Proactive Fault Tolerance Using Preemptive Migration

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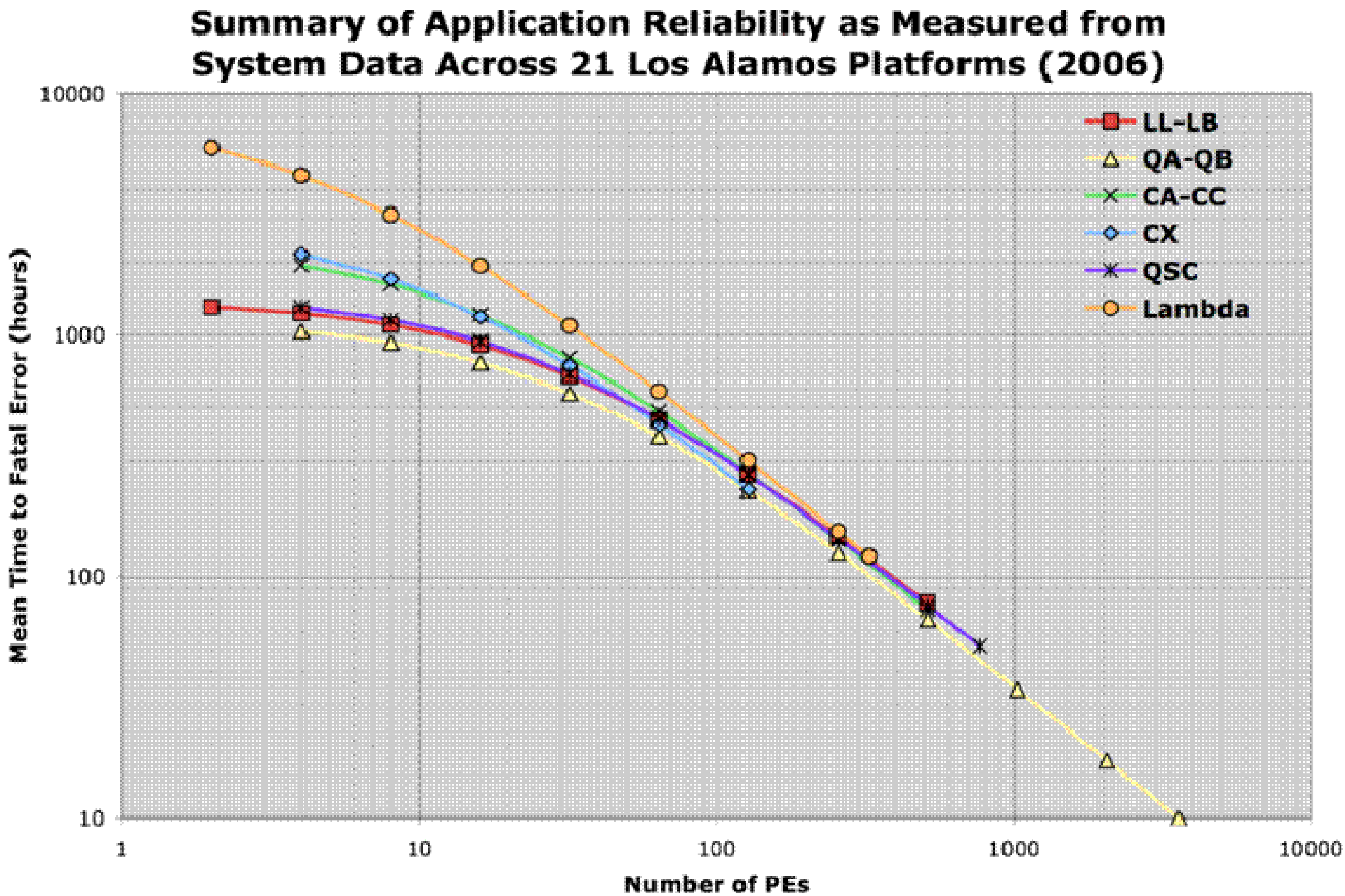
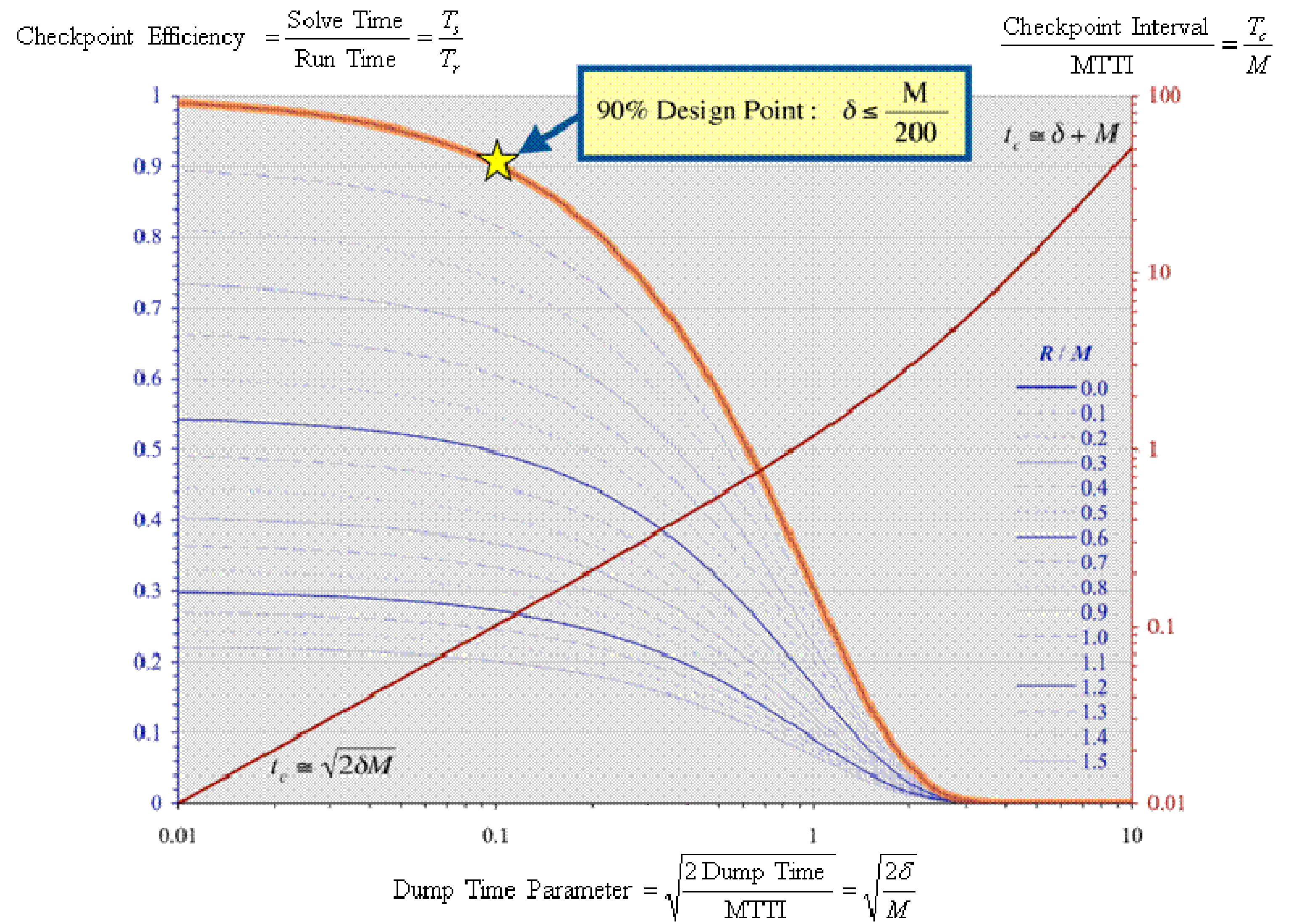
Motivation

