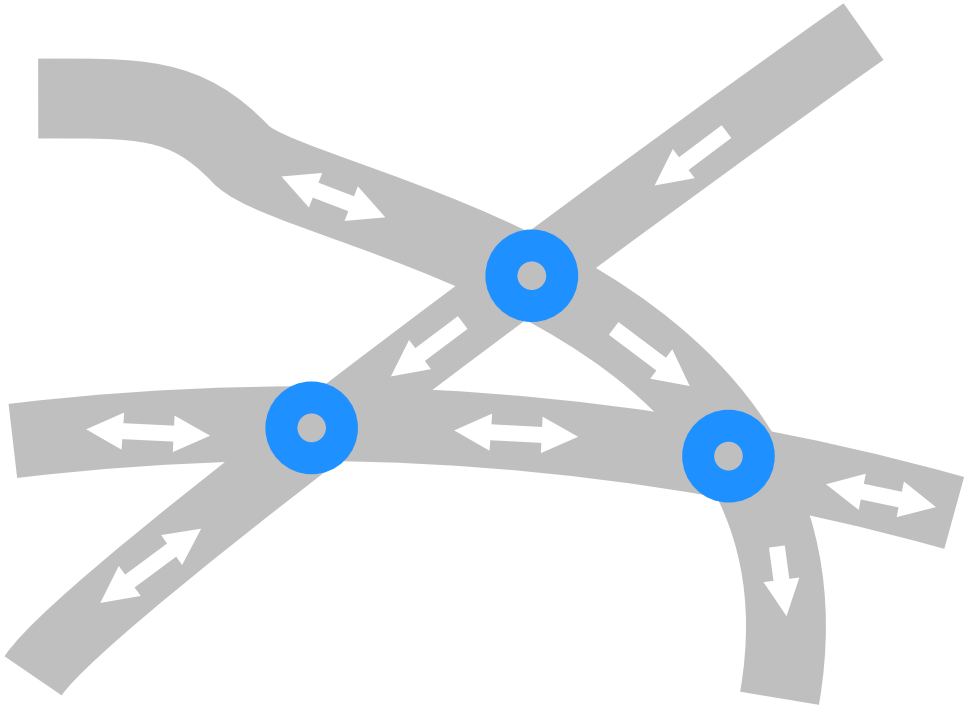
Building Blocks: Logical Process (LP), LP State, and Event



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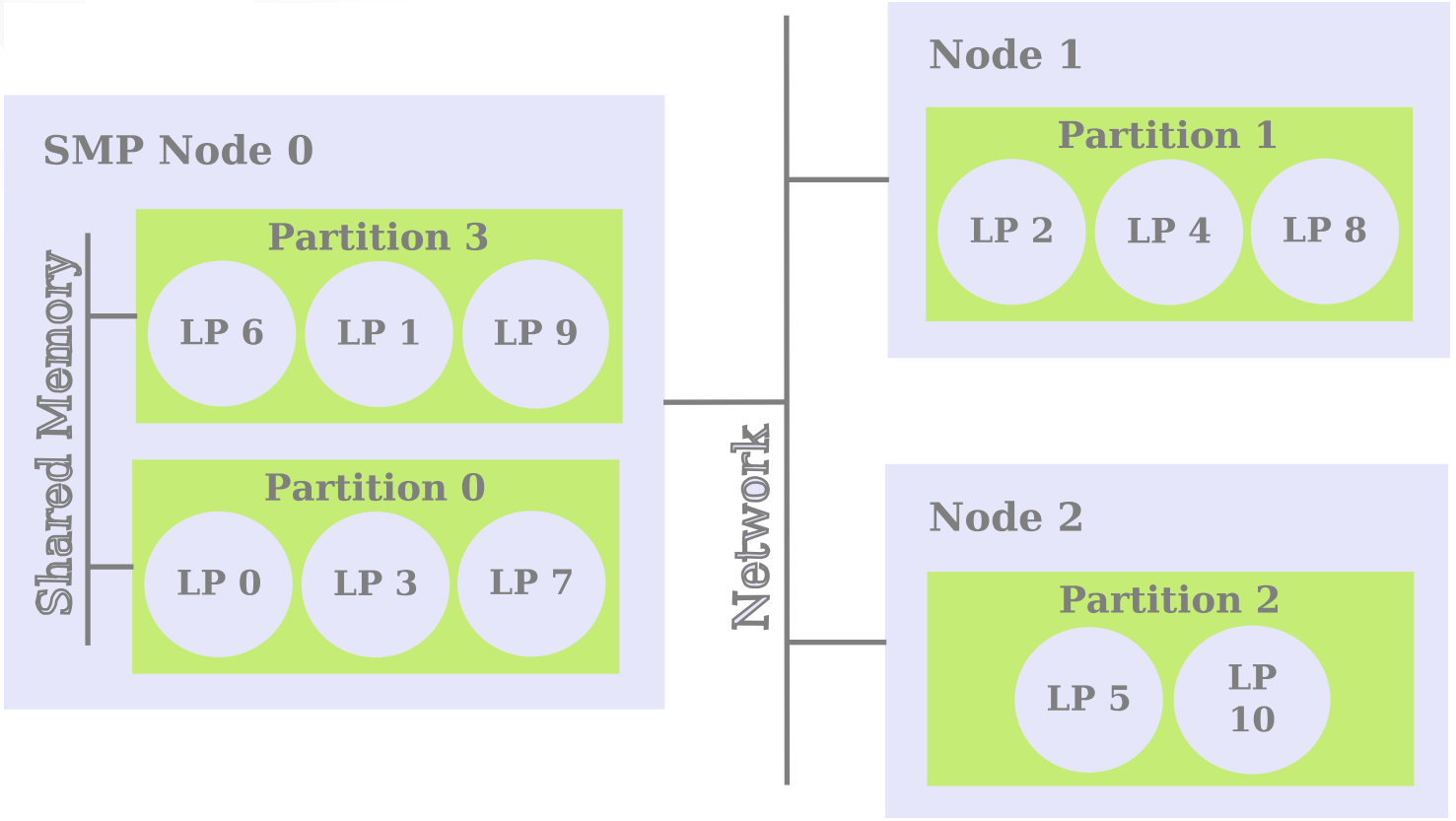
Parallel Discrete Event Simulation (PDES)



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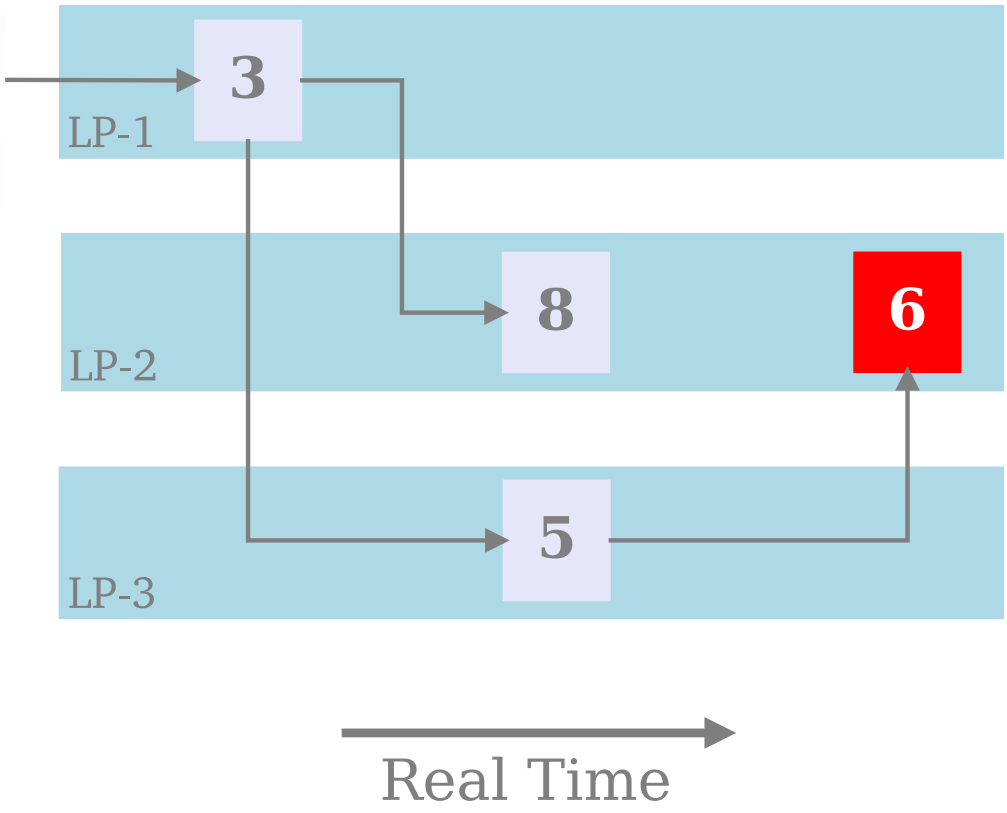
Event Causality



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The Time Warp Mechanism

- Each LP processes events w/o regard for progress of other LPs
- Causal Violation triggered by a **Straggler event**
- **Rollback** used to recover from a causal violation
    - Reset state and time
    - Send **anti-messages** to cancel prematurely sent events
    - Continue event processing at reset time

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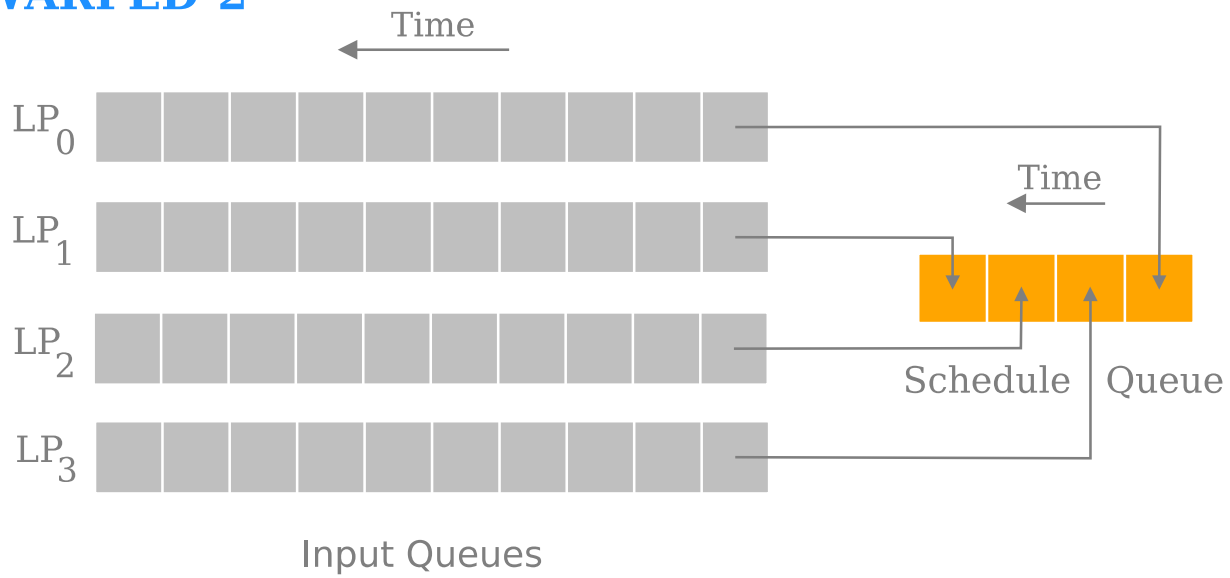
The Evolution of WARPED to Multi-Core

