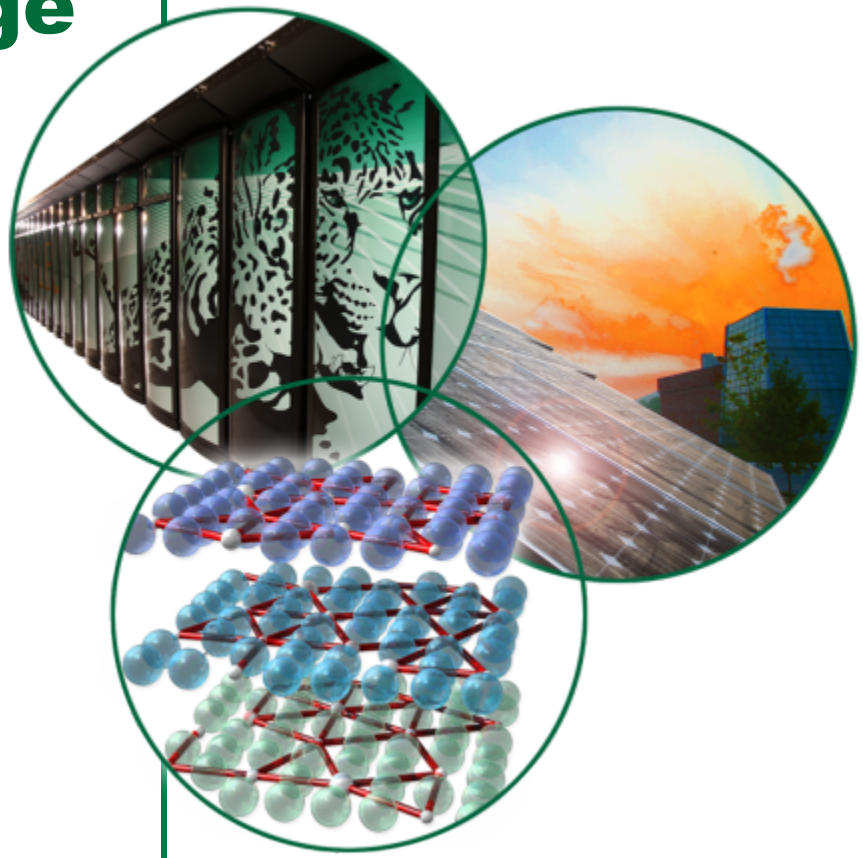
Supporting the Development of Soft-Error Resilient Message Passing Applications using Simulation



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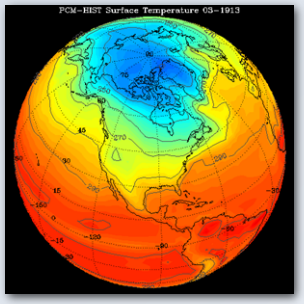
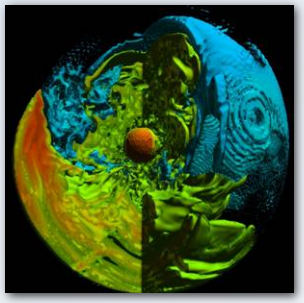
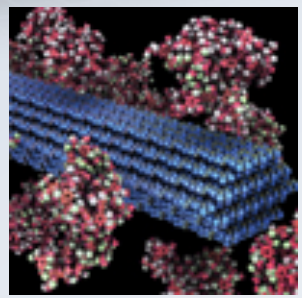
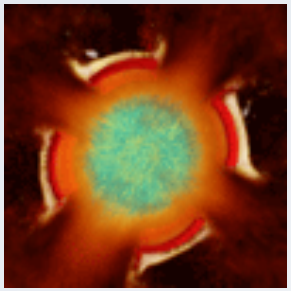
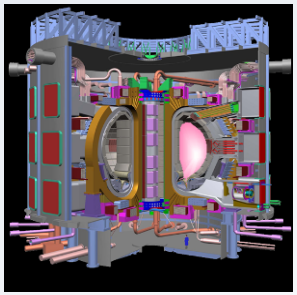
Scientific Computing and Simulation at ORNL