- **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 larger-scale systems**
  - **ORNL ~300,000, LLNL~ 2,000,000**
- **Significant increase in component count and complexity**
- **Expected matching increase in failure frequency**
- **Checkpoint/restart is becoming less and less efficient**



J. T. Daly. Methodology and metrics for quantifying application throughput. In Proceedings of the Nuclear Explosives Code Developers Conference (NECDC) 2006, Los Alamos, NM, USA, Oct. 23-27, 2006.



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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 failures through preventative measures**
  - **Employed mechanisms anticipate failures**
  - **Example: Preemptive migration**

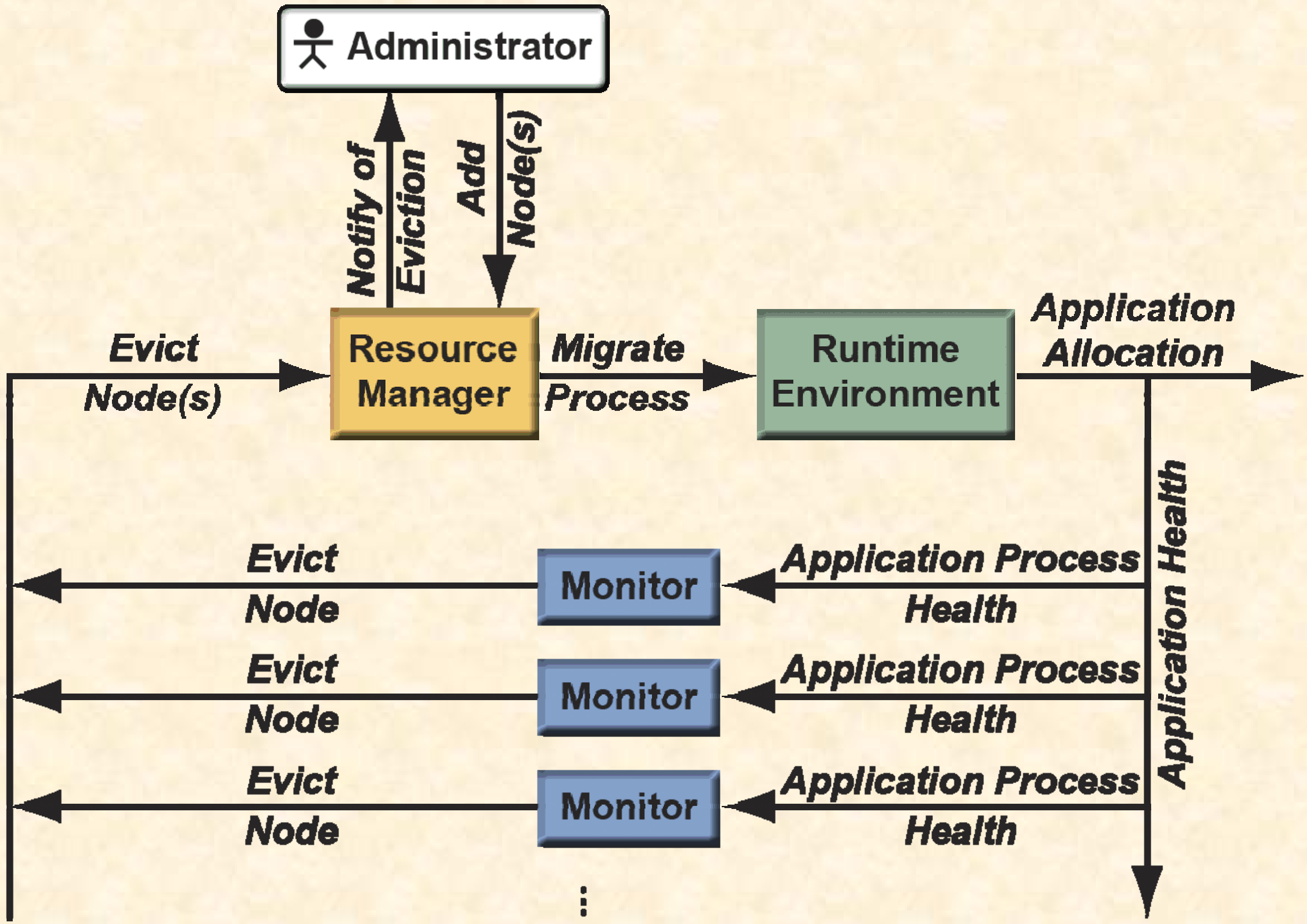
Proactive Fault Tolerance using Preemptive Migration

- **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 Types

- **Feedback-loop control quality of service depends on**
  - **Monitoring data capturing capabilities**
    - **Sensor types**
    - **Sample frequency**
    - **Intrusiveness**
  - **Monitoring data filtering mechanisms**
    - **Threshold triggering**
    - **Thrend filtering**
  - **Monitoring data analysis techniques**
    - **Reliability analysis**
    - **Correlation in space (across nodes) and time (across app. runs)**
- **Four distinct types can be derived**
  - **Type 1-4**