WARPED

WARPED-2



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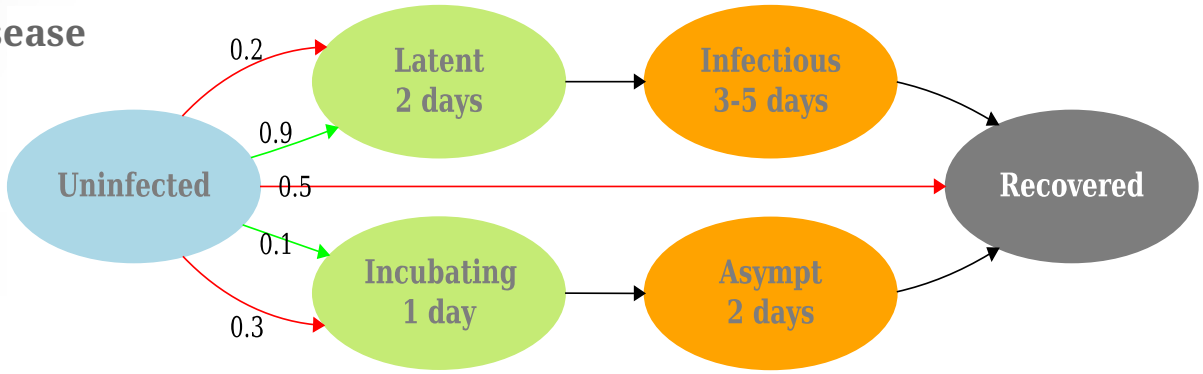
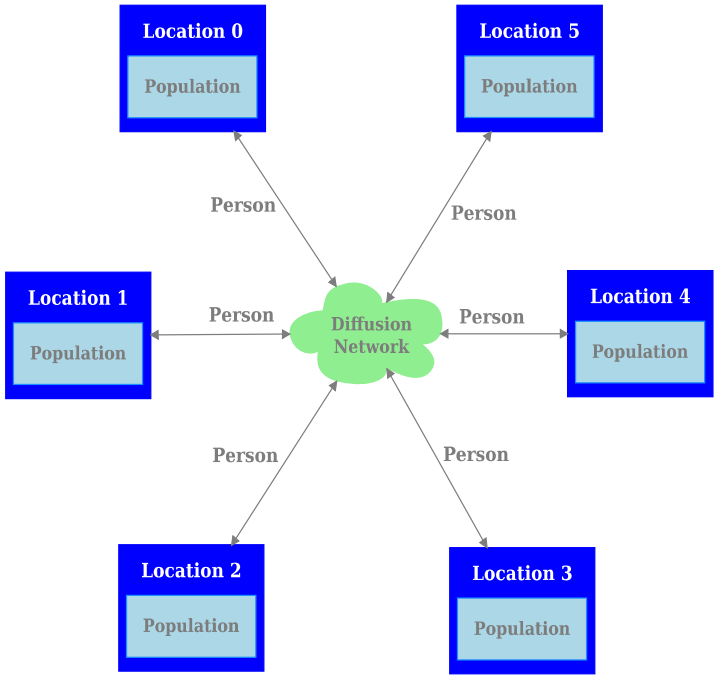
Simulation Model: Epidemic

State Transition of Disease





Diffusion Network: 2 types

- Watts-Strogatz
- Barabasi-Albert

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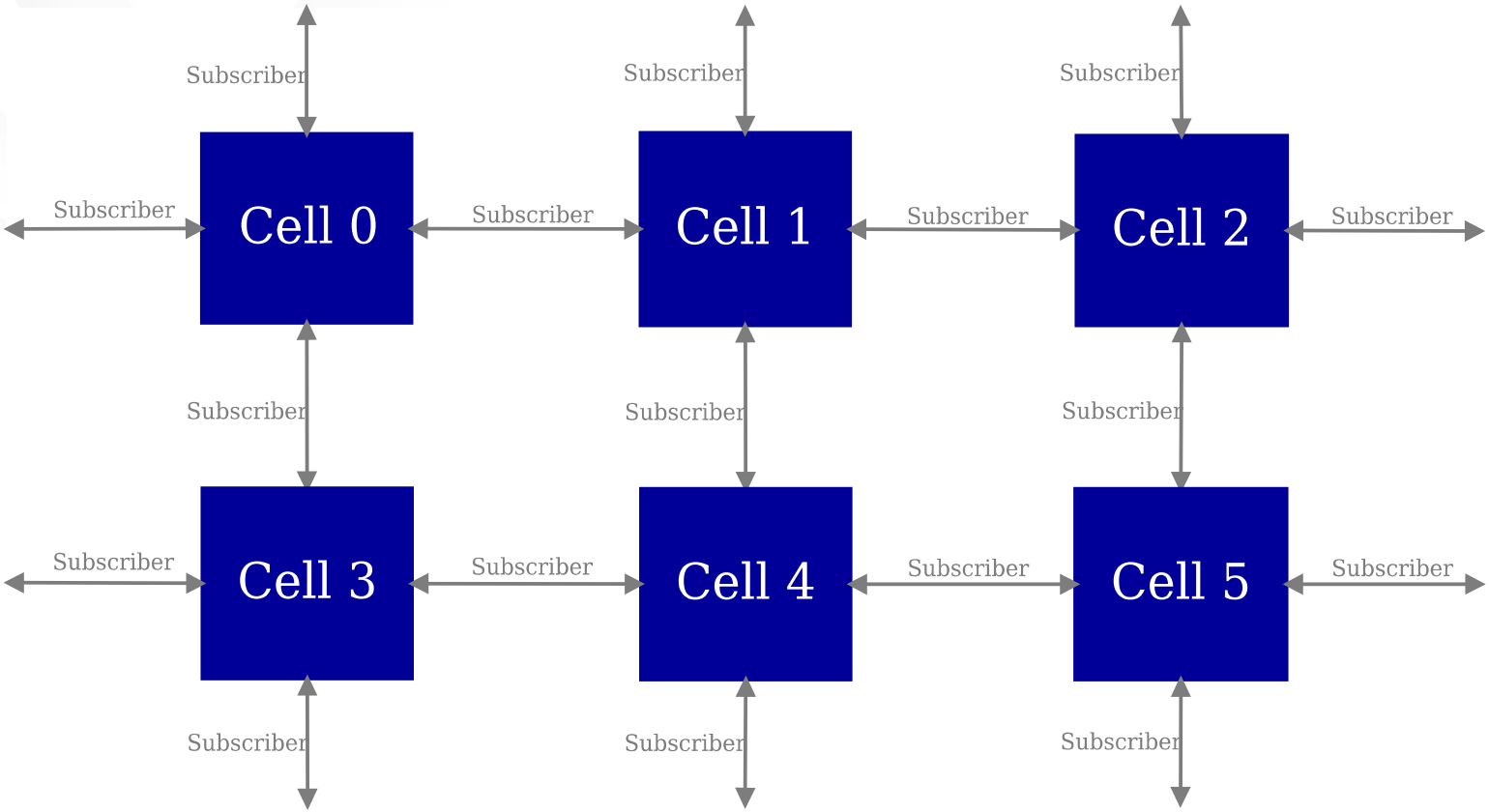
PCS Model : Network Structure



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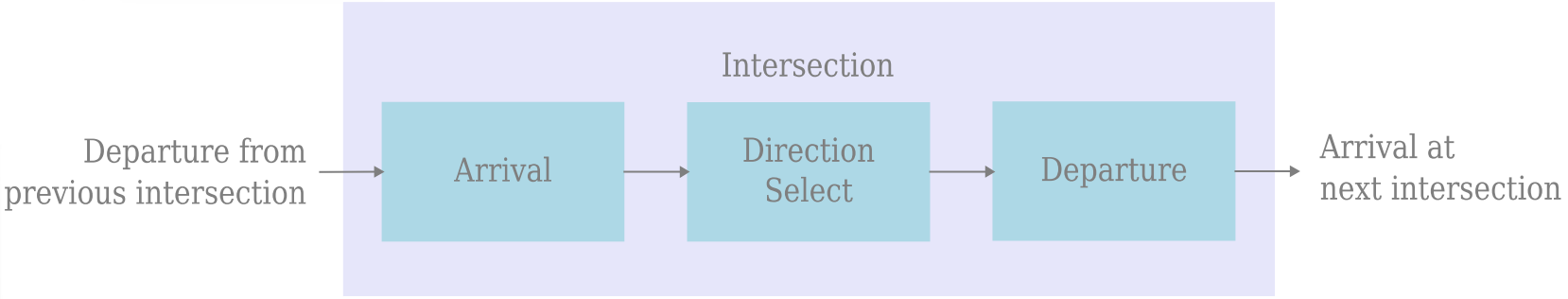
Traffic Model : Events



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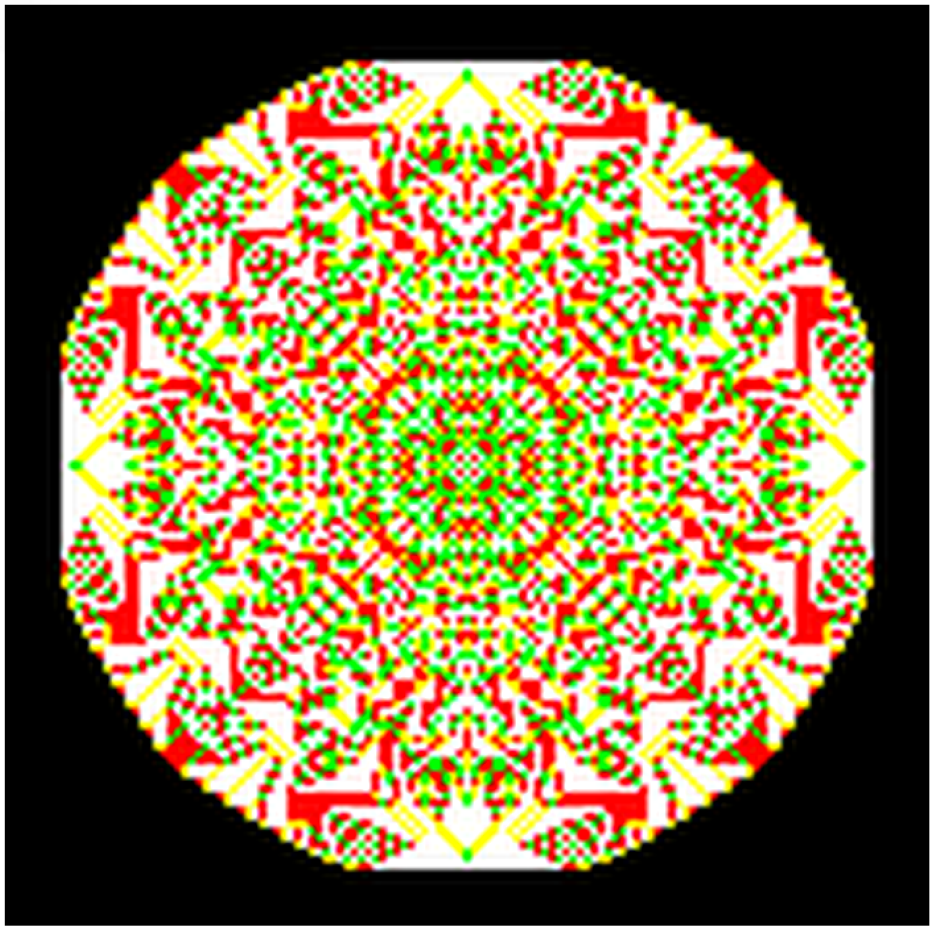
Sandpile Model : Generated patterns



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WARPED-2: Pending Event Set

Schedule Queue: Data Structure Options

- **STL MultiSet:** *Red-Black Tree, sorted*
- **Splay Tree:** *Self-adjusting Binary Search Tree, sorted*
- **Calendar Queue:** *Partitions events into "months" based on timestamp*
  - Difficult to size a month
  - Largely unused due to size/resize complications & costs
- **Ladder Queue:** *Variant of calendar queue that solves month sizing issue*
  - Lightweight, self-sizing
  - Previously unknown to the PDES community

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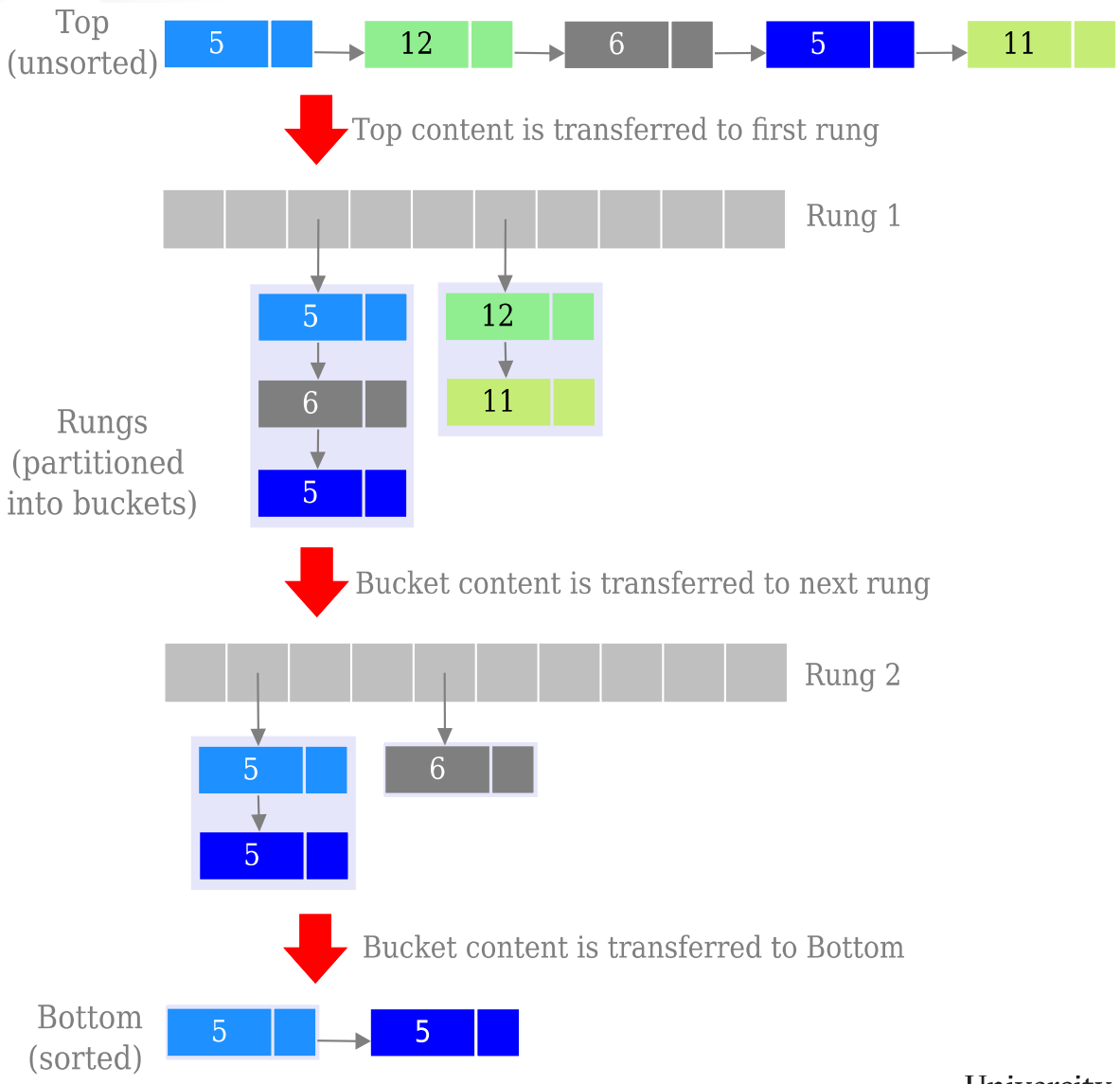
Ladder Queue