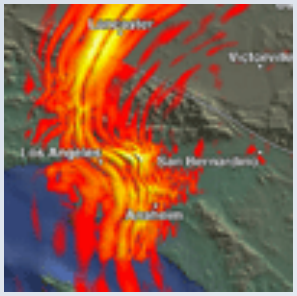


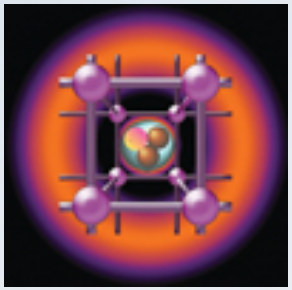


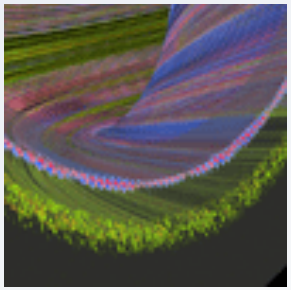


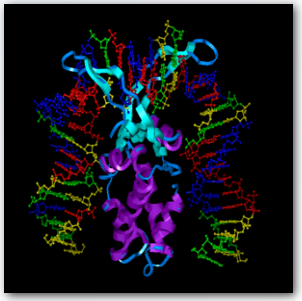










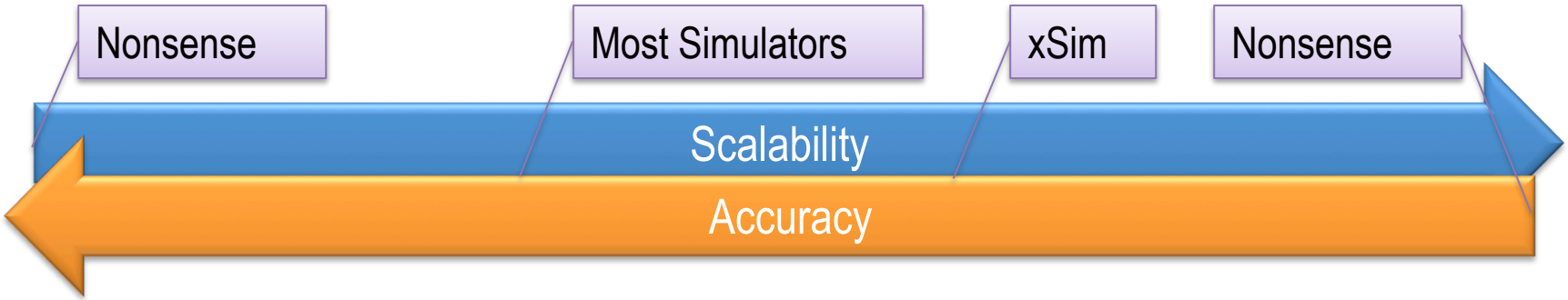


Motivation

- At the forefront of extreme-scale scientific computing
  - Titan at ORNL: Currently 2nd fastest supercomputer in the world
  - 560,640 cores (AMD Opteron + NVIDIA Kepler GPUs, 17.6 PFlops)
- We are on road to exascale computing: 1,000 Pflop/s by 2023
  - Potentially billions of densely-packed compute cores
- There are several major challenges:
  - *Power consumption*: Envelope of ~20-40 MW (drives everything else)
  - *Programmability*: Accelerators and PIM-like architectures
  - *Performance*: Extreme-scale parallelism (up to 1B hardware threads)
  - *Data movement*: Complex memory hierarchy and locality
  - *Data management*: Too much data to track and store
  - *Resilience*: Faults will occur continuously

HPC Hardware/Software Co-Design

- Helps closing the system-peak vs. application performance gap
- Execution of real applications, algorithms, or their models atop a simulated HPC environment at scale for:
  - Performance evaluation, including identification of resource contention and underutilization issues
  - Investigation at extreme scale, beyond the capabilities of existing simulation efforts
- xSim: A highly scalable solution that trades off accuracy



