BLUE WATERS

SUSTAINED PETASCALE COMPUTING

Characterizing the Influence of System Noise on Large-Scale Applications by Simulation

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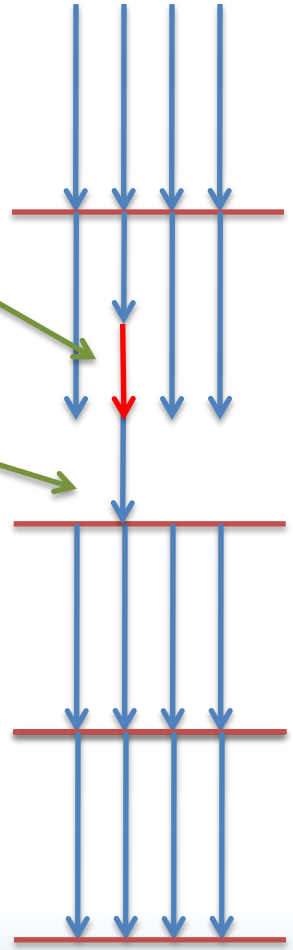
GREAT LAKES CONSORTIUM
FOR PETASCALE COMPUTATION

System Noise – Introduction and History

- CPUs are time-shared
  - Deamons, interrupts, etc. steal cycles
  - No problem for single-core performance
    - Maximum seen: 0.26%, average: 0.05% overhead
  - "Resonance" at large scale (Petrini et al '03)
- Numerous studies
  - Theoretical (Agarwal'05, Tsafrir'05, Seelam'10)
  - Injection (Beckman'06, Ferreira'08)
  - Simulation (Sottile'04)

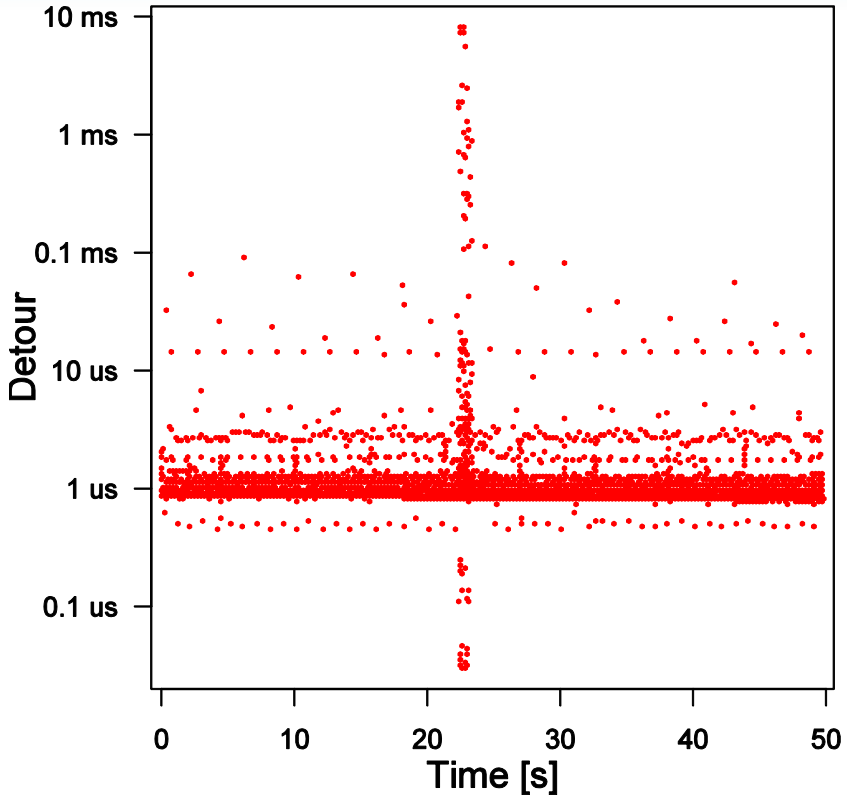


Measuring OS Noise on a Single Core

- Selfish Detour Benchmark (Beckman et al.)
  - Tight execution loop, benchmark iteration time
  - Record each outlier in iteration time
  - Improved detour (~30% better resolution)

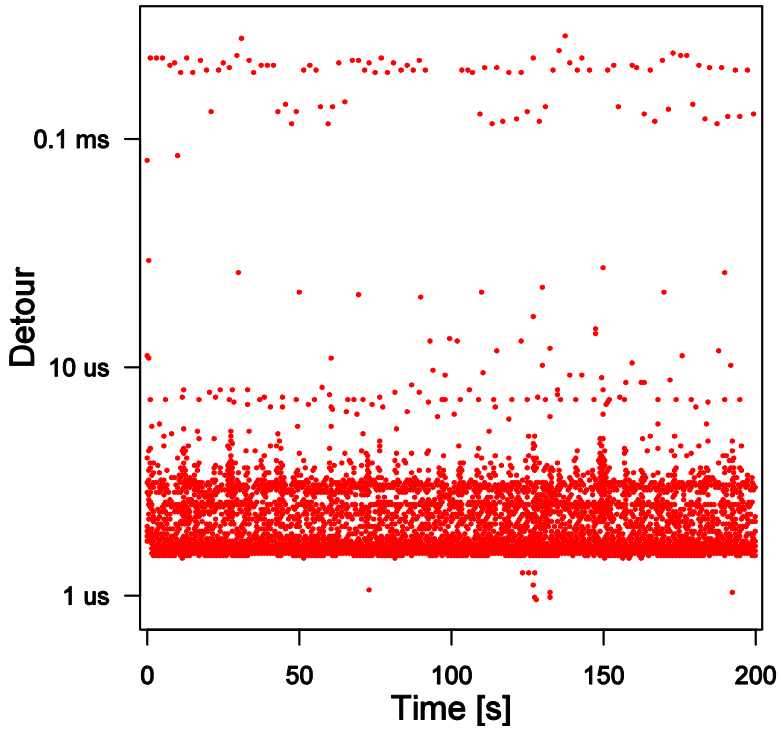
- Detour implemented in Netgauge benchmark tool
  - Also FWQ, FTQ (not used in this work)
  - Available at: `http://www.unixer.de/Netgauge`

Measurement Results – CHiC Linux (diskless)



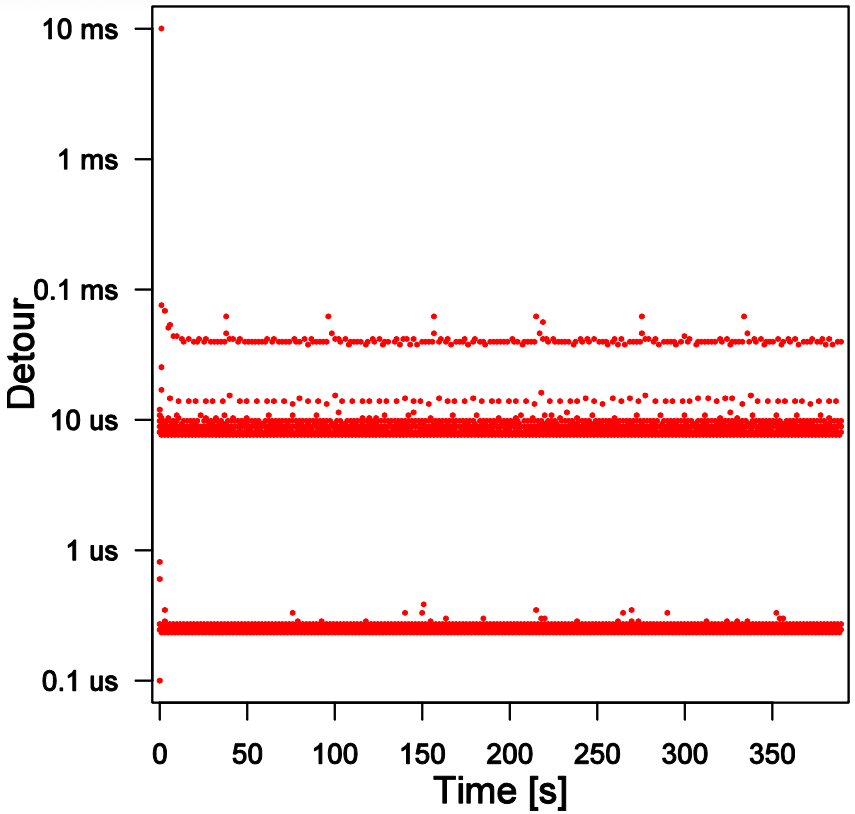
- 2152 Opteron cores, 11.2 Tflop/s Linux 2.6.18
- Resolution: 3.74 ns, noise overhead: 0.21%

