A Tunable Holistic Resiliency Approach for High-Performance Computing Systems

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Motivation

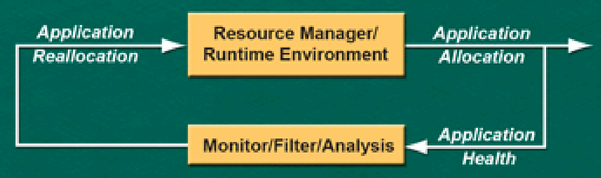
- The 1PFlop/s (10^{15} Floating Point Operations Per Second) barrier has been broken
  - #1: LANL Roadrunner with 129,600 processor cores
  - #2: ORNL Jaguar with 150,152 processor cores
- Other large-scale systems exist
  - LLNL @ 212,992, ANL @ 163,840, TACC @ 62,976
- The trend is toward even larger-scale systems
- The significant increase in component count and complexity leads to an increase in failure frequency
- Checkpoint/restart is becoming less and less efficient

Reactive vs. Proactive Fault Tolerance

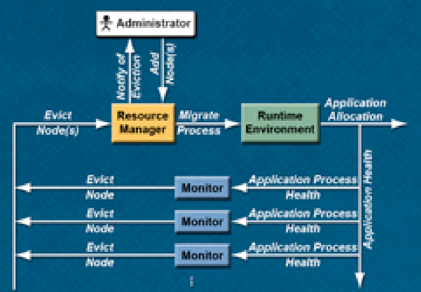
- Reactive fault tolerance
  - Keeps parallel applications alive through recovery from experienced failures
  - Employed mechanisms react to failures
  - Examples: Checkpoint/restart, message logging/replay
- Proactive fault tolerance
  - Keeps parallel applications alive by avoiding experiencing failures through preventative measures
  - Employed mechanisms anticipate failures
  - Example: Preemptive migration

Proactive Fault Tolerance using Preemptive Migration

- Relies on a feedback-loop control mechanism
  - Application health is constantly monitored and analyzed
  - Application is reallocated to improve its health and avoid failures
  - Closed-loop control similar to dynamic load balancing
- Real-time control problem
  - Need to act in time to avoid imminent failures
- No 100% coverage
  - Not all failures can be anticipated, such as random double-bit ECC errors

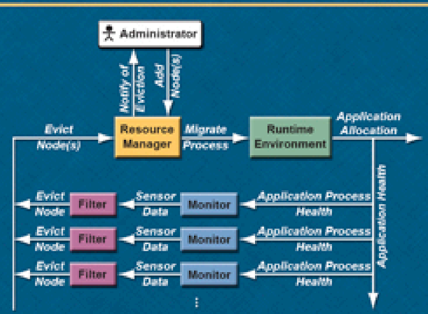


Feedback-Loop Control Architecture



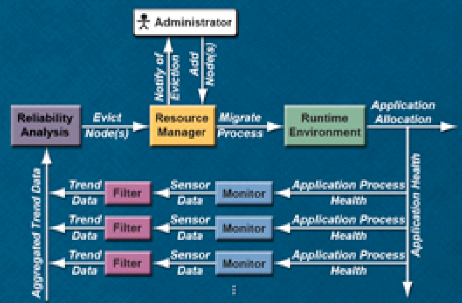
Type 1

- Alert-driven coverage for basic failures
  - Fan fault, overheating and other precursors to hard errors
- No evaluation of application health history or context
  - Prone to false positives
  - Prone to false negatives
  - Prone to miss real-time window
  - Prone to decrease application health through migration
  - No correlation of health context (space) or history (time)



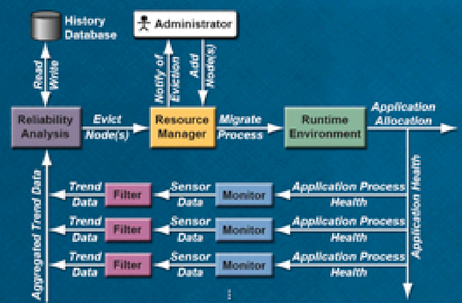
Type 2

- Trend-driven coverage for basic failures
  - Fan fault, overheating and other precursors to hard errors
  - Less prone to false positives
  - Less prone to false negatives
- No evaluation of application reliability
  - Prone to miss real-time window
  - Prone to decrease application health through migration
  - No correlation of health context (space) or history (time)



Type 3

- Reliability-driven coverage of failures
  - Basic and correlated failures
  - Even less prone to false positives
  - Even less prone to false negatives
  - Able to maintain real-time window
  - Not prone to decrease application heath through migration
  - Correlation of short-term health context and history
- No correlation of long-term health context or history
  - Unable to match system and application reliability patterns



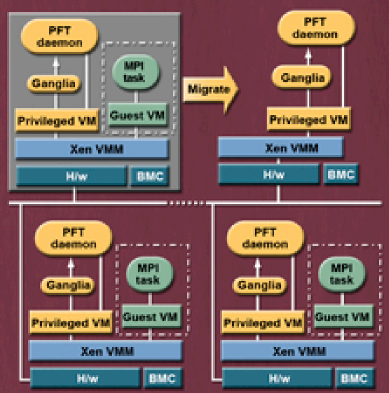
Type 4

- Reliability-driven coverage of failures and anomalies
  - Basic and correlated failures, anomaly detection
  - Even less prone to false positives
  - Even less prone to false negatives
  - Able to maintain real-time window
  - Not prone to decrease application health through migration
  - Correlation of short and long-term health context and history