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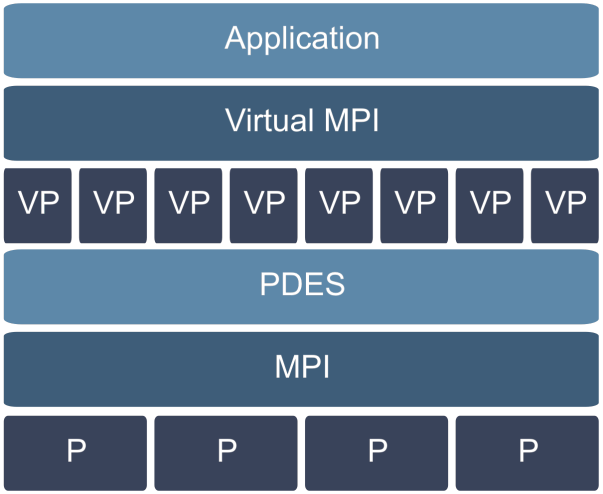
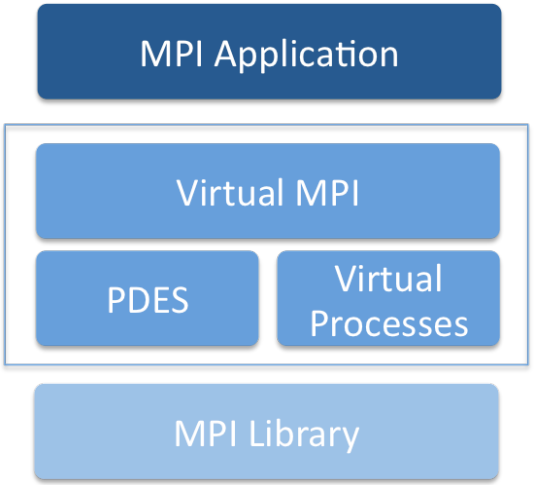
xSim – The Extreme-Scale Simulator

- A simulation-based performance/resilience investigation toolkit for MPI applications
- Combining oversubscribed execution, a virtualized MPI & POSIX API, and a time-accurate parallel discrete event simulation
- Support for C, C++ and Fortran applications
- Easy to use:
  - Compile the application with xSim header
  - Link the application with the xSim library
  - Run: mpirun -np <np> <application>\
    -xsim-np <virtual process count>\
    <simulation parameters>\
    <application parameters>



Architecture



Design

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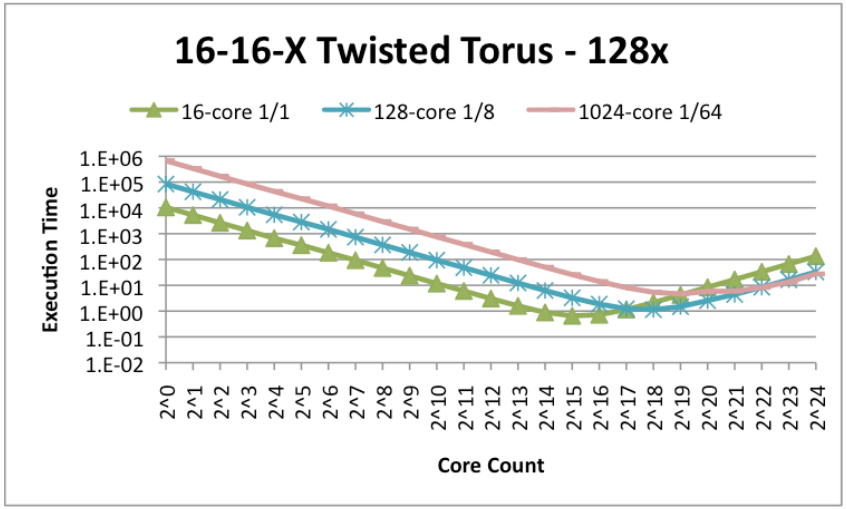
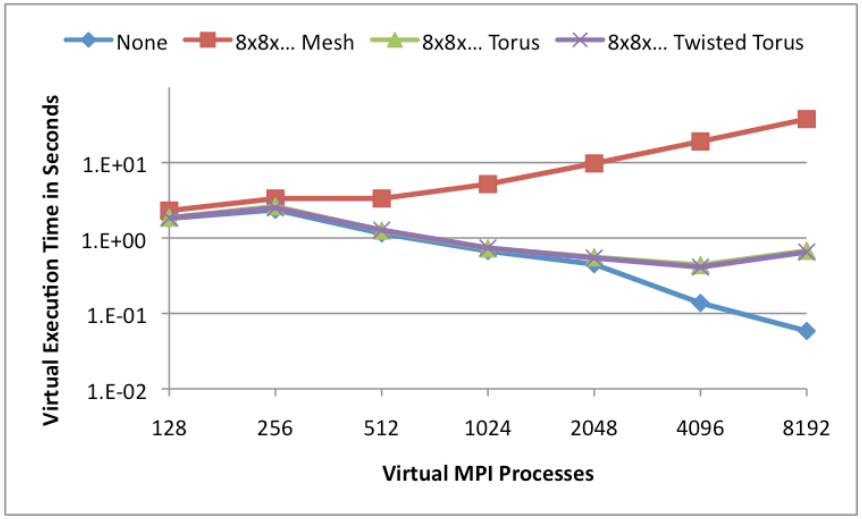
xSim Performance Simulation Features