Measurement Results – SGI Altix



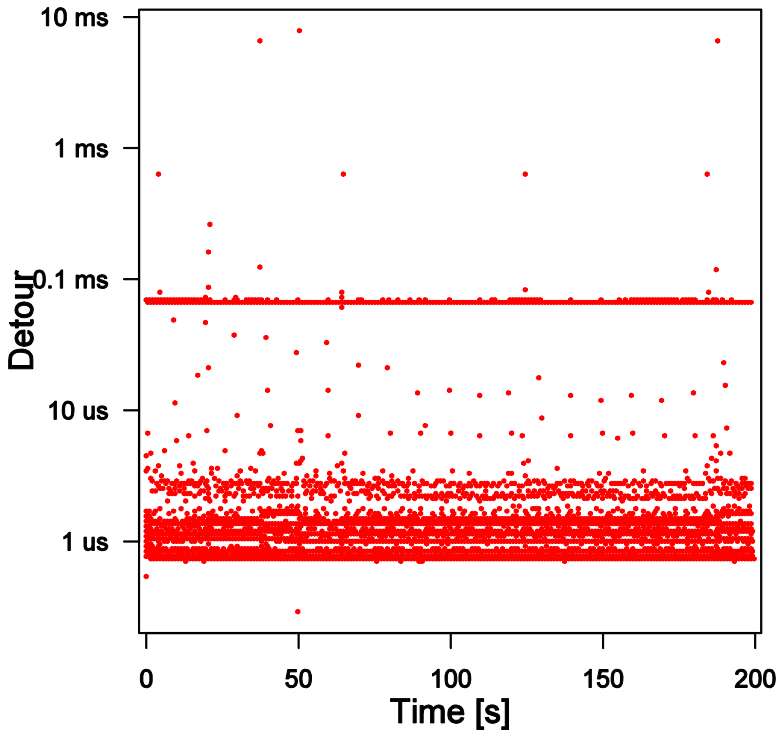
- Altix 4700, 2048 Itanium II cores, 13.1 Tflop/s, Linux 2.6.16
- Resolution: 25.1 ns, noise overhead: 0.05%

Measurement Results – BG/P ZeptoOS



- 164k PPC 450 cores, 485.6 Tflop/s, ZeptoOS 2.6.19.2
- Resolution: 29.1 ns, noise overhead: 0.08%

Measurement Results – Cray XT-4 (Jaguar)



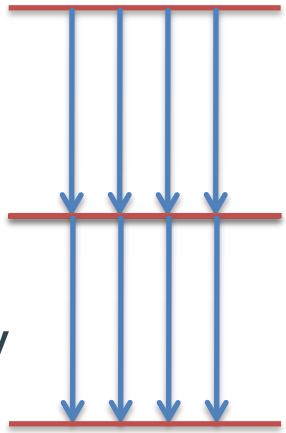
- 150k Opteron cores, 1.38 Pflop/s, Linux 2.6.16 CNL
- Resolution: 32.9 ns, noise overhead: 0.02%

An Analytical Model for Noise Propagation

- Synchronization propagates or absorbs noise
  - Lamport's happens-before-relation for messages
  - Depends on relative time of send/recv (or wait)
- Several protocol-specific details
  - Small (eager), large (rendezvous), and nonblocking
- LogP model to express communication
  - Several missing pieces
  - LogGPS model (Ino et al.) captures most effects!
  - We added "O" to capture s/r overhead per byte

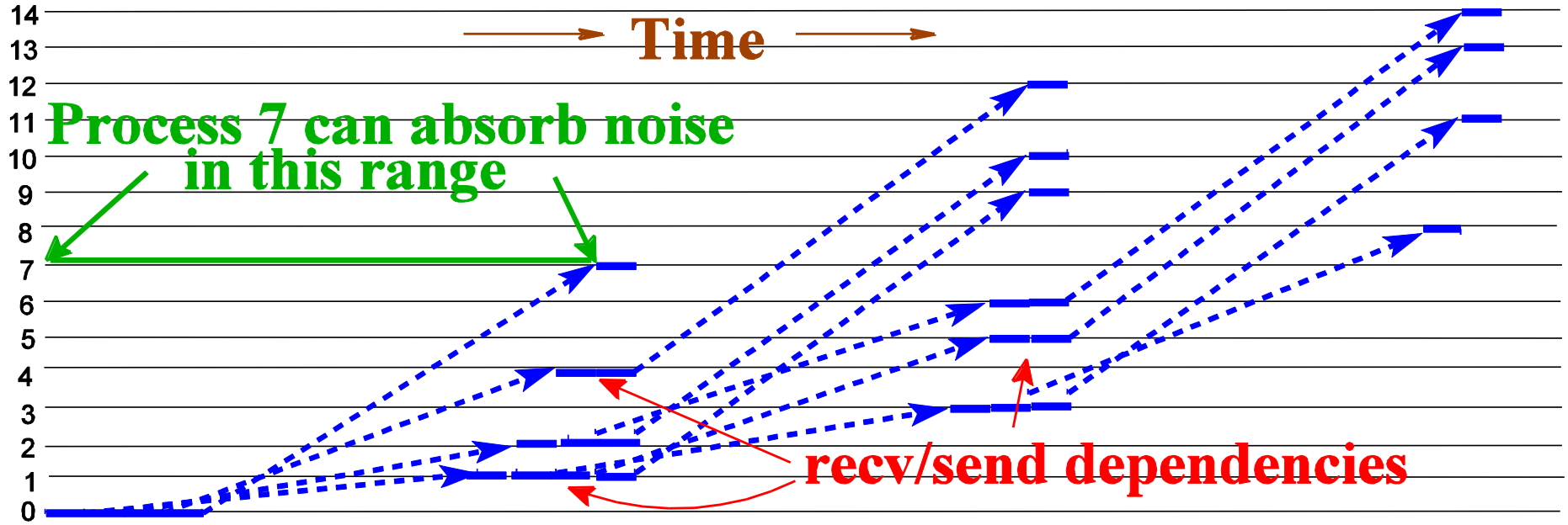
Collective Operations

- MPI-2.2: *"[...] a collective communication call may, or may not, have the effect of synchronizing all calling processes. This statement excludes, of course, the barrier function."*