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Ladder Queue Options

- **Unsorted Bottom**
  - **Causal Independence** of events in Bottom
  - **Lock-free** implementation of Unsorted Bottom
    - **Compare-and-Swap (CAS)** operations
    - No need for computationally-intensive operations (sorting, searching and random deletion)

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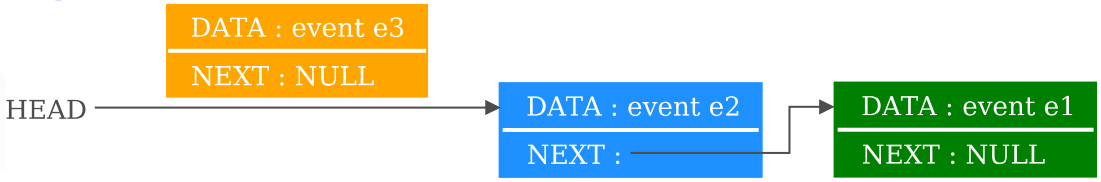
Lock-free Unsorted Bottom in a Ladder Queue

Event Insert

Step 1 : Create a node for event e3



Step 2: CAS operation to insert this new node as HEAD

Event Remove

Step 1: CAS operation to set HEAD as HEAD->NEXT

Step 2 : Return dequeued event e1

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Modification to the Ladder Queue Algorithm

- **Overflow of events in Bottom**
  - Reorganization triggered in original Ladder Queue
  - Events are split between Bottom and lowest rung
  - New algorithm ignores this trigger
- **Value of Bottom Threshold**
  - Value mentioned in paper not relevant for Pending Event Set
    - event time window matters more than event count

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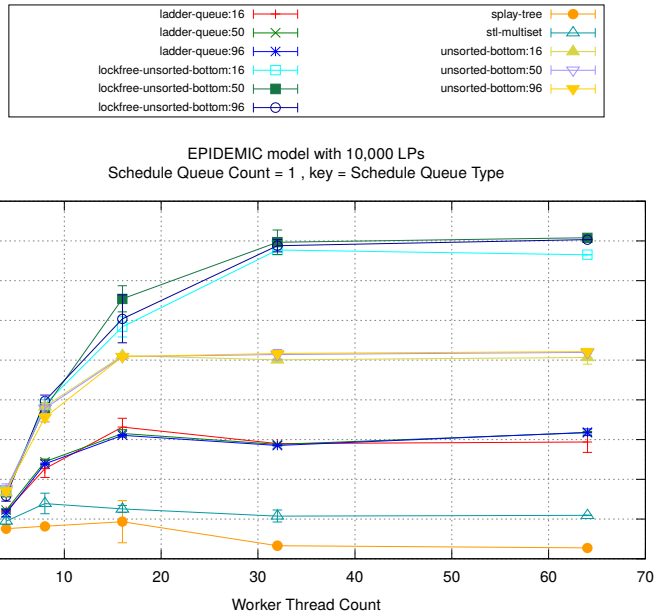
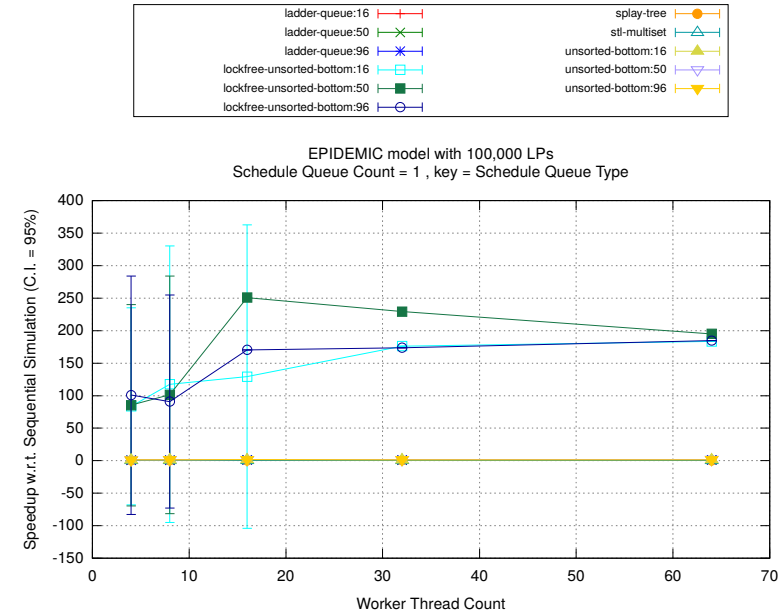
Performance of Schedule Queue Types