- Simulated timing with scaling processor model
  - Application executed on native processor
  - Simulated timing is relative to native
  - Operating system noise injection
  - Does not support accelerators yet
- Simulated timing with network model
  - Completely simulated network at the MPI messaging level
  - Latency, bandwidth, contention, routing, and rendezvous protocol
  - Star, ring, mesh, torus, twisted torus, and tree topologies
  - Hierarchical combinations of topologies, e.g. on-chip, on-node, & off-node



Monte Carlo solver w/ different core speeds/counts



NAS MG in a dual-core 3D mesh or twisted torus

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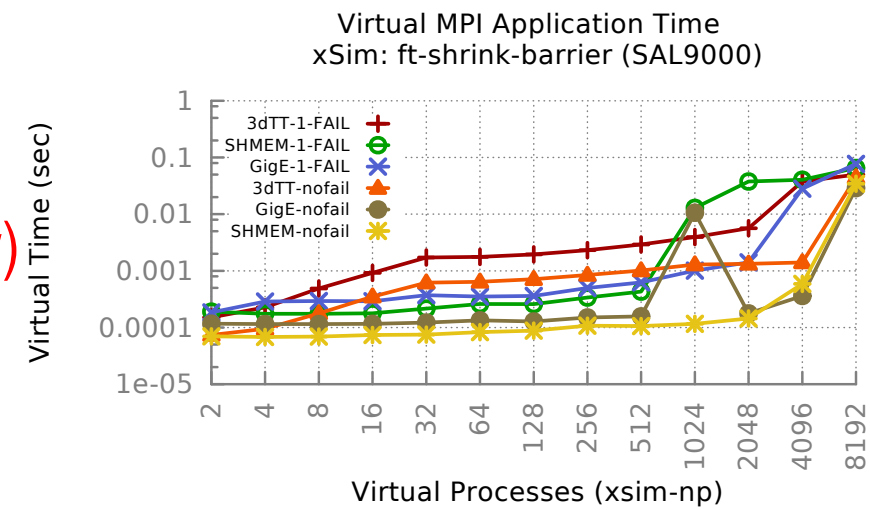
Resilience Simulation Features

- Simulating MPI process failures
  - Injection, propagation, and detection in simulated architecture during application execution
- Simulating MPI application checkpoint abort, and restart cycle
- Simulating fault tolerant MPI
  - Implementation of the User-level failure mitigation proposal of the MPI fault Tolerance Working Group
- Simulating memory bit flip faults (new)
  - Injection in during application
  - High degree of injected fault types (e.g., SECDED ECC faults in main memory vs. parity faults in registers)

Table 1: Varying the checkpoint interval and system MTTF

$MTTF_S$	C	E_1	E_2	F	$MTTF_A$
—	1,000	5,248 s	—	0	—
6,000 s	500	5,258 s	7,957 s	1	3,978 s
6,000 s	250	6,377 s	7,074 s	1	3,537 s
6,000 s	125	6,601 s	6,750 s	1	3,375 s
3,000 s	500	5,258 s	10,584 s	2	3,528 s
3,000 s	250	6,377 s	8,618 s	2	2,872 s
3,000 s	125	6,601 s	7,948 s	2	2,649 s