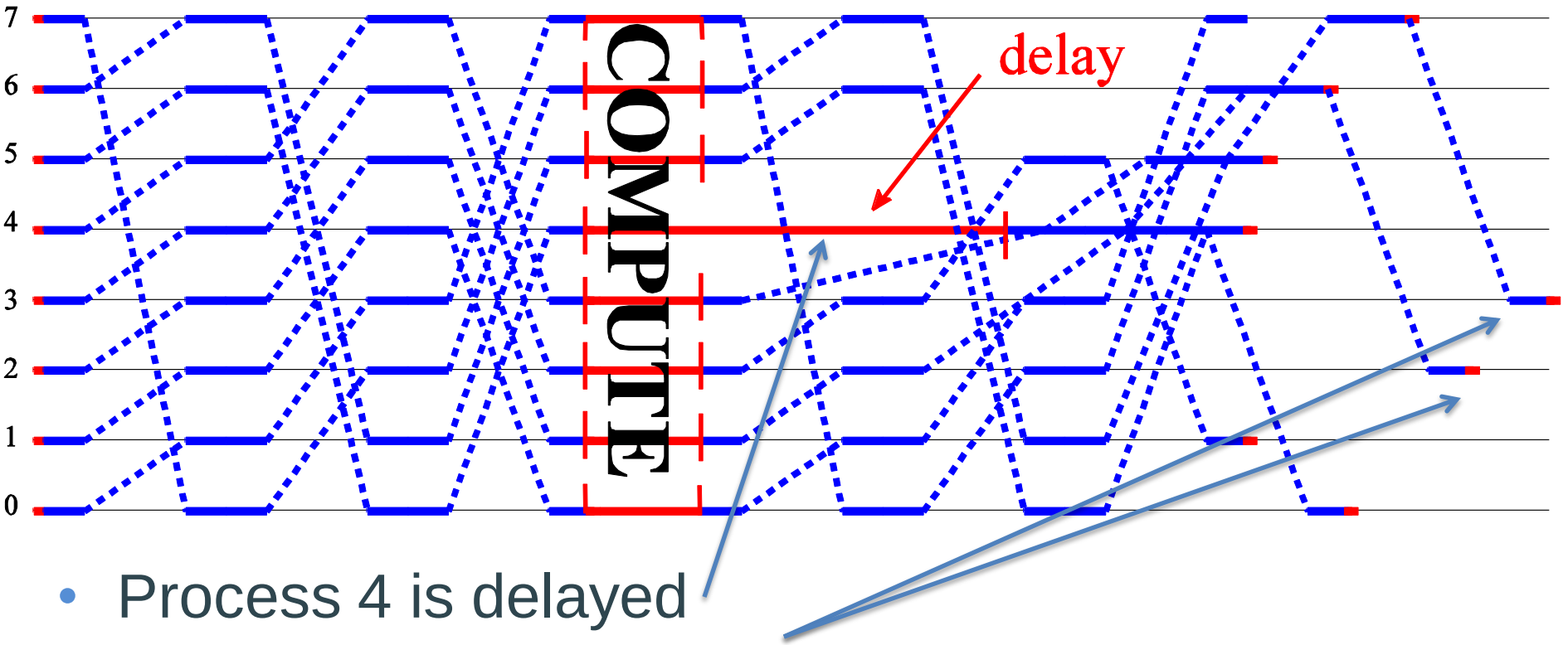
- Main weaknesses in theoretical models:
  - Assumption 1: All collective operations synchronize
    - In fact, many do not (e.g., Bcast, Scan, Reduce, …)
  - Assumption 2: Collectives synchronize instantaneously
    - In fact, they (most likely) communicate with messages
  - Assumption 3: All processes leave collective simultaneously
    - In fact, they leave as early as possible (when data is consistent)

Example: Binomial Broadcast Tree



- Violates all three assumptions:
  - No global or instant synchronization, asynchronous exit

A Noisy Example – Dissemination Barrier



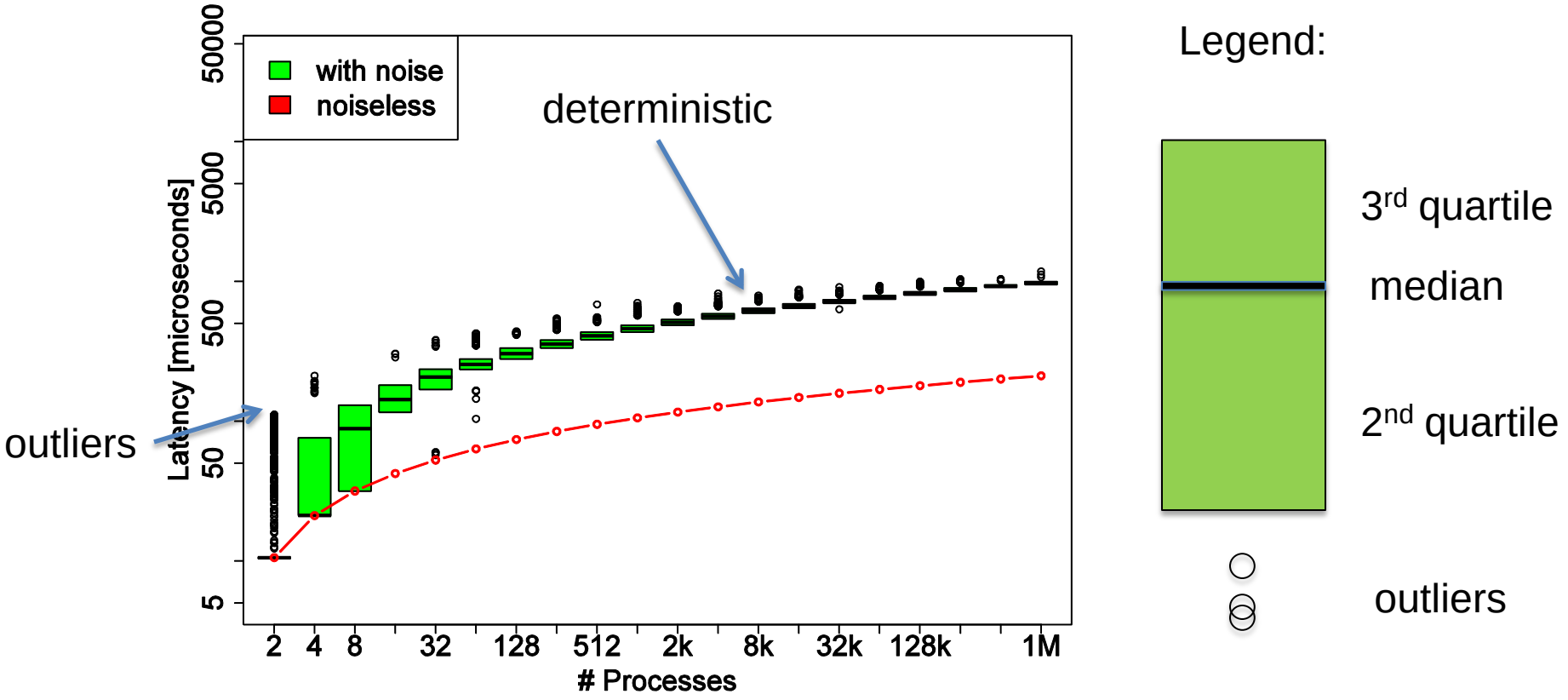
- Process 4 is delayed
  - Noise propagates "*wildly*" (of course deterministic)

LogGOPS Simulation Framework

- Detailed analytical modeling is hard!
- Model-based (LogGOPS) simulator
  - Available at: `http://www.unixer.de/LogGOPSim`
  - Discrete-event simulation of MPI traces (<2% error) or collective operations (<1% error)
  - > 10^6 events per second!
- Allows for trace-based noise injection
  - In o_s, o_r, O, local reduction, and application time
- Validation
  - Simulations reproduce measurements by Beckman and Ferreira well!