Prototype 1

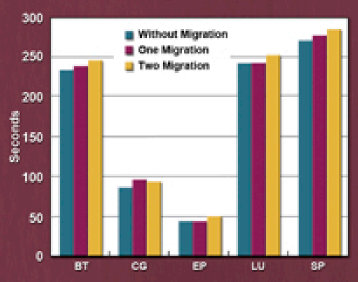
VM-level Preemptive Migration using Xen

- Type 1 system setup
  - Xen VMM on entire system
  - Host OS for management
  - Guest OS for computation
  - Spare nodes without Guest OS
  - System monitoring in Host OS
  - Decentralized scheduler/load balancer using Ganglia
- Deteriorating node health
  - Ganglia threshold trigger
  - Migrate guest OS to spare
  - Utilize Xen's migration facility



VM-level Migration Performance Impact

- Single node migration
  - 0.5-5% longer run time
- Double node migration
  - 2-8% longer run time
- Migration duration
  - Stop & copy : 13-14s
  - Live : 14-24s
- Application downtime
  - Stop & copy > Live

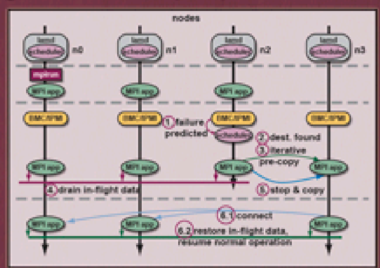


16-node Linux cluster at NCSU with dual core, dual-processor AMD Opteron and Gigabit Ethernet

Prototype 2

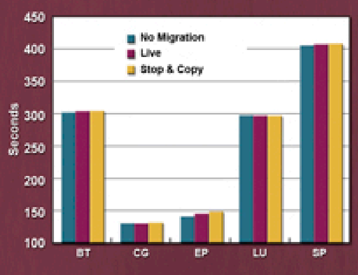
Process-Level Preemptive Migration using BLCR

- Type 1 system setup
  - LAM/MPI with Berkeley Lab Checkpoint/Restart (BLCR)
  - Per-node health monitoring
    - Baseboard management controller (BMC)
    - Intelligent platform management interface (IPMI)
  - New decentralized scheduler/ load balancer in LAM
  - New process migration facility in BLCR (stop&copy and live)
- Deteriorating node health
  - Simple threshold trigger
  - Migrate process to spare



Process-Level Migration Performance Impact

- Single node migration overhead
  - Stop & copy : 0.09-6 %
  - Live : 0.08-2.98%
- Single node migration duration
  - Stop & copy : 1.0-1.9s
  - Live : 2.6-6.5s
- Application downtime
  - Stop & copy > Live
- Node eviction time
  - Stop & copy > Live



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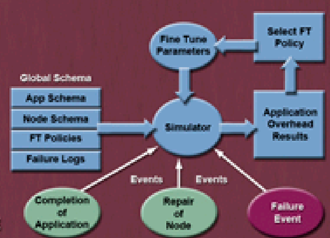
Prototype 3

Simulation Framework for Fault Tolerance Policies Tolerance

- Evaluation of fault tolerance policies
  - Reactive only
  - Proactive only
  - Reactive/proactive combination
- Evaluation of fault tolerance parameters
  - Checkpoint interval
  - Prediction accuracy
- Event-based simulation framework using actual HPC system logs
- Customizable simulated environment
  - Number of active and spare nodes
  - Checkpoint and migration overheads

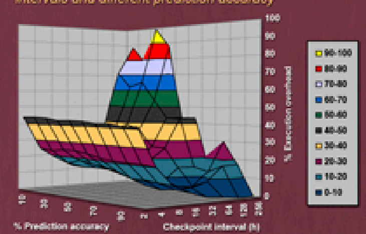


Combining Proactive and Reactive Fault Tolerance

- Best: Prediction accuracy >60% and checkpoint interval 16-32h
- Better than only proactive or only reactive
- Results for higher accuracies and very low intervals are worse than only proactive or only reactive

Number of processes	125
Active/Spare nodes	125/12
Checkpoint overhead	50min
Migration overhead	1 min

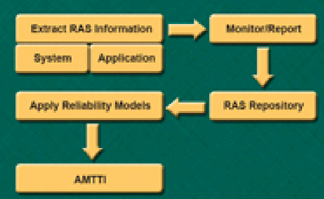
Execution overhead for various checkpoint intervals and different prediction accuracy



Simulation based on ASCI White system logs (nodes 1-125 and 500-512)

Research in Reliability Modeling

- Type 3 system setup
  - Monitoring of application and system health
  - Recording of application and system health monitoring data
  - Reliability analysis on recorded data
  - Application mean-time to interrupt (AMTTI) estimation



- Type 4 system setup
  - Additional recording of application interrupts
  - Reliability analysis on recent and historical data