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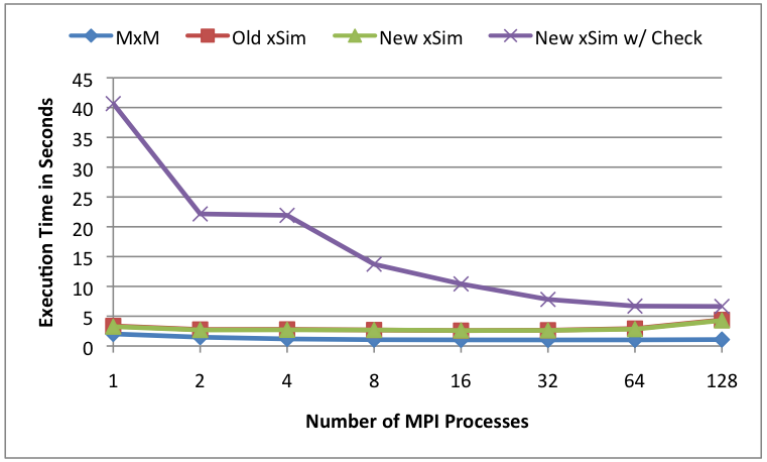
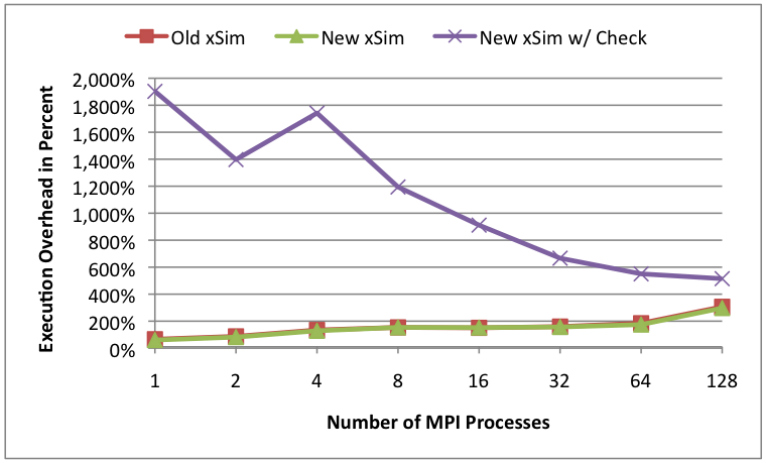
New Resilience Simulation Features

- Radiation-induced bit flip faults are of particular concern in extreme-scale HPC systems
- A newly added bit flip fault injection feature:
  - Permits the specification of injection location(s),
  - Allows the specification of fault activation time(s), and
  - Supports a significant degree of configurability to study different fault scenarios in detail.
- *xSim is the very first simulation-based MPI performance tool that supports the injection of MPI process failures and bit flip faults*