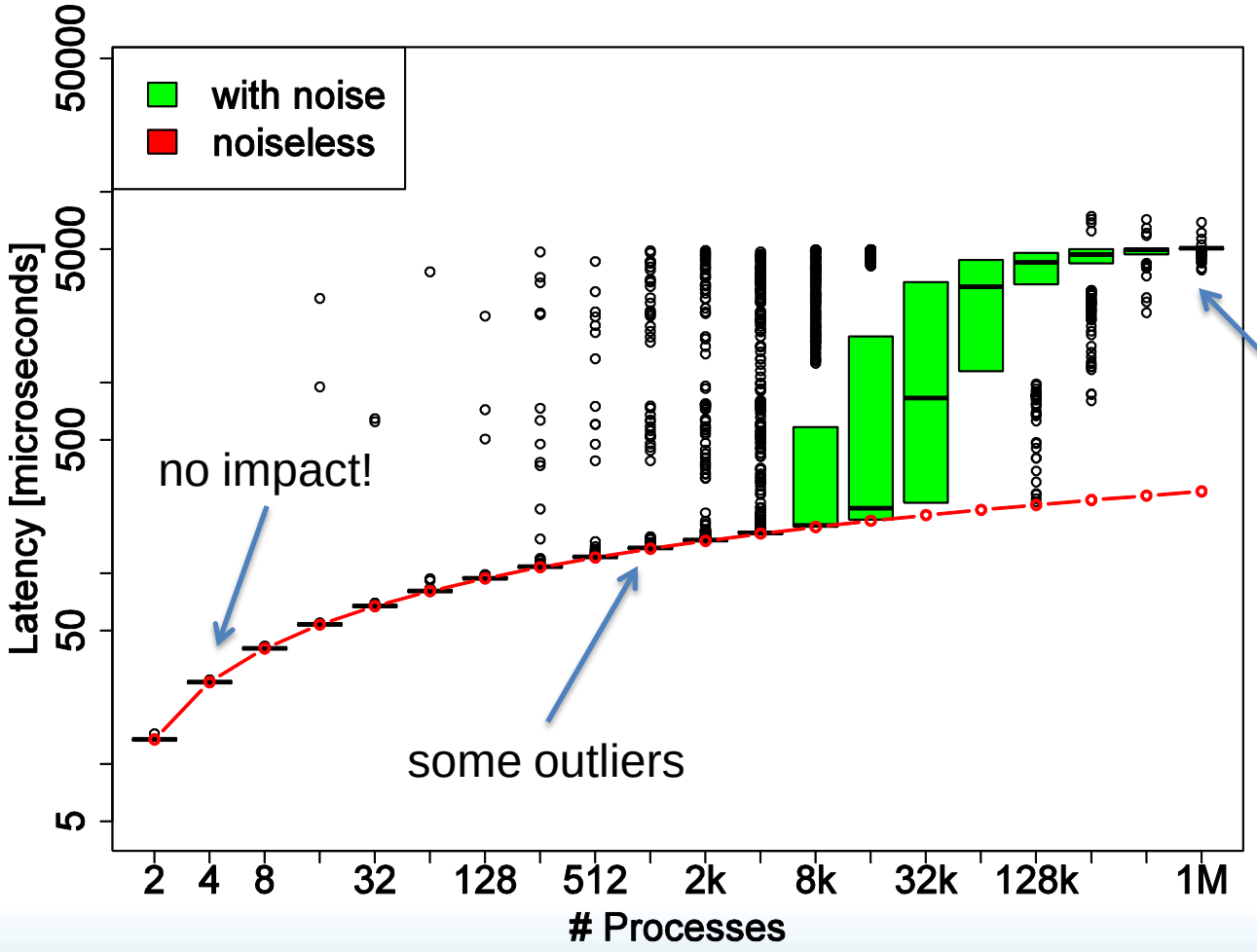
- Details: Hoefler et al. LogGOPSim – Simulating Large-Scale Applications in the LogGOPS Model (Workshop on Large-Scale System and Application Performance, Best Paper)

Single Collective Operations and Noise



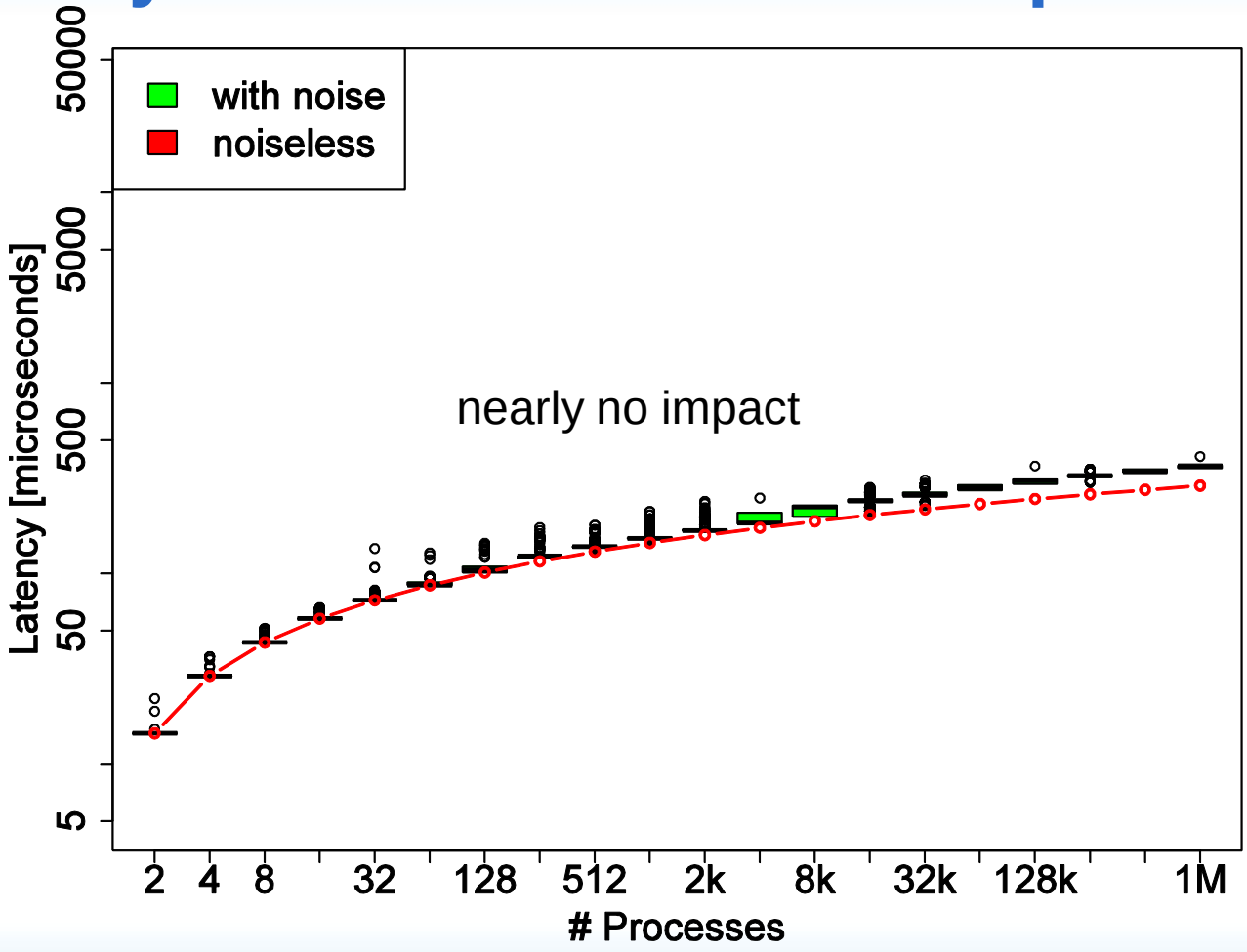
- 1 Byte, Dissemination, regular noise, 1000 Hz, 100 µs