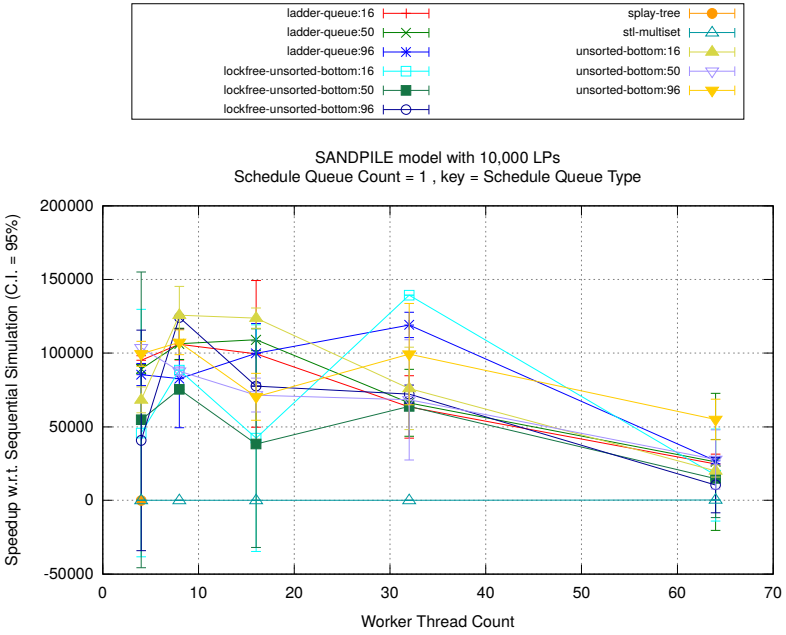
Epidemic 10K-WS



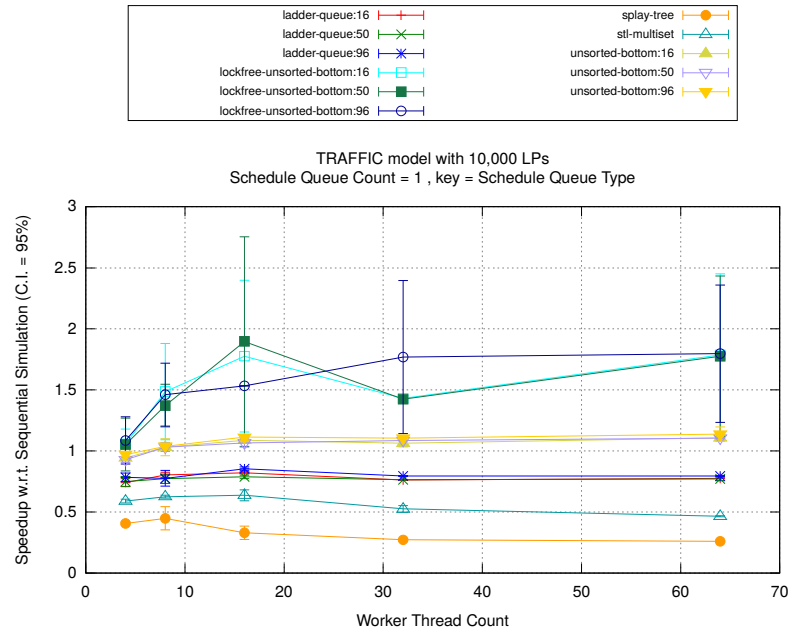
Epidemic 100K-WS



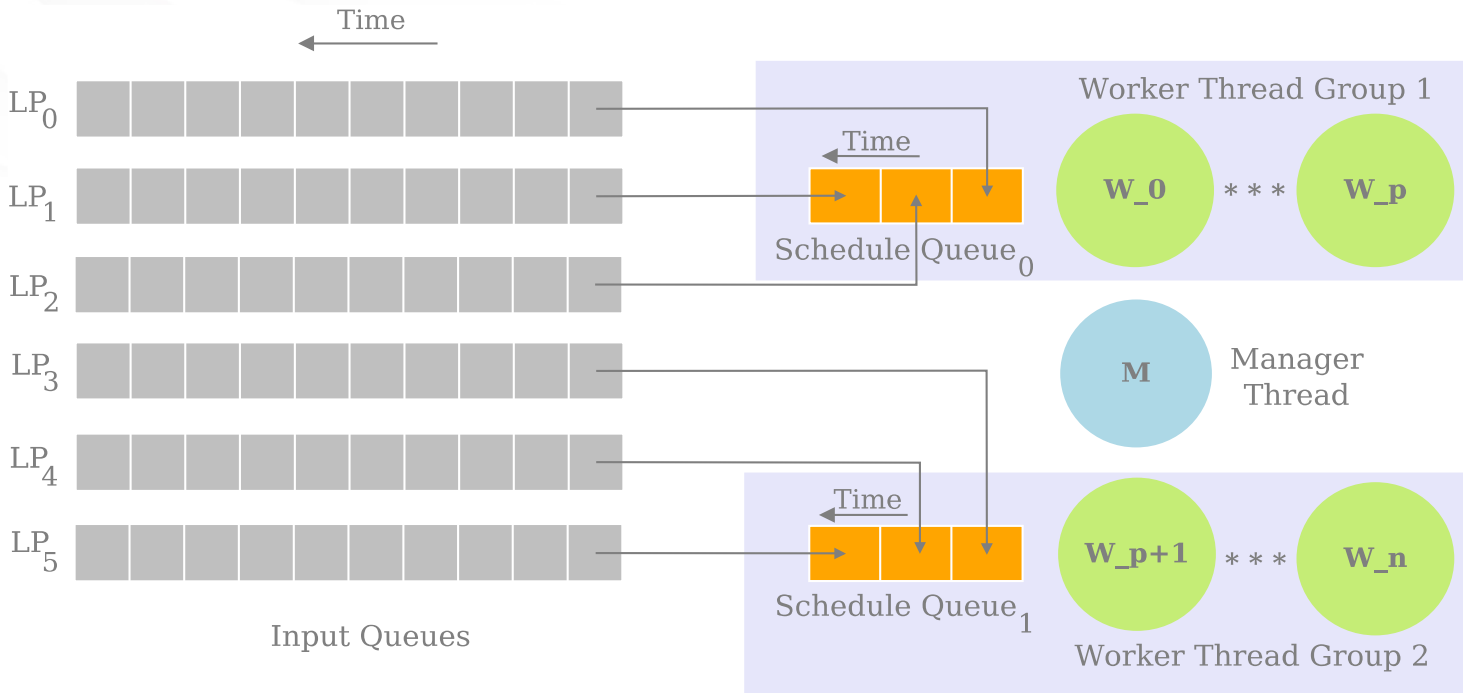
Sandpile-10K



Traffic-10K



Multiple Schedule Queues



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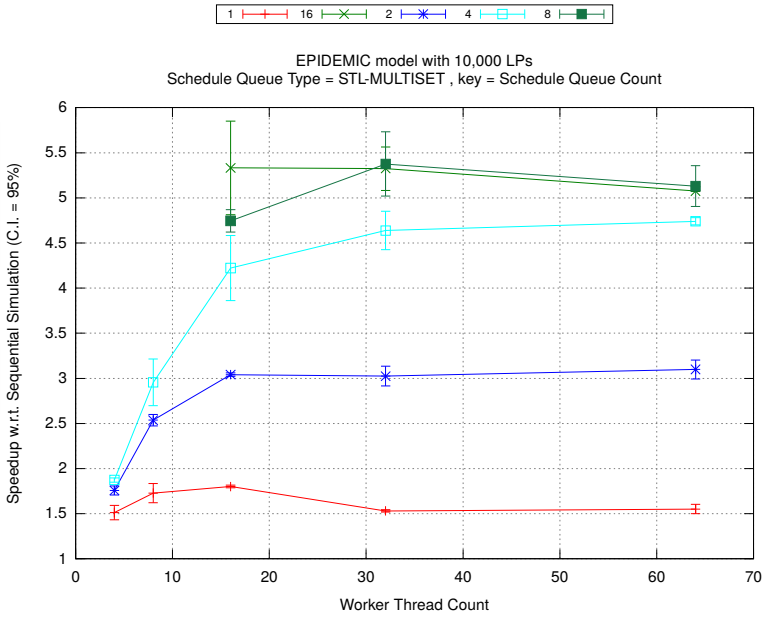
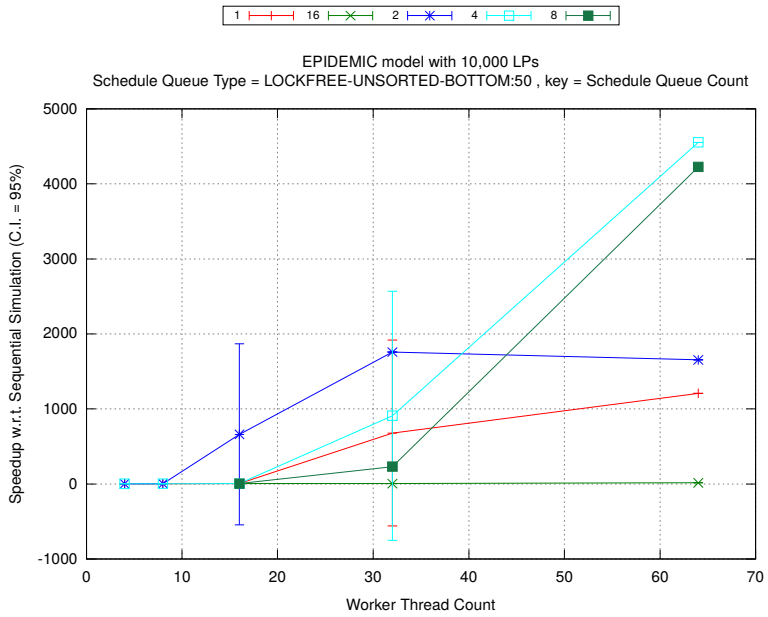
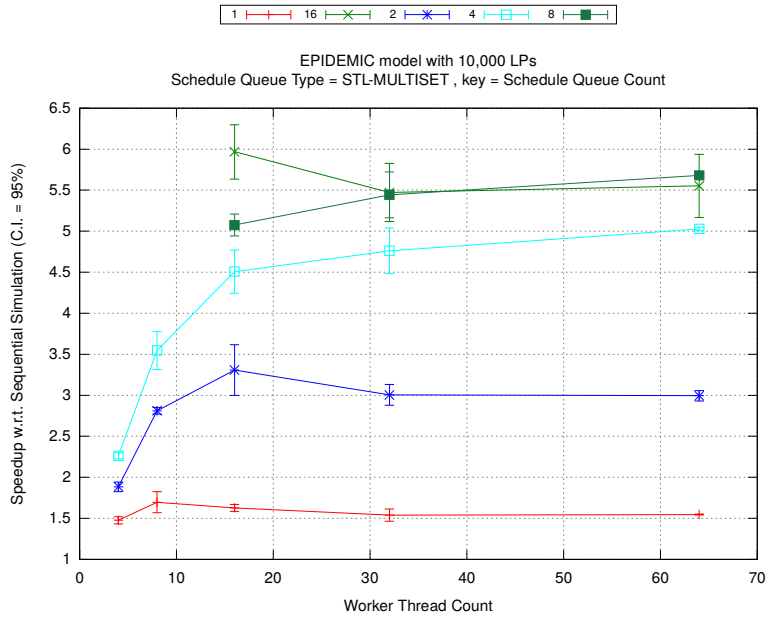
Performance of Multiple Schedule Queues: Epidemic, 10K LPs

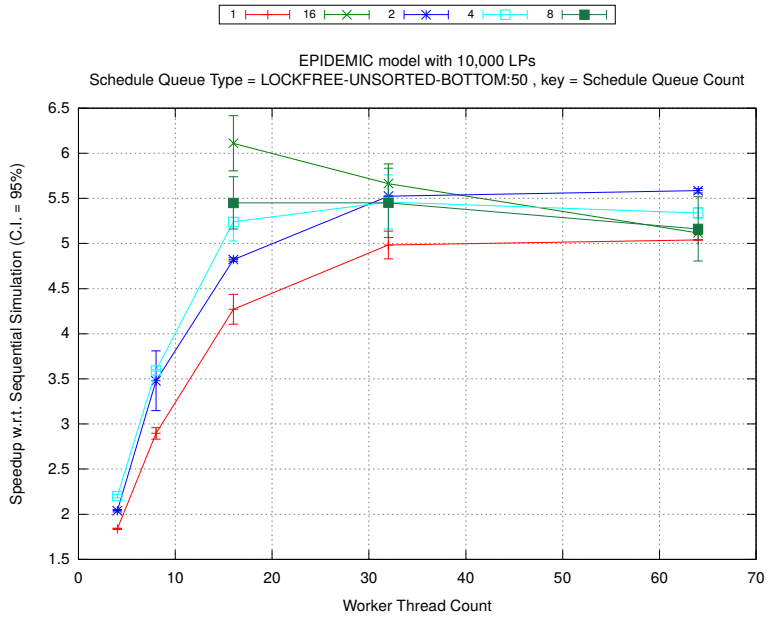
BA Network





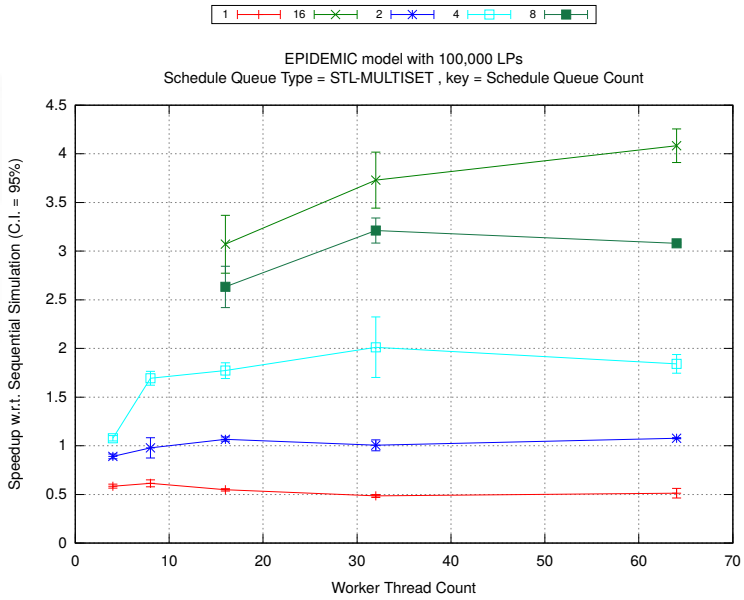
WS Network

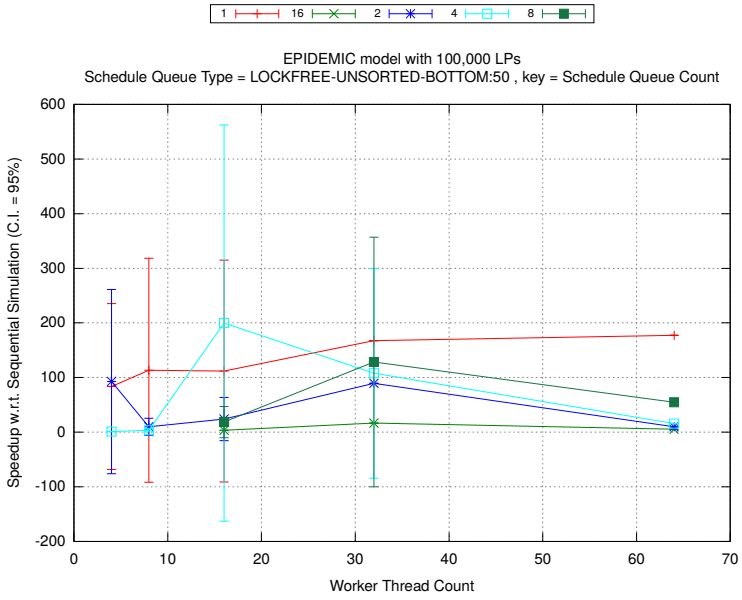




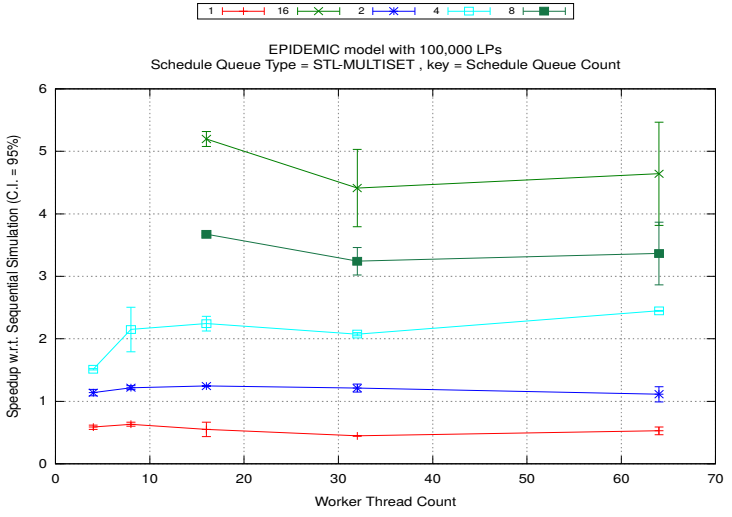
Performance of Multiple Schedule Queues :Epidemic, 100K LPs