Results: Simulator Performance

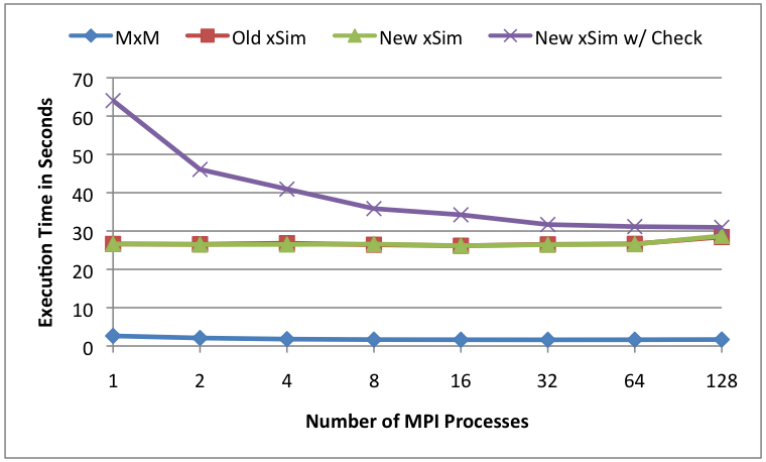


(a) Comparison of execution times in seconds

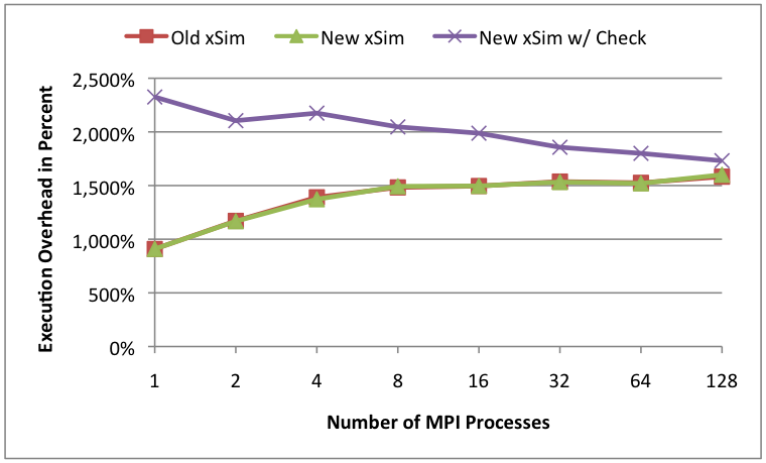


(b) Simulator execution overheads in percent

Figure 1. Performance evaluation of the matrix-matrix multiply application vs. running it atop the old xSim vs. running it atop the new xSim, all without file I/O



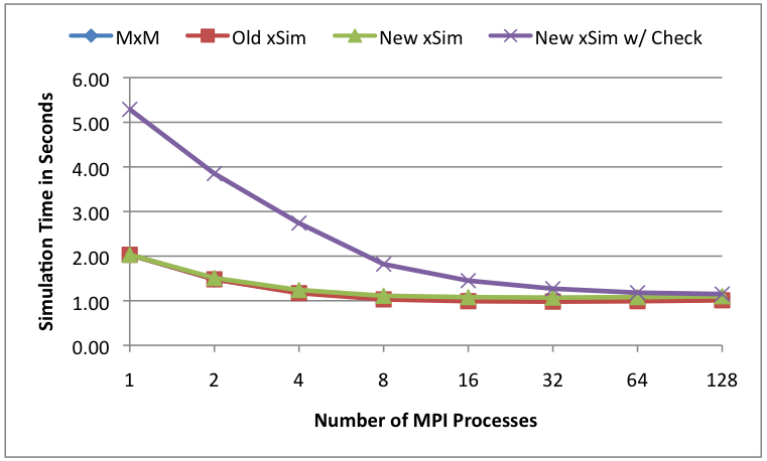
(a) Comparison of execution times in seconds



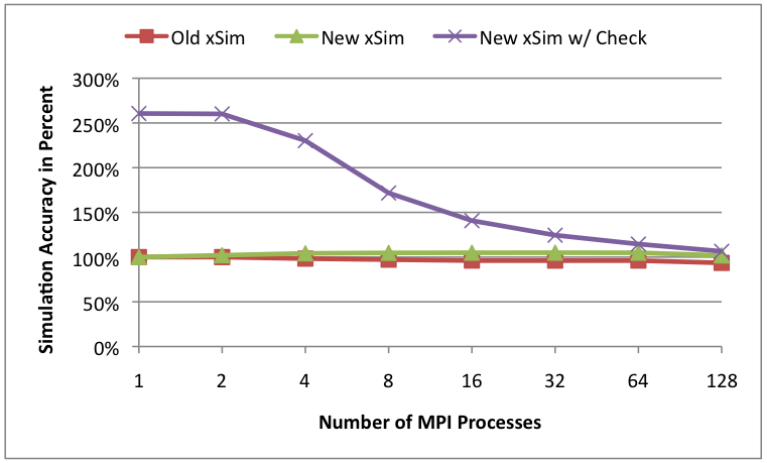
(b) Simulator execution overheads in percent

Figure 2. Performance evaluation of the matrix-matrix multiply application vs. running it atop the old xSim vs. running it atop the new xSim, all with file I/O