Single Byte Dissemination on Jaguar

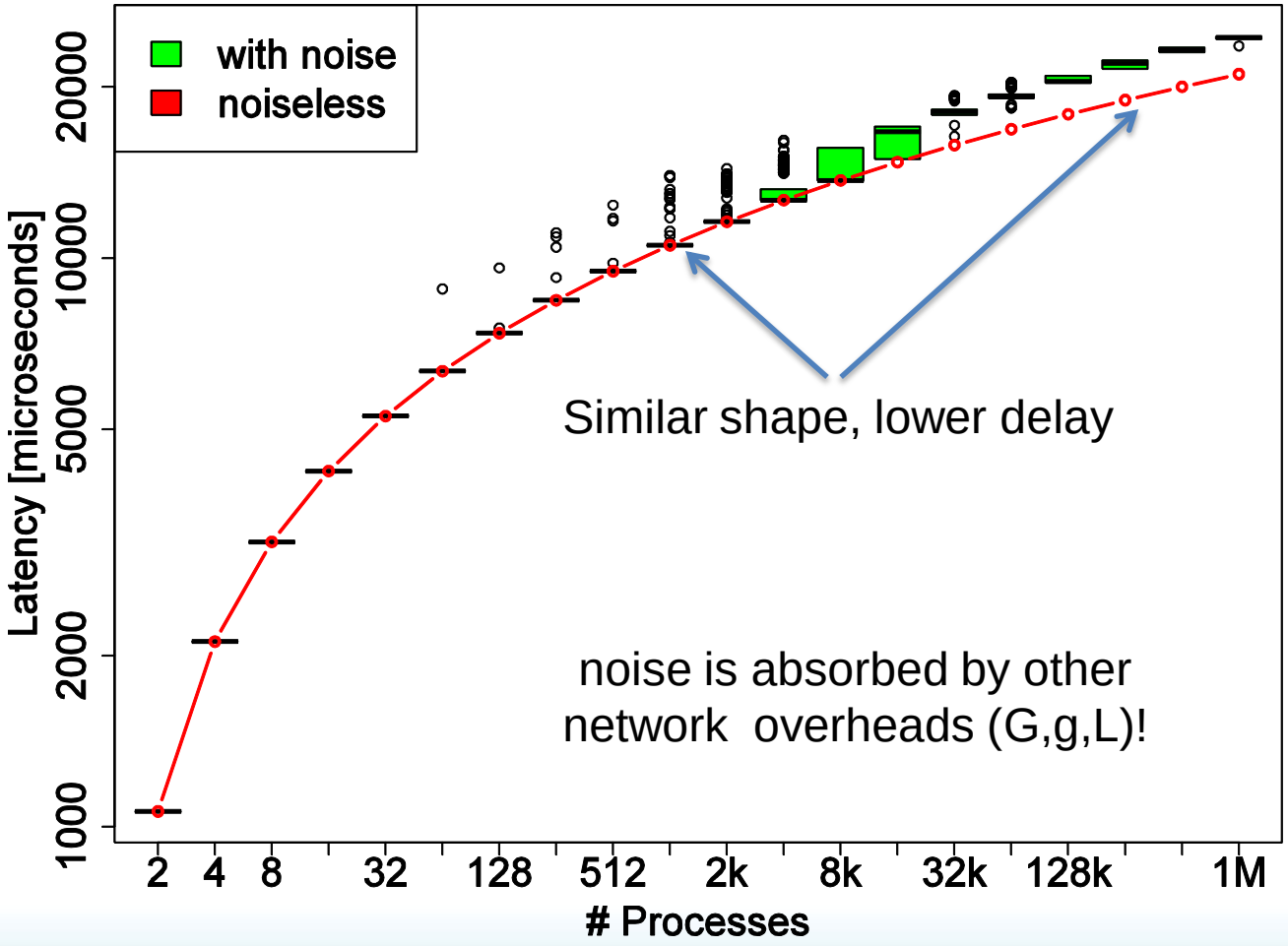


deterministic slowdown (noise bottleneck)

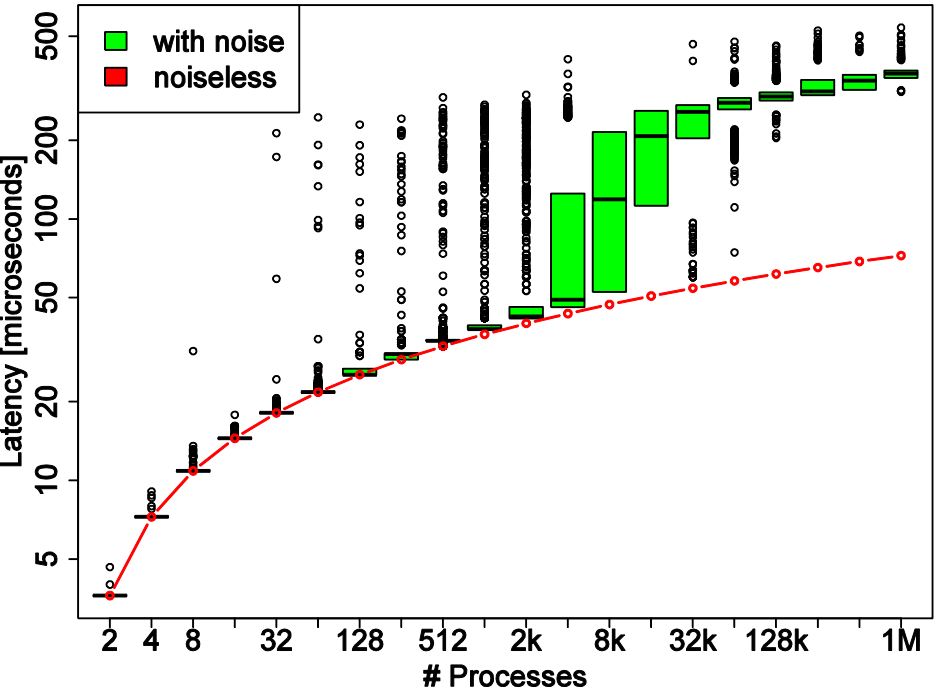
Single Byte Dissemination on ZeptoOS



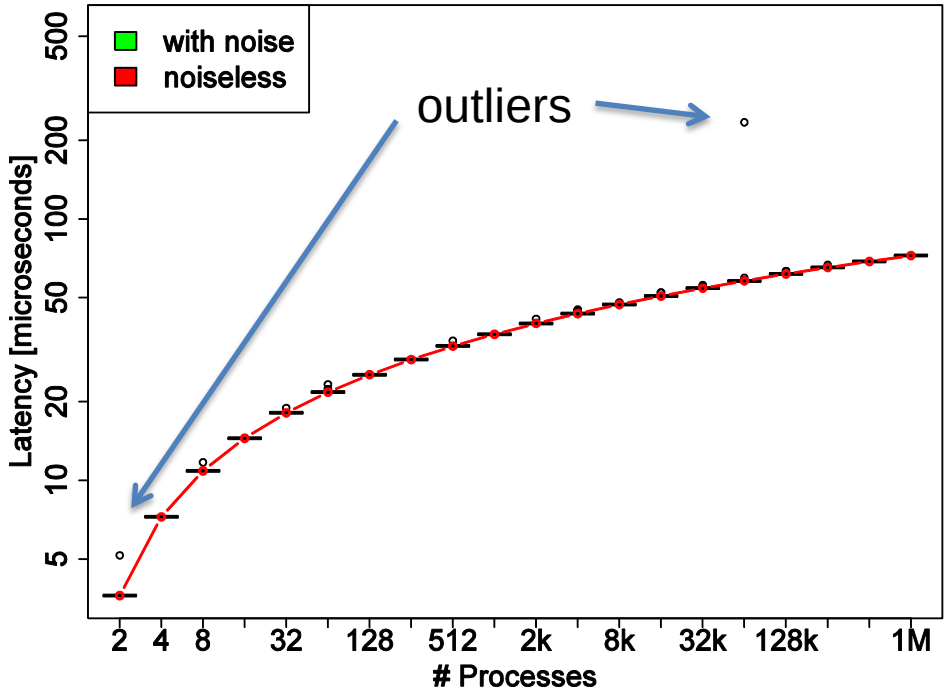
1MiB Messages on Jaguar



Effect of Co-Scheduling Noise (Altix)