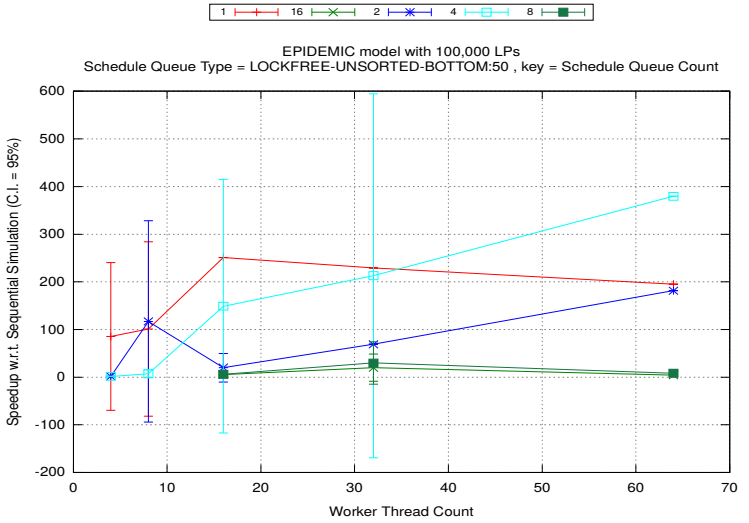
BA Network



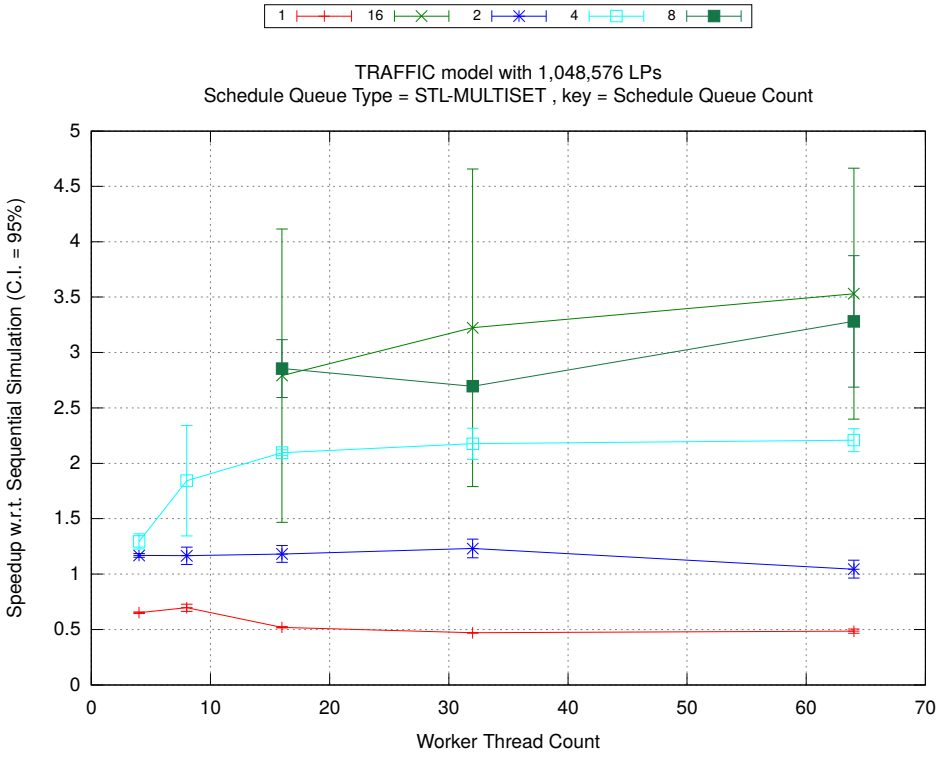


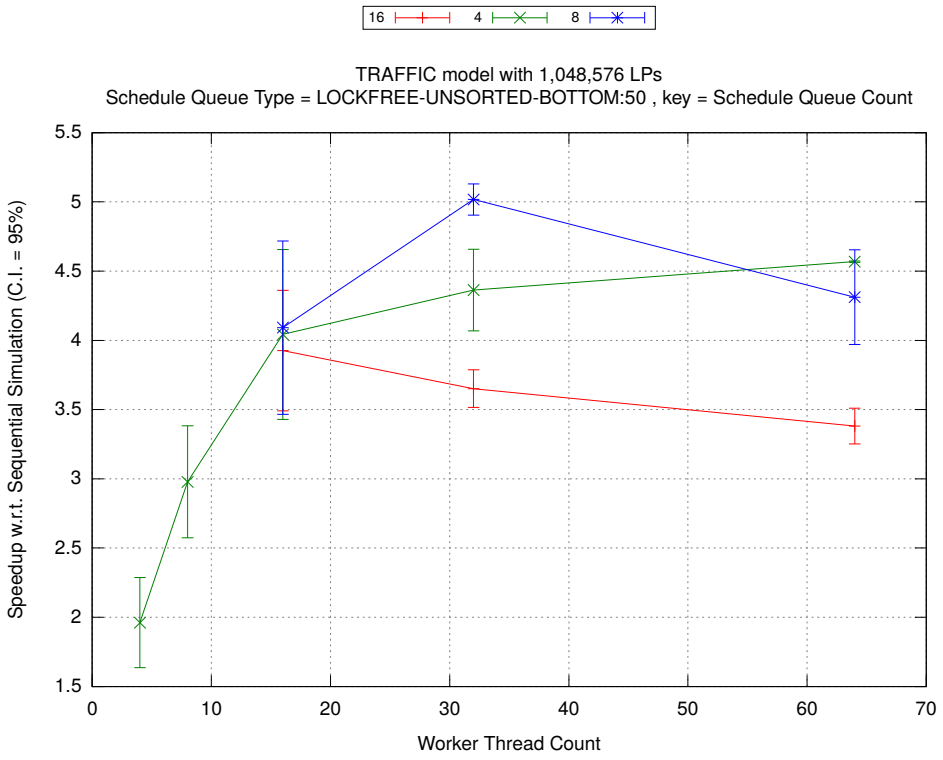
WS Network





Performance of Multiple Schedule Queues :
Traffic, 1,048,576 LPs





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Schedule Events in Groups

- Schedule **multiple events** to a worker thread at the same time.
- Three types:
  - **Event Chains:** *schedule multiple events from one LP*
  - **Event Blocks:** *schedule multiple events from the schedule queue*
  - **Event Bags:** *LPs grouped into **communities** based on event traffic statistics*
    - Schedule multiple events from each bag
    - Static memory allocation and circular organization of bags

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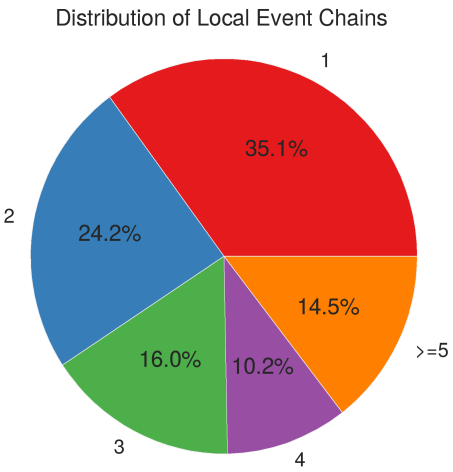
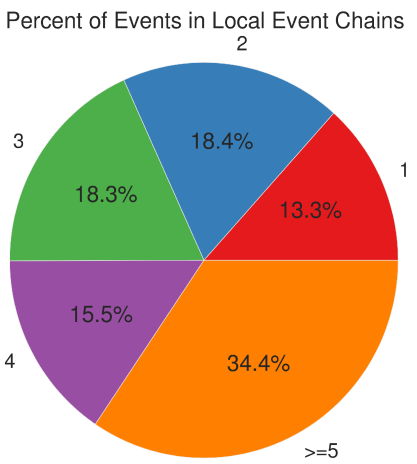
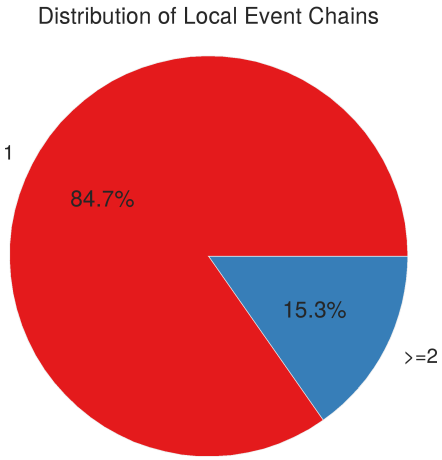
DESMetrics Analysis: Event Chains

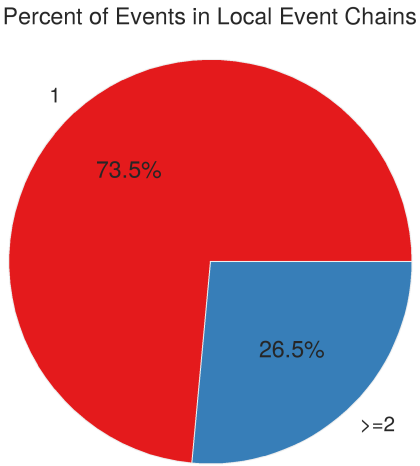
Traffic Model





Epidemic (WS) Model





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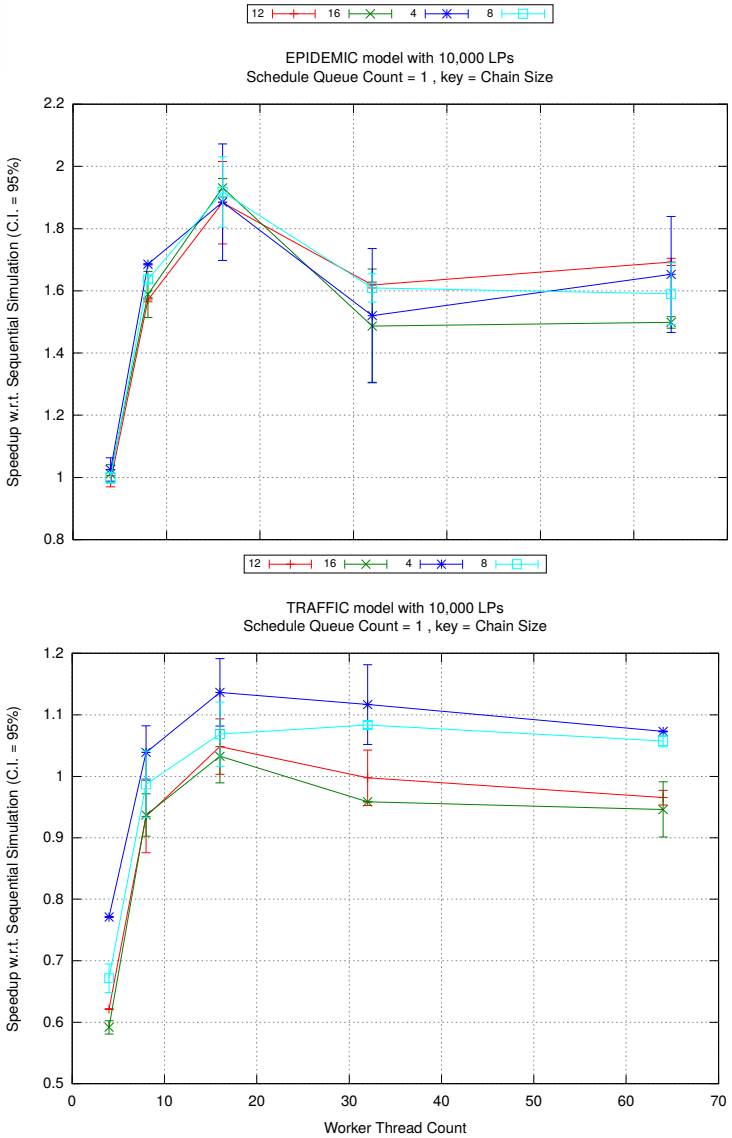
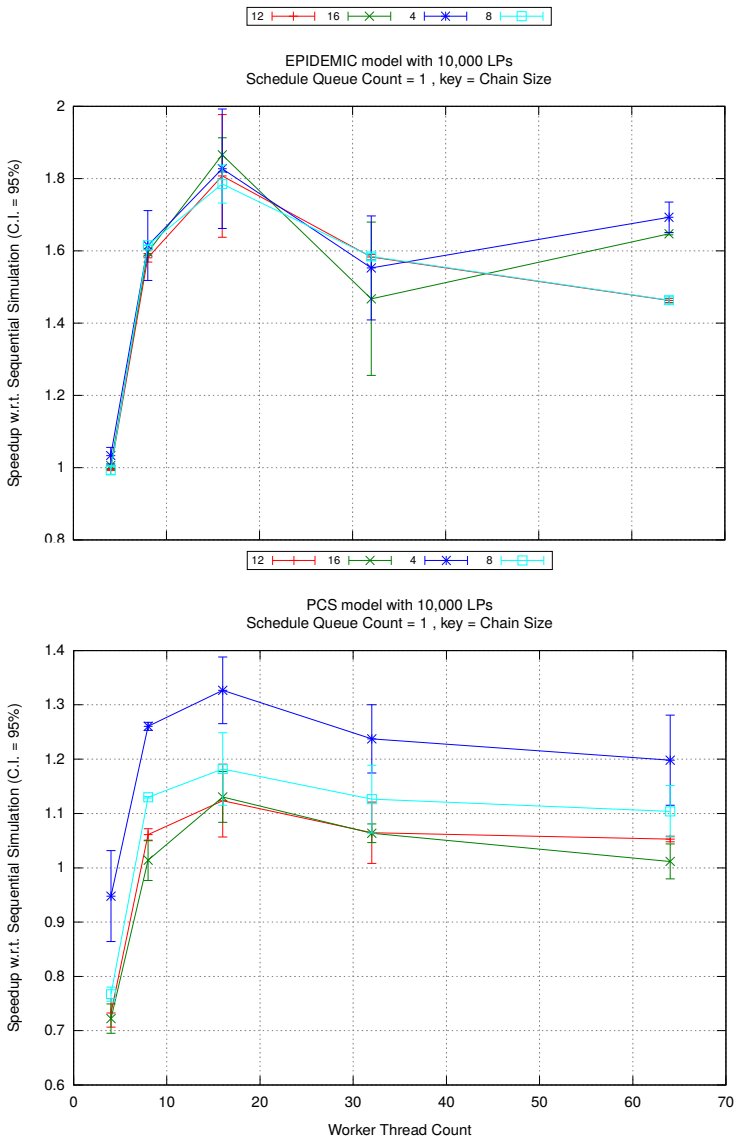
Performance Impact of Chain Scheduling