Results: Simulation Accuracy

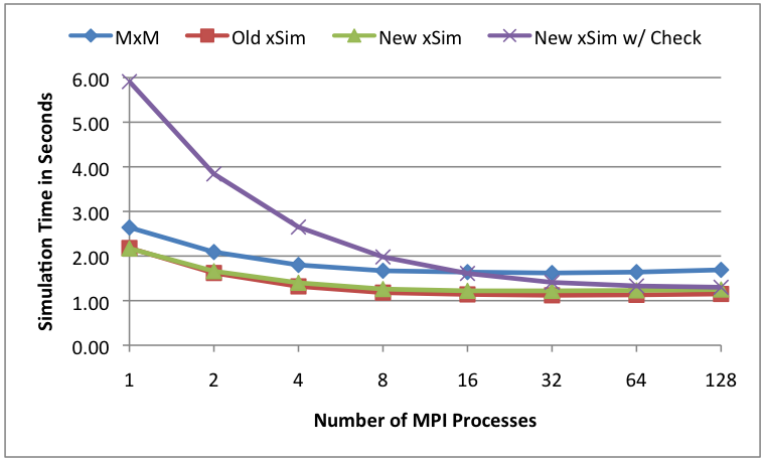


(a) Comparison of native vs. simulated execution times in seconds



(b) Simulation accuracy in percent

Figure 3. Simulation accuracy evaluation of the the old xSim vs. the new xSim with the matrix-matrix multiply application without file I/O



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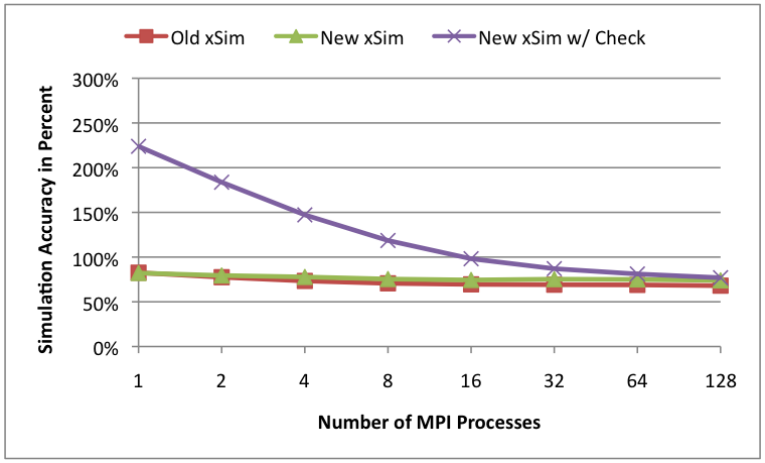
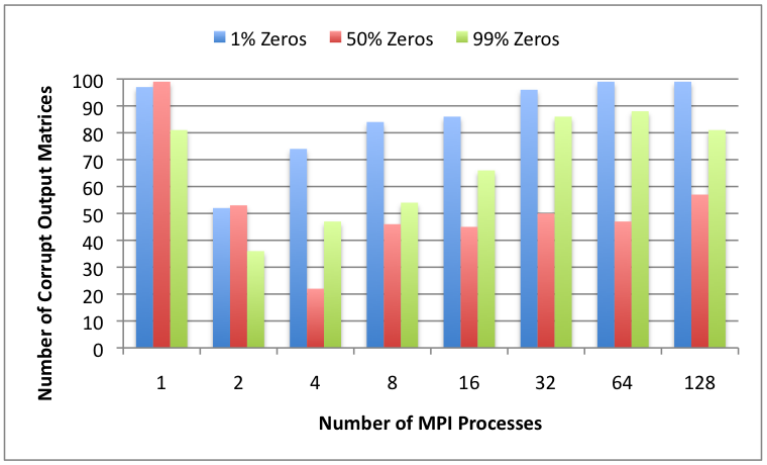