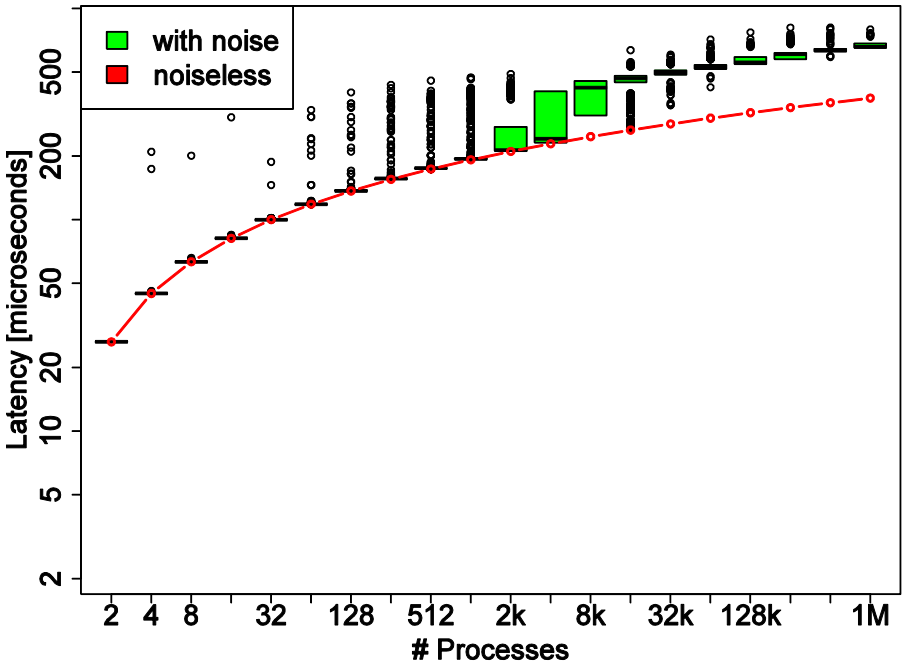


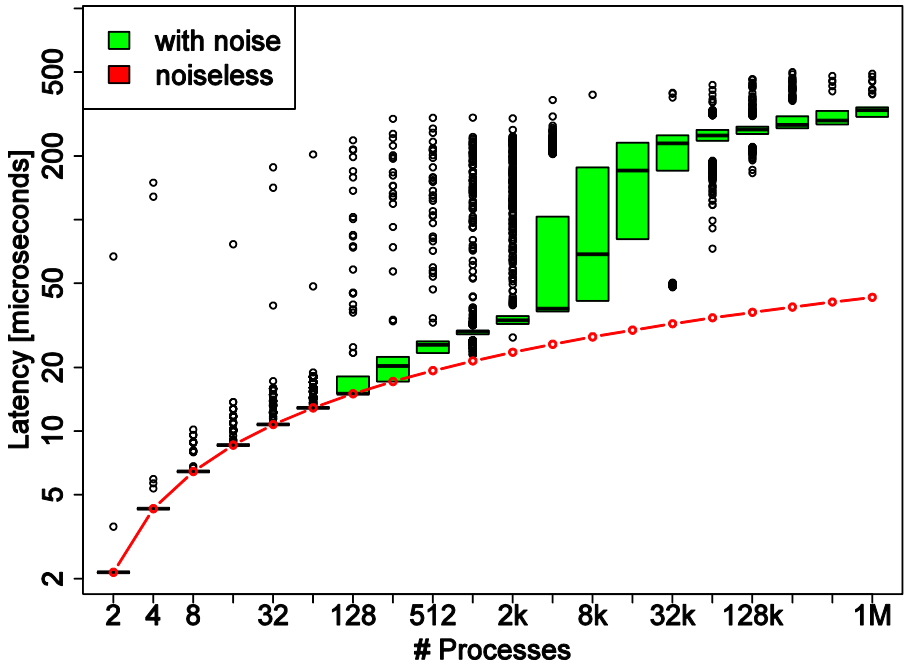
Normal



Co-Scheduled

Does the Network Speed Matter?





