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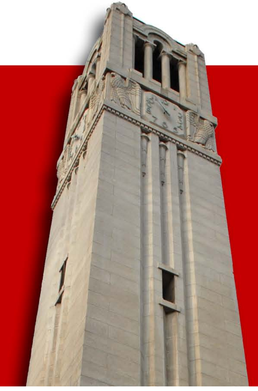

Detection and Correction of Silent Data Corruption for Large-Scale High-Performance Computing

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Sandia National Laboratories

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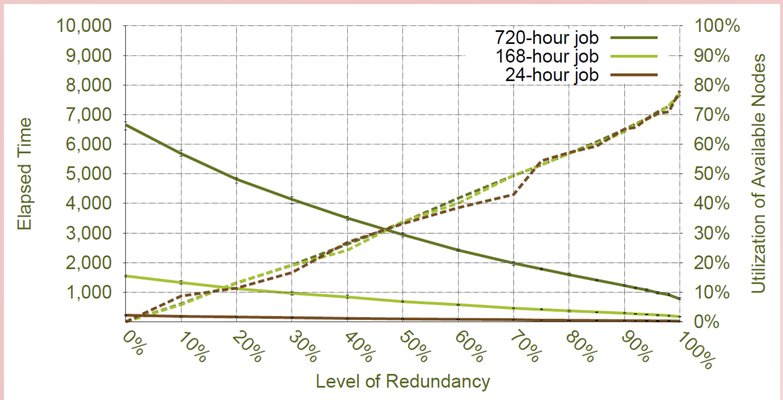
Motivation

- Component failures require support of checkpoint/restart (C/R)
- Adding hardware increases the likelihood of faults
  - The probability of component failure combinatorially explodes
  - The mean-time-between-failure (MTBF) shortens
  - Overhead due to C/R increases exponentially
    - Computation vs. overhead ratio can be between 85%-55%
- Redundancy can reverse this trend
  - Each redundant process decreases the probability of failure of replica processes
  - Less interruptions produces greater utilization
  - 100% redundancy provides 5x job throughput [Sandia]



- Silent Data Corruption (SDC) faults manifest themselves as bit-flips in storage or even within processing cores
  - In some cases bit-flips are not correctable or even detected
  - Exacerbating this situation, when SDC goes undetected invalid results are reported
    - Memory becomes corrupt, but applications continue to run
    - This is a severe problem for today's large-scale simulations

Contributions

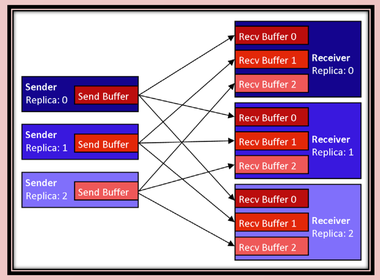
- Design and implementation of efficient mechanisms for fault tolerance in HPC
  - Propose efficient protocols for SDC protection
  - Investigate the cost of different levels of redundancy
- Demonstrate capabilities of SDC protection at the communication layer
  - Through fault injection we study failures in a native cluster environment

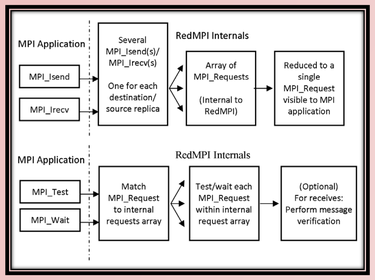
Design

- Provide transparency by linking unmodified MPI applications with our library: RedMPI
- RedMPI provides redundancy to MPI applications by instrumenting the MPI profiling layer
  - Adjusted MPI rank and size provide illusion of normal rank numbers
  - SDC protection is afforded by augmenting MPI_Isend, MPI_Irecv, and MPI_Wait/MPI_Test to communicate with replicas

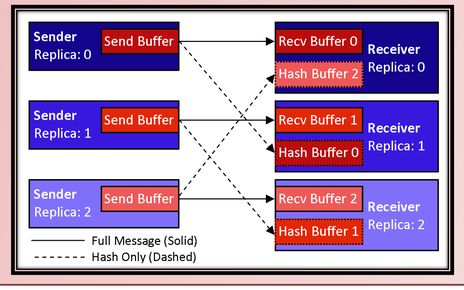
	No Redundancy	Dual Redundancy	Triple Redundancy or higher
Live SDC Detection	✗ No	✓ **Yes**	✓ **Yes**
Live SDC Correction	✗ No	✗ No	✓ **Yes** (via voting algorithm)

- Naïve SDC protection may be achieved by transmitting and comparing *r*r* messages amongst *r* total replicas.
  - Induces high interconnect contention / bandwidth degradation
  - Compare received buffers, discard a mismatch





- Enhance performance by sending the original message plus a small hash to a separate replica
  - No longer dependent on *r*r* communication
  - Comparison still performed on receiver-side
  - Hash mismatch triggers secondary voting protocol amongst receiving replicas



Results

- Experiments performed on 96 cluster nodes
  - AMD Opteron 6128 (Magny Core) – 16 cores per node
  - 32GB RAM per node
  - 40Gbit/s Infiniband for MPI Communication
  - Gigabit ethernet for network filesytem

1x: Uninstrumented Open MPI (No Redundancy)
2x: RedMPI with Dual Redundancy
3x: RedMPI with Triple Redundancy

LAMMPS – CHUTE.SCALE					
Size	1x [sec]	2x [sec]	3x [sec]	2x OV	3x OV
128	137.5	138.4	139.0	0.6%	1.1%
256	138.3	140.4	140.0	1.6%	1.3%
512	139.2	140.2	141.0	0.7%	1.1%

SWEEP3D					
Size	1x [sec]	2x [sec]	3x [sec]	2x OV	3x OV
128	390.3	389.5	393.1	-0.2%	0.7%
256	428.2	427.5	431.2	-0.1%	0.7%
512	488.1	488.9	494.1	0.2%	1.2%

HPCCG					
Size	1x [sec]	2x [sec]	3x [sec]	2x OV	3x OV
128	99.8	99.8	125.8	0.0%	26.0%
256	99.6	128.8	131.0	29.3%	31.5%
512	126.4	146.2	152.3	15.7%	20.5%

NPB - CG					
Size	1x [sec]	2x [sec]	3x [sec]	2x OV	3x OV
128-D	201.4	205.9	215.5	2.2%	7.0%
256-D	127.2	132.6	136.6	4.2%	7.4%
512-D	70.1	77.5	83.7	10.6%	19.4%

NPB-EP					
Size	1x [sec]	2x [sec]	3x [sec]	2x OV	3x OV
128-D	72.3	72.6	72.7	0.4%	0.6%
256-E	579.9	581.0	581.2	0.2%	0.2%
512-E	289.8	290.8	291.3	0.4%	0.5%

- The cost of triple redundancy is relatively low after dual redundancy
- Redundancy is a viable method to detect and protect from SDCs
- Fault injection experiments successfully demonstrate capacity to detect and correct SDCs in a cluster environment

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