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
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>
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

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

<table>
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<tr>
<th>MTTF <em>S</em> (s)</th>
<th>C</th>
<th>E₁ (s)</th>
<th>E₂ (s)</th>
<th>F</th>
<th>MTTF <em>A</em> (s)</th>
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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

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

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

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

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

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

(a) Matrix $A$ injections
(b) Matrix $C$ injections

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

(a) Matrix $A$ injections
(b) Matrix $C$ injections
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 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.*