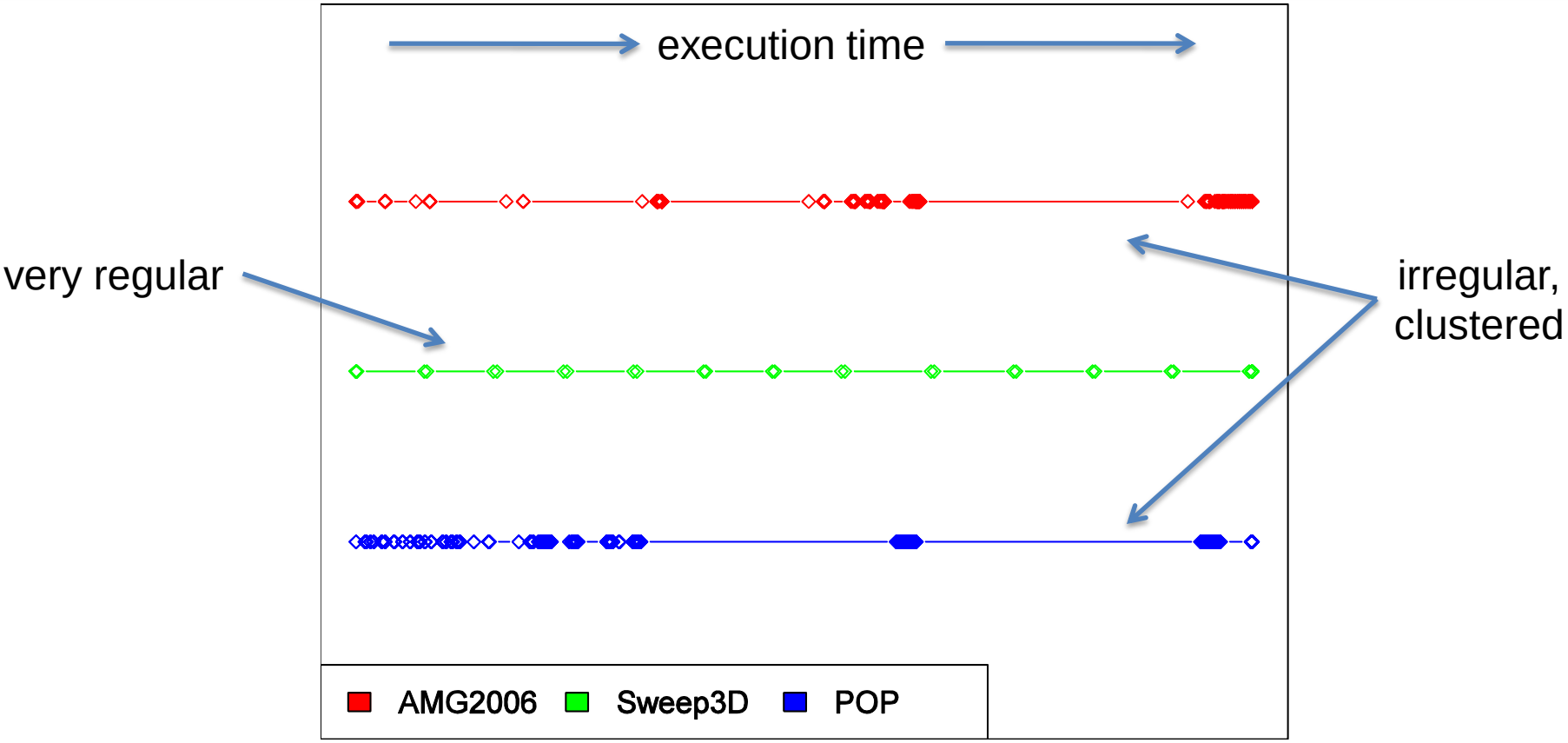
0.1x network speed

10x network speed

Method: increase/decrease L,G,g

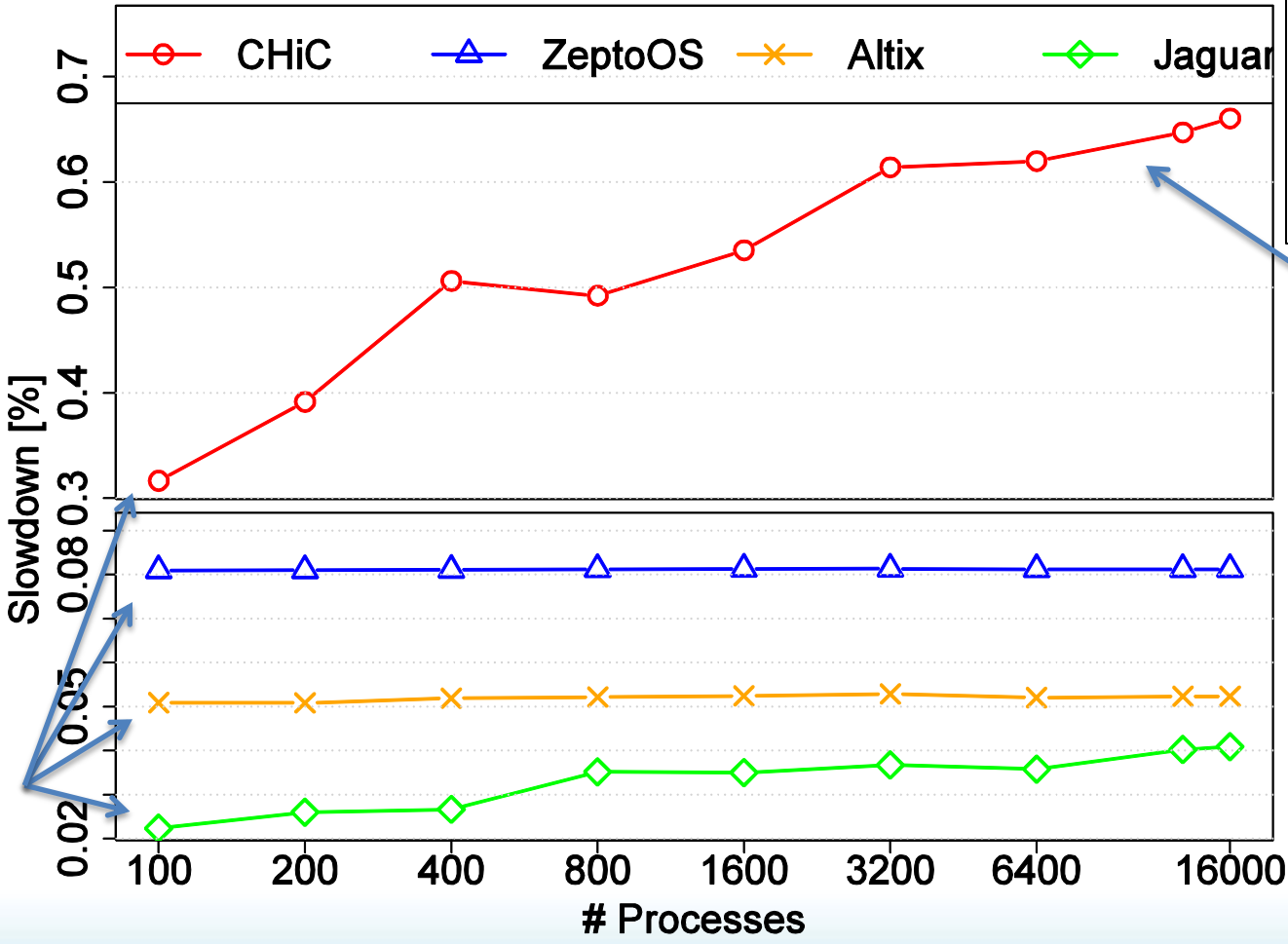
Observation: noise bottleneck independent of network speed

Real Applications



Distribution of Collective Operations

Sweep3D (Collective and Point-to-Point)



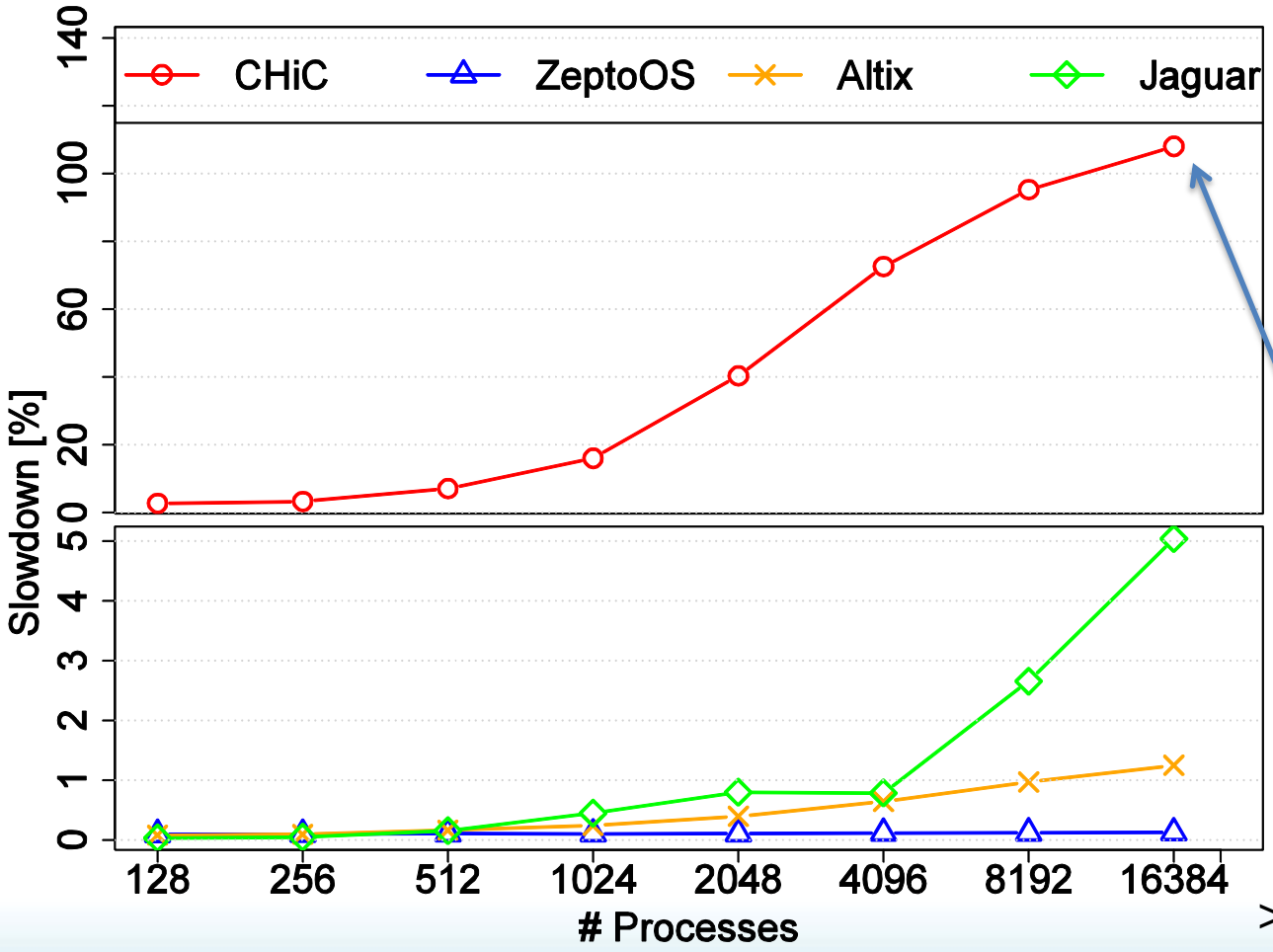
92.4% bl p2p
4 bcast
3 barrier
32 allreduce

<0.7%

serial noise overheads

>289 million messages!