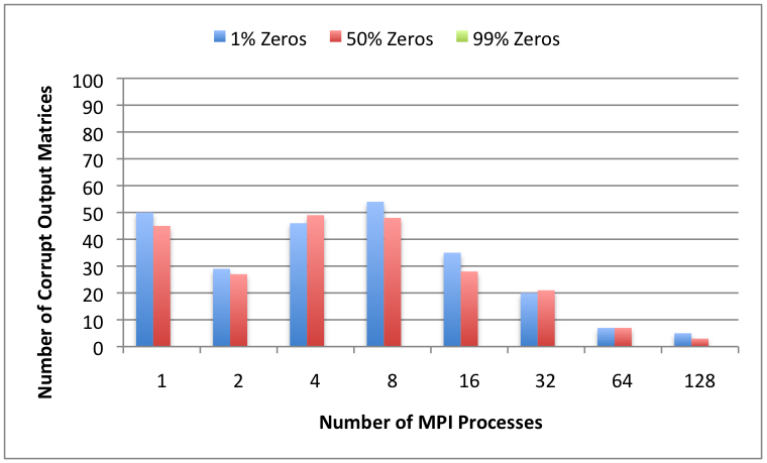
(b) Simulation accuracy in percent

Figure 4. Simulation accuracy evaluation of the the old xSim vs. the new xSim with the matrix-matrix multiply application with file I/O

Results: Fault Injection Campaign

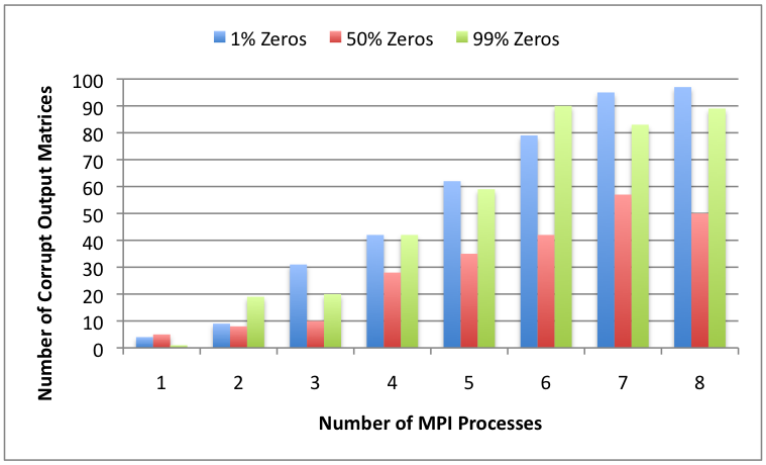


(a) Matrix A injections



(b) Matrix C injections

Figure 5. The number of output matrices C corrupted by fault injection with calling the `check()` function



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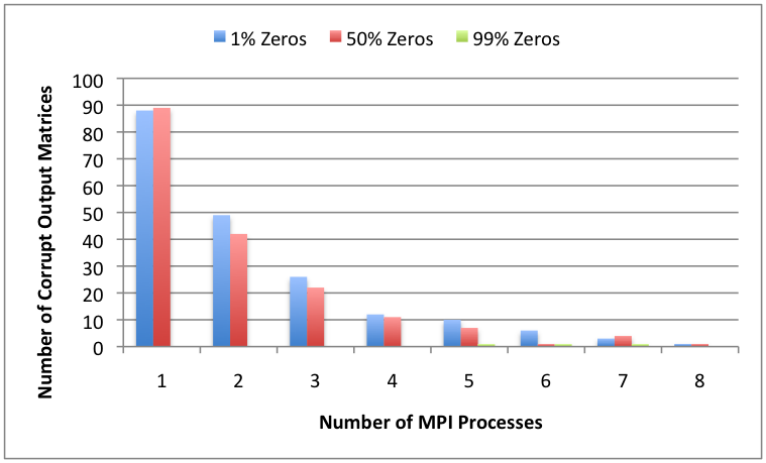

(b) Matrix C injections

Figure 6. The number of output matrices C corrupted by fault injection without calling the `check()` function

Conclusion

- The Extreme-scale Simulator (xSim) is a performance/resilience investigation toolkit that utilizes a PDES and oversubscription
- It can simulate future-generation extreme-scale HPC systems
- The new features enable the injection of bit flip faults at specific of injection location(s) and fault activation time(s), while supporting a significant degree of configurability of the fault type.
- Experiments show that the simulation overhead with the new feature is ~2,325% for serial execution and ~1,730% at 128 MPI processes, both with very fine-grain fault injection
- *It is the very first simulation-based MPI performance tool that supports the injection of MPI process failures and bit flip faults*

Questions