Epidemic-10K-BA



Epidemic-10K-WS

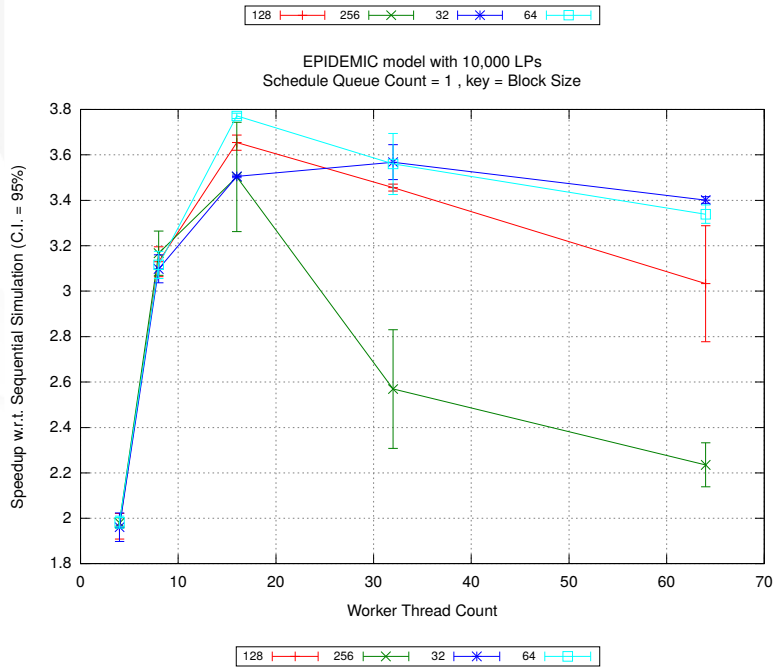


Traffic-10K

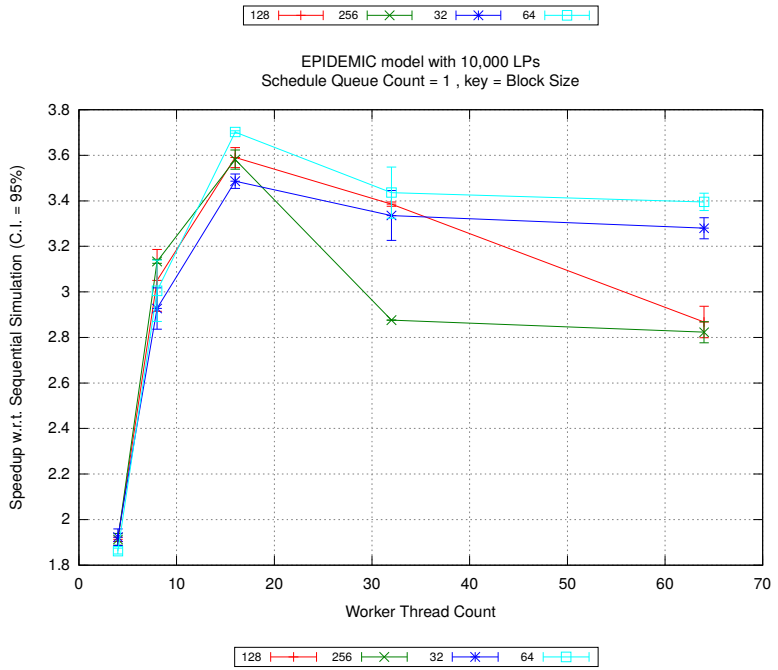
PCS-10K

Performance Impact of Block Scheduling

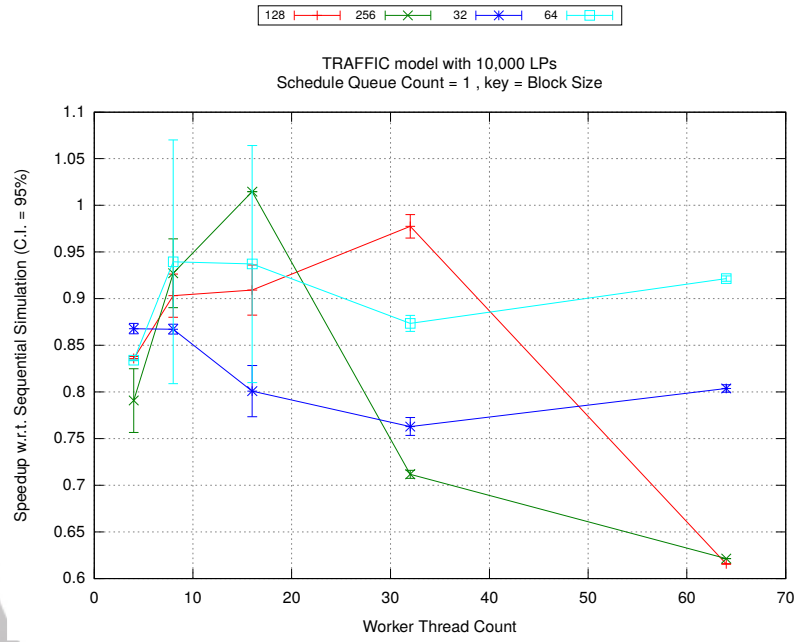
Epidemic-10K-BA



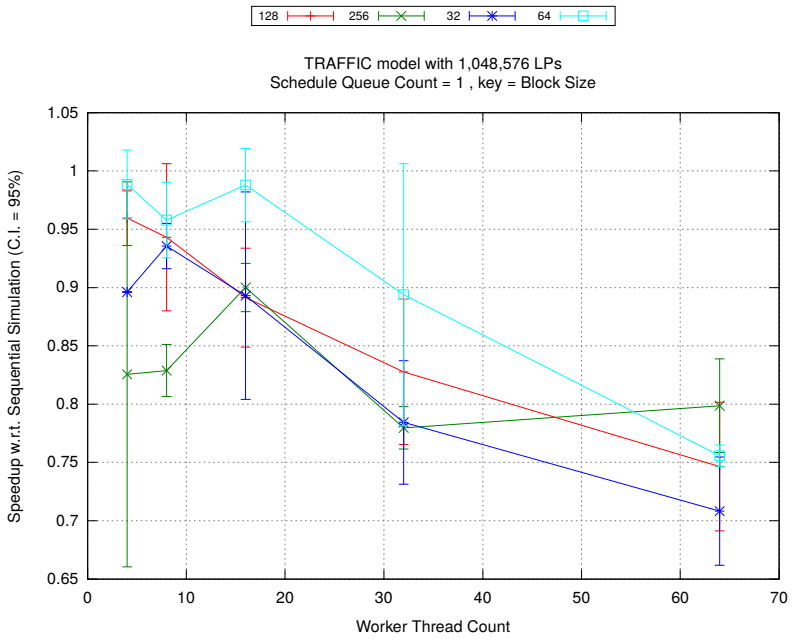
Epidemic-10K-WS



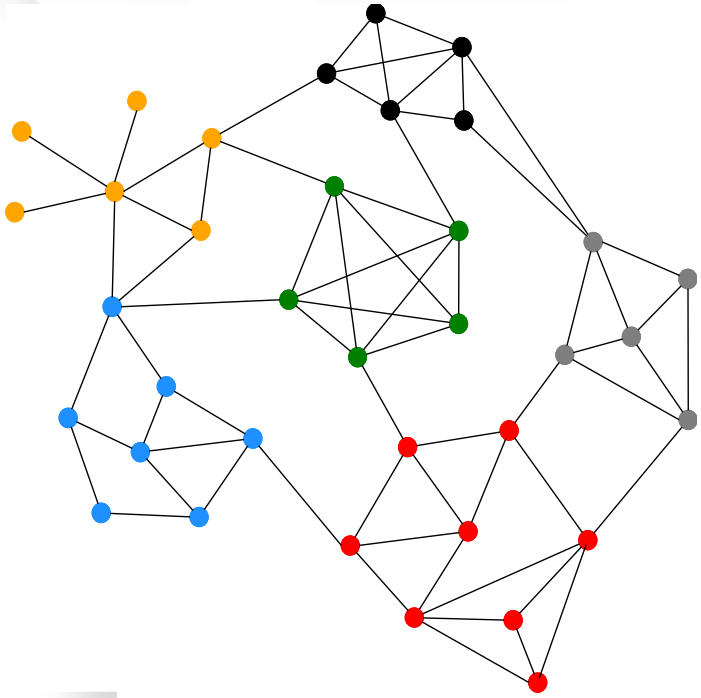
Traffic-10K

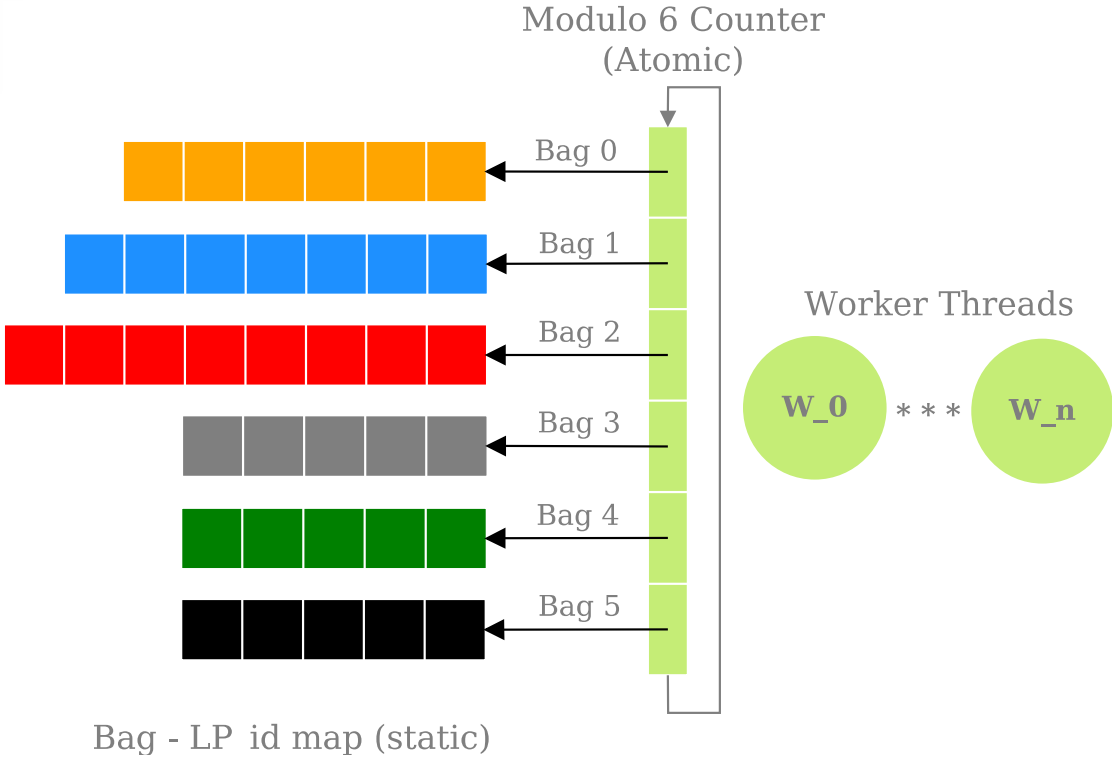


Traffic-1M



Louvain Partitioner and Bag Scheduling





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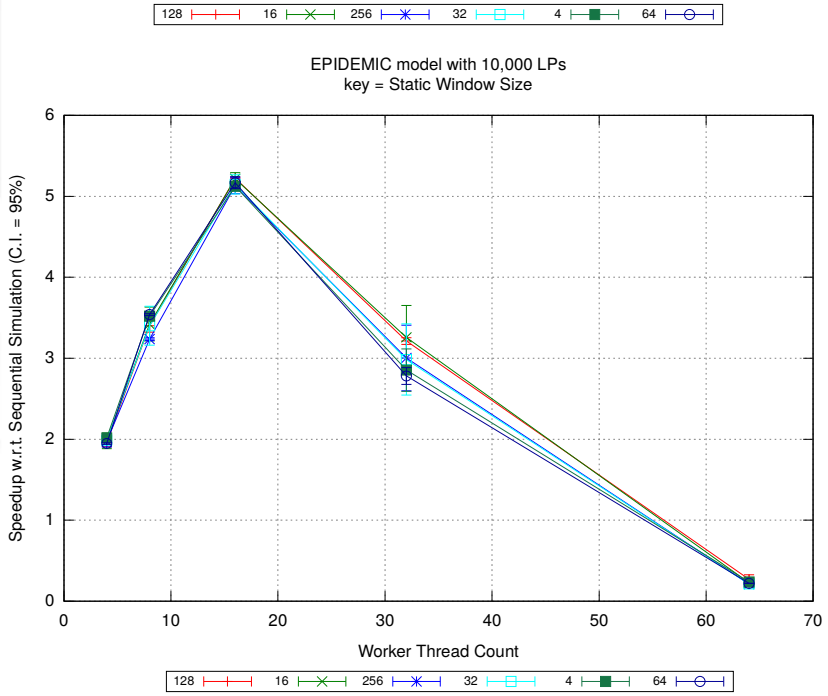
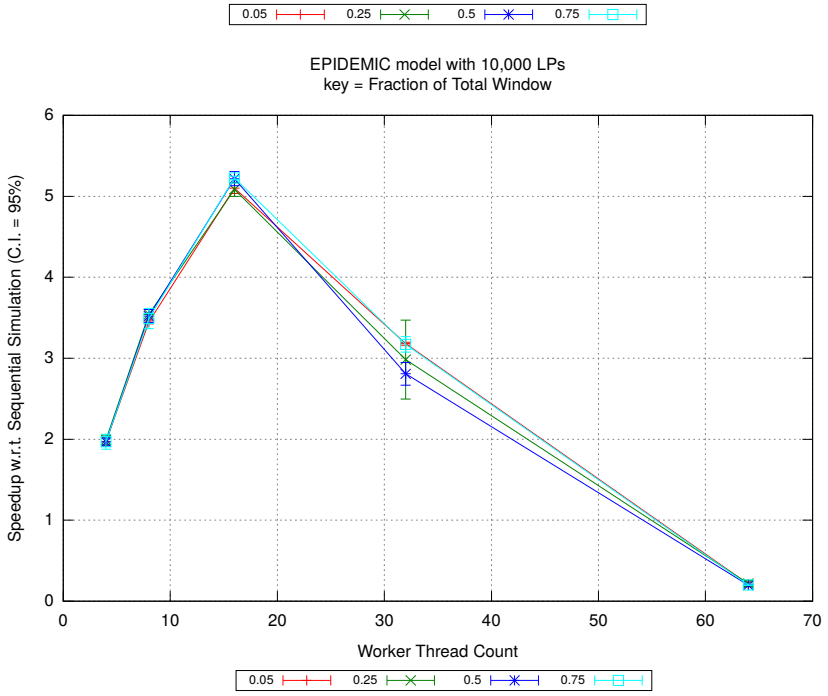
Performance Impact of Bag Scheduling: 10K LPs