POP (Collective and Point-to-Point)



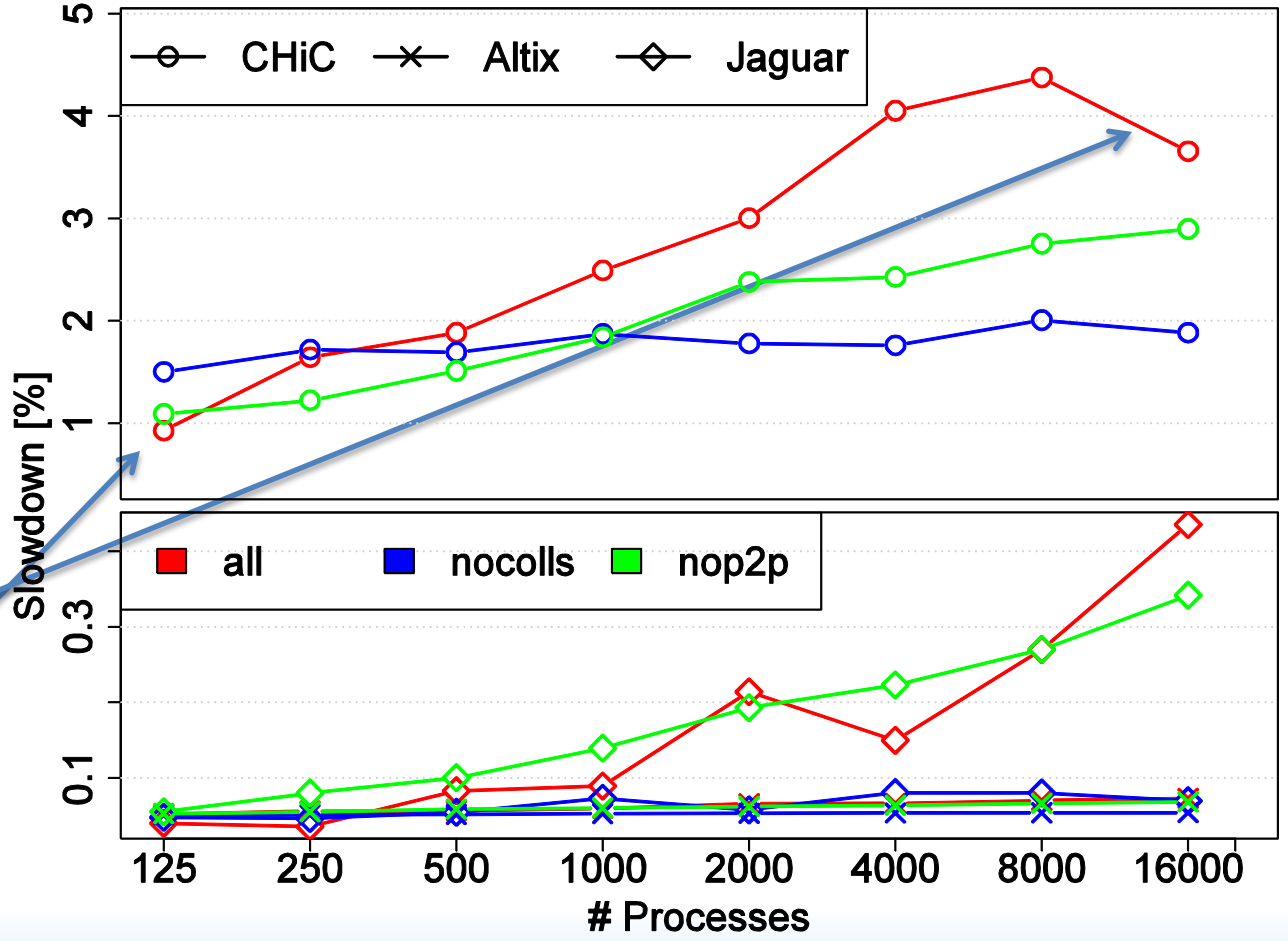
0.2% nb p2p
703 bcast
575 barrier
608 allreduce

>2x slowdown!

>625 million messages!

Does Point-to-Point Communication Matter?

AMG 2006

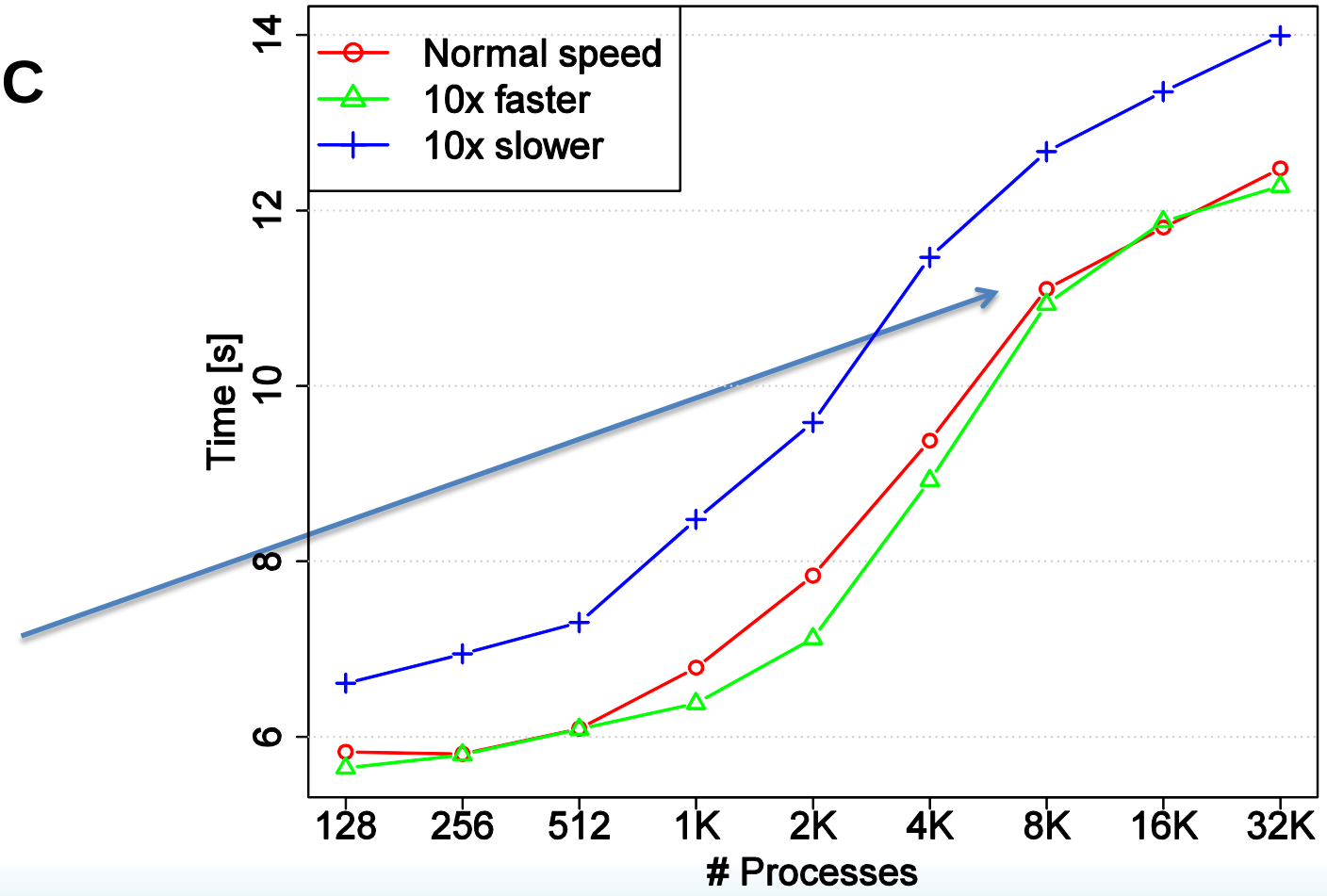


p2p propagates

p2p absorbs

Influence of Network Speed on Applications

POP @ CHiC



Noise bottleneck: faster network does not increase performance

Conclusions & Future Work

- Modeling OS noise is not that simple
  - Will validate used models with simulation
- Model-based simulation approach scales well
  - Results match previous benchmark studies (<6% error)
- Overhead depends on noise *shape* rather than *intensity*
  - ZeptoOS shows nearly no propagation! (0.08% overhead)
  - Cray XT is severely impacted! (0.02% overhead)
- Noise bottleneck is serious at scale!
  - Faster network or CPU cannot help, noise will dominate!
- We developed a tool-chain to adjust the bottleneck
  - Available online: `http://www.unixer.de/LogGOPSim`

Collaborators, Acknowledgments & Support

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