Epidemic-WS





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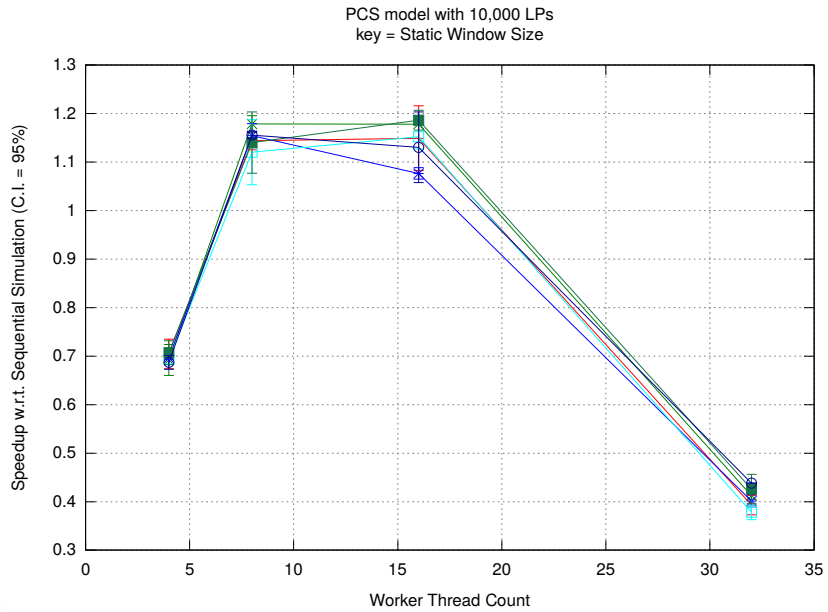

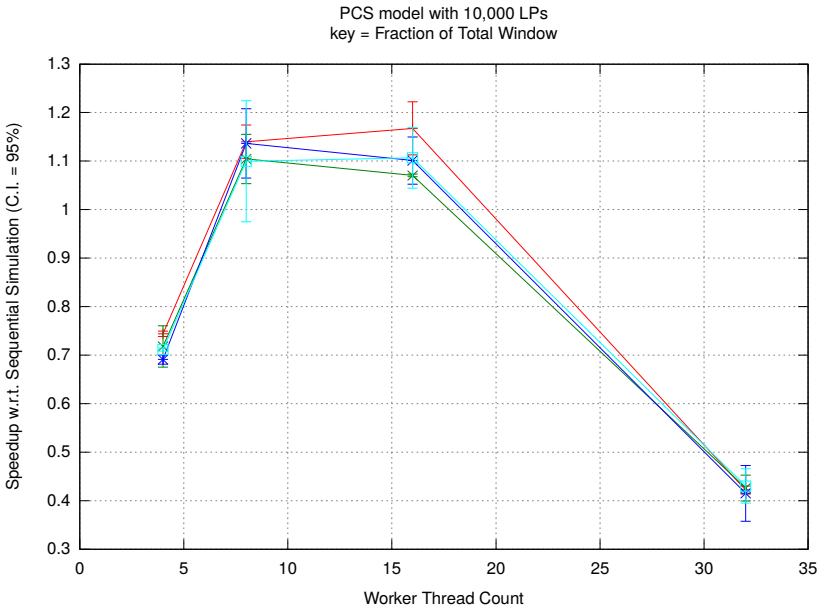

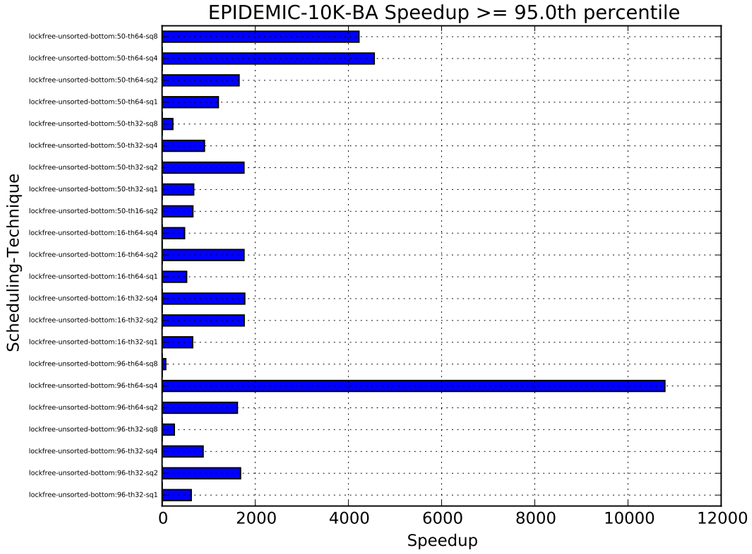

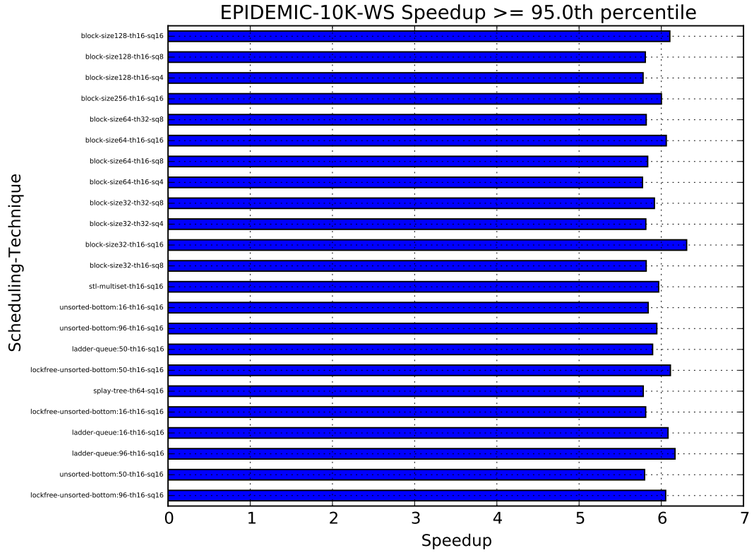

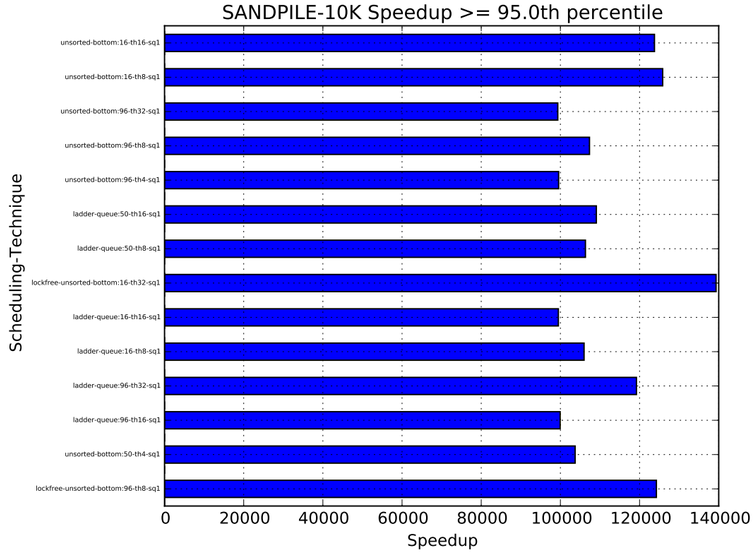

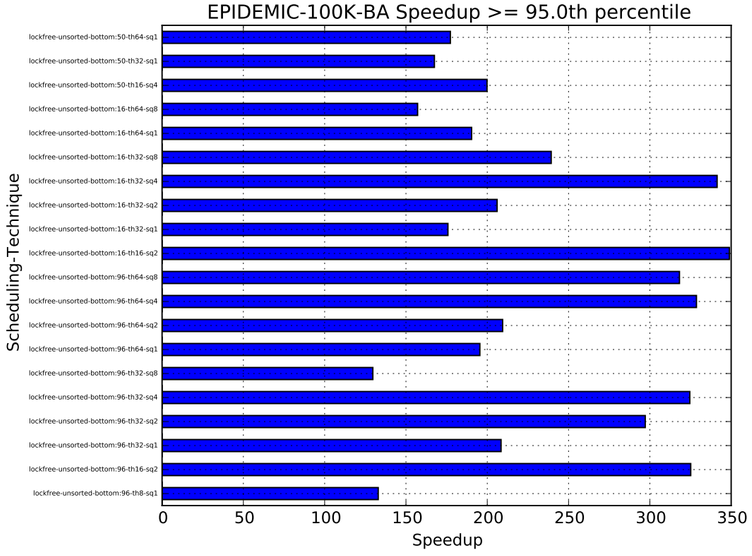

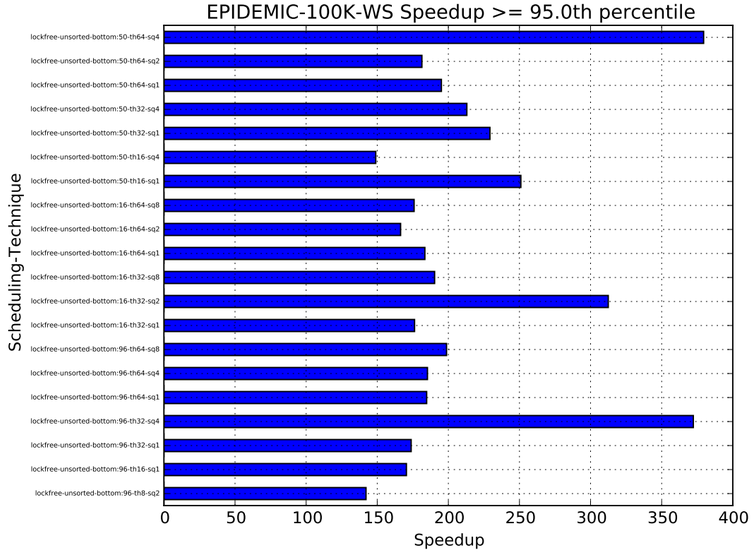

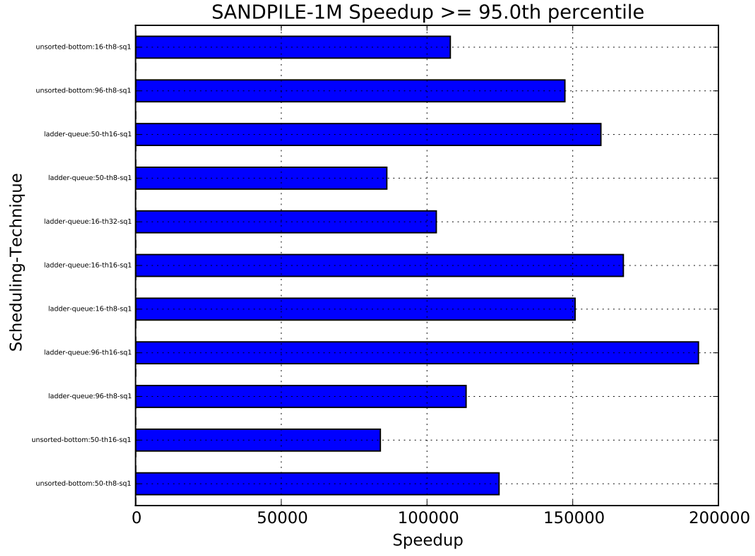

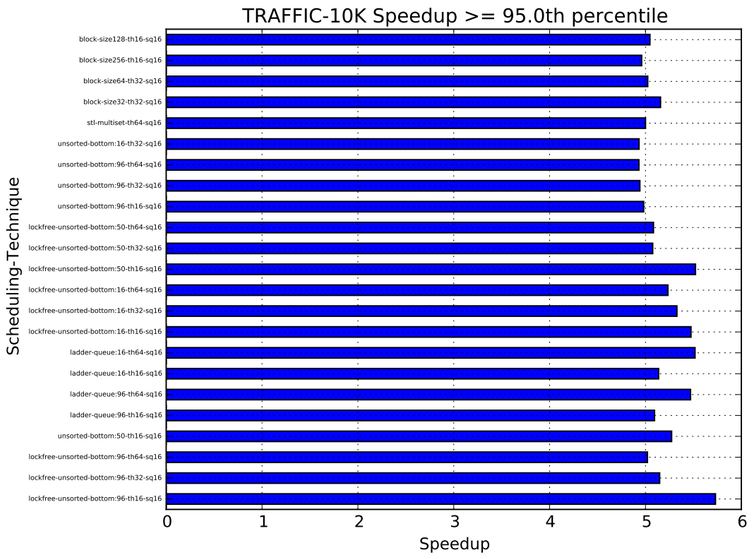

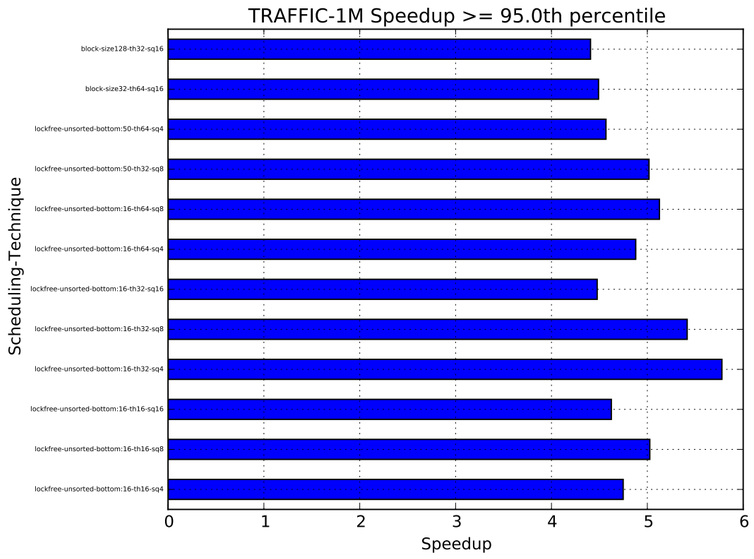

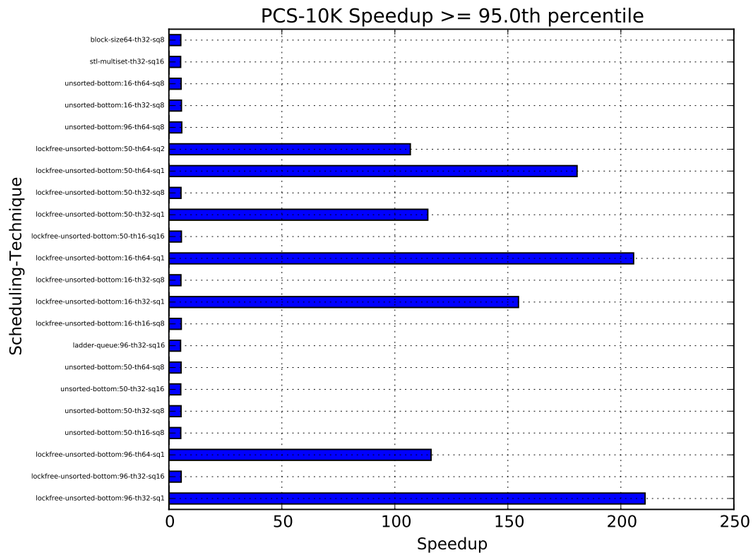

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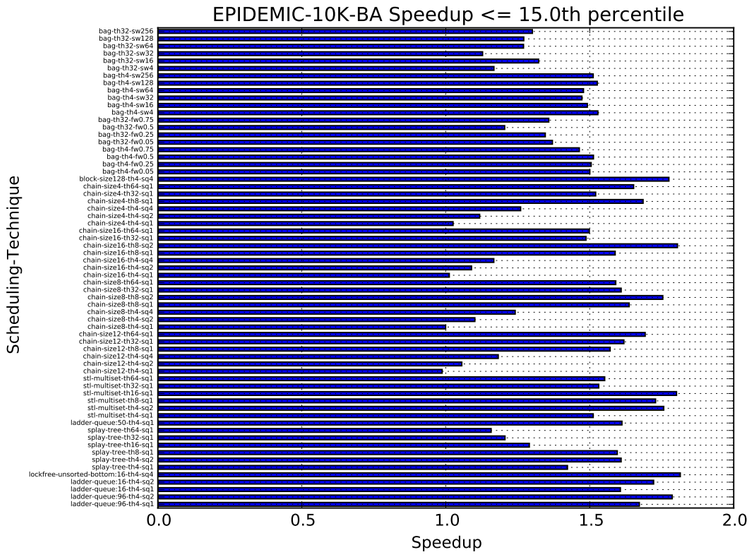

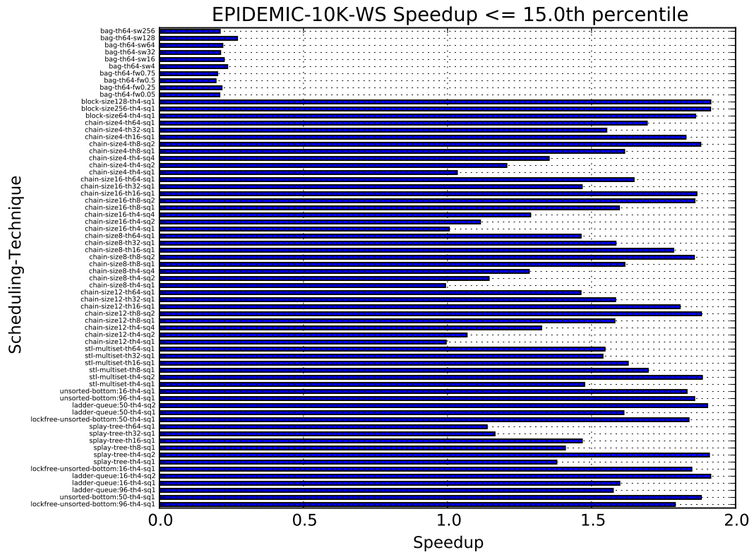

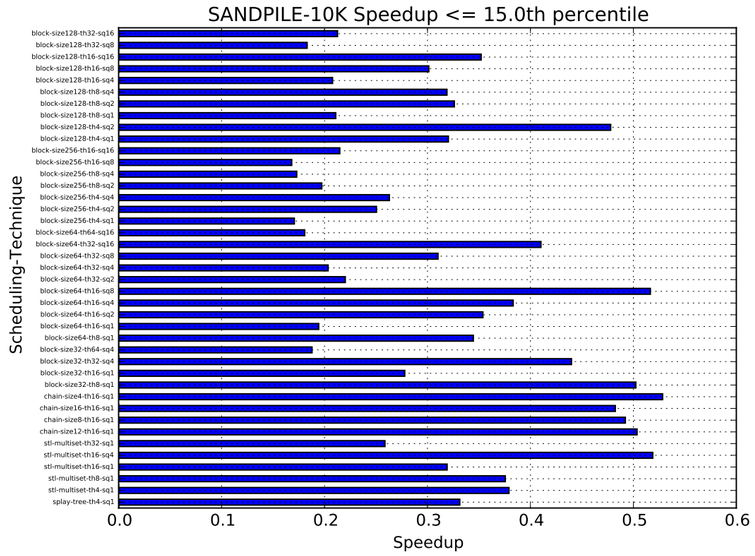

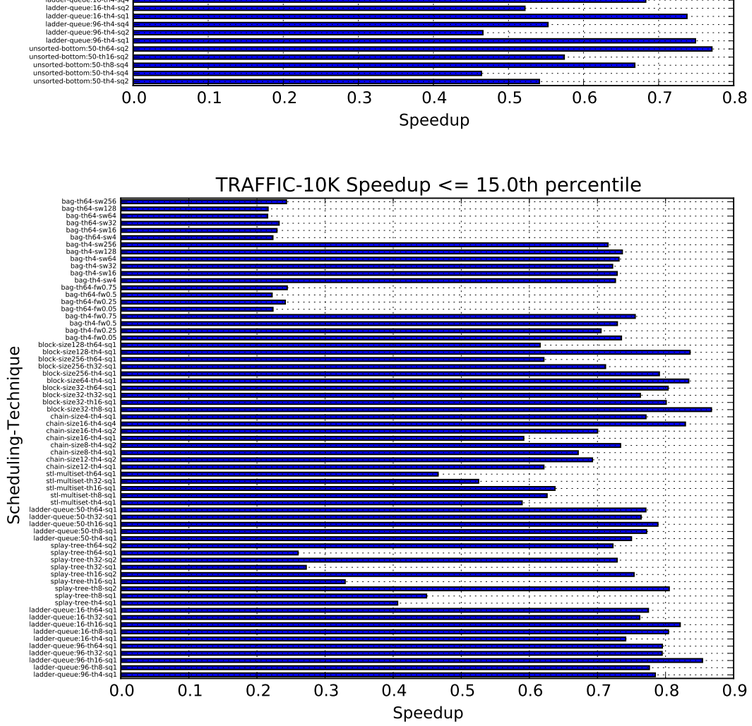

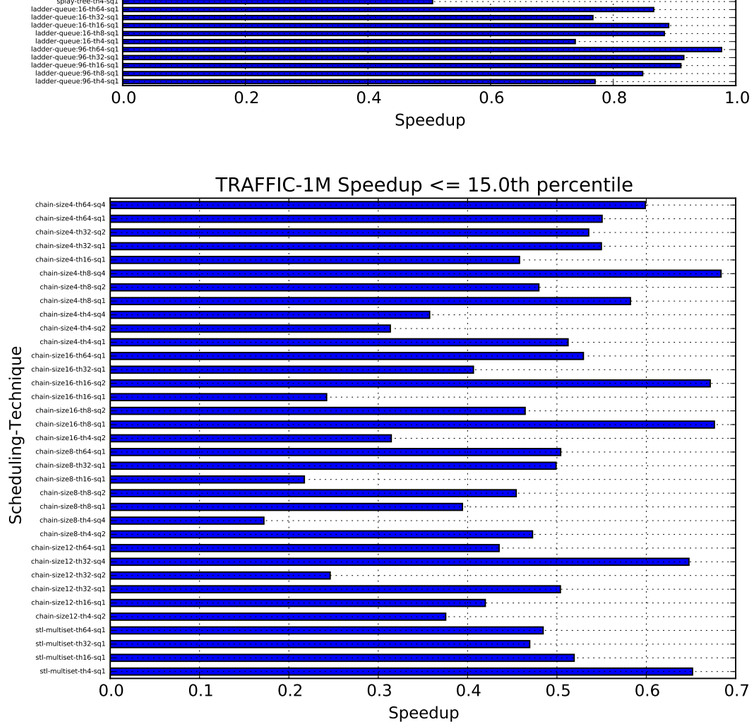

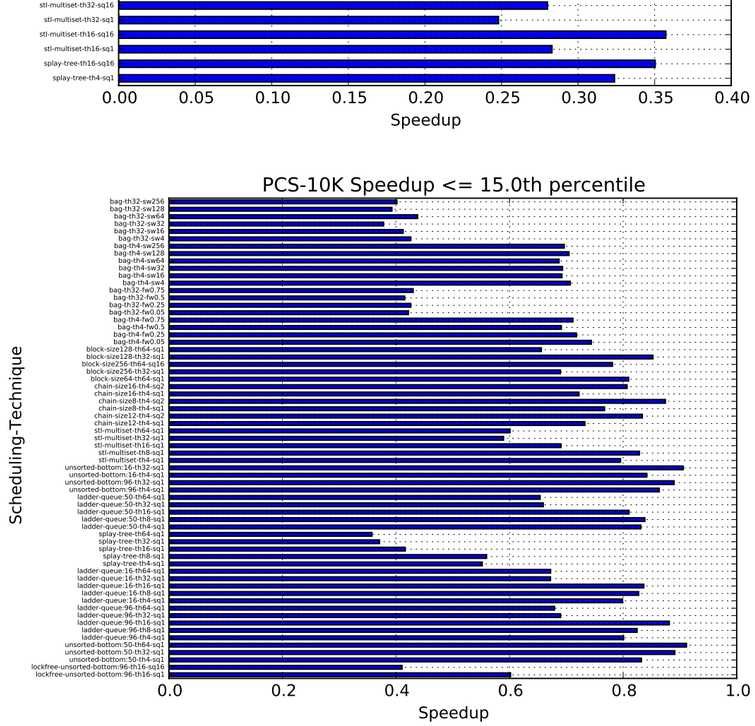

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Thank You !

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