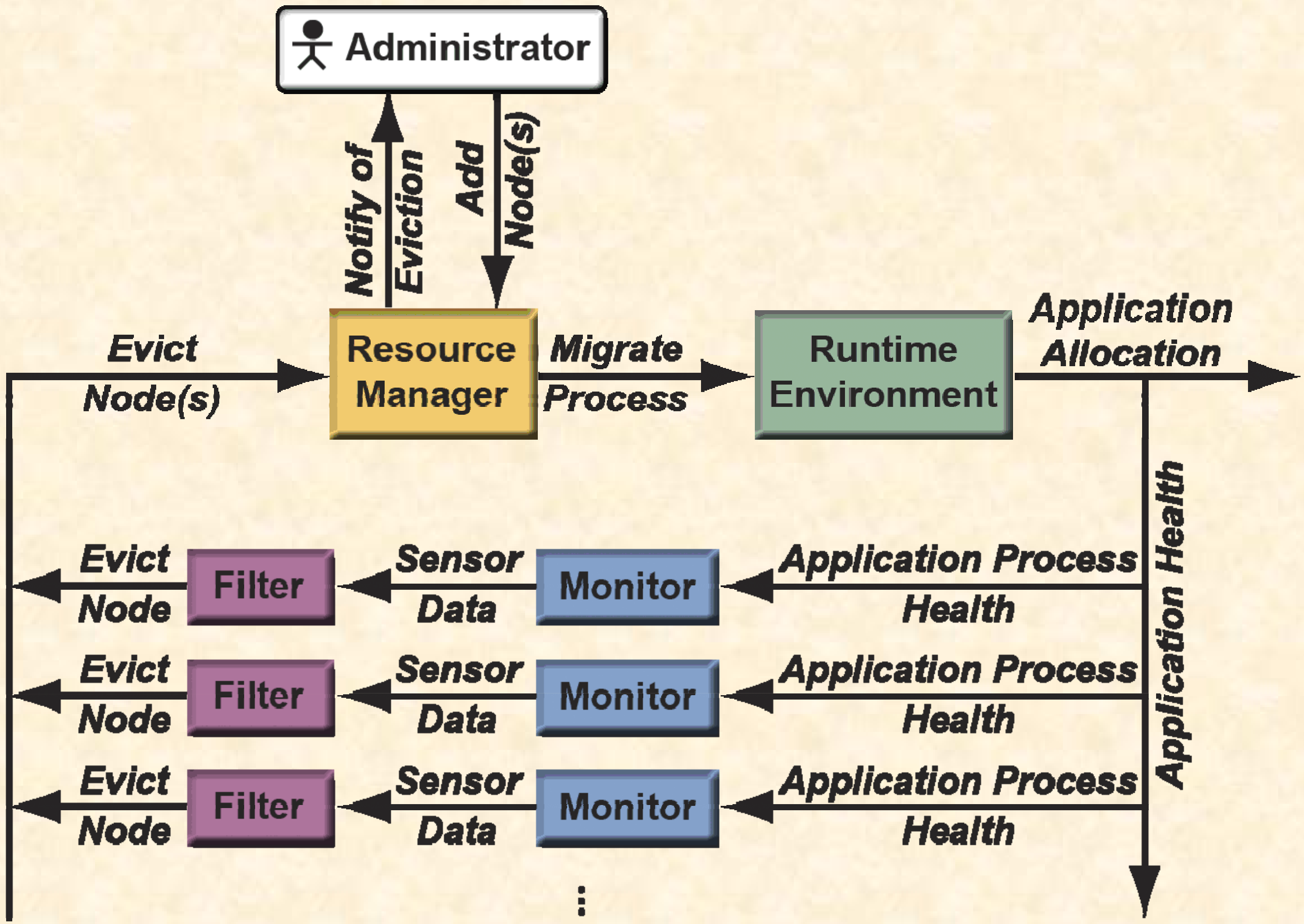
Type 1 Feedback-Loop Control Architecture



Type 1 Feedback-Loop Control Properties

- 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
    - Executing unnessecarry migration(s)
  - Prone to false negatives
    - Not executing nessecarry migration(s)
  - Prone to miss real-time window
    - Application fails during/before migration
  - Prone to decrease application heath through migration
    - Migration to arleady unhealthy nodes
  - No correlation of health context (space) or history (time)
    - Resulting in false positives and false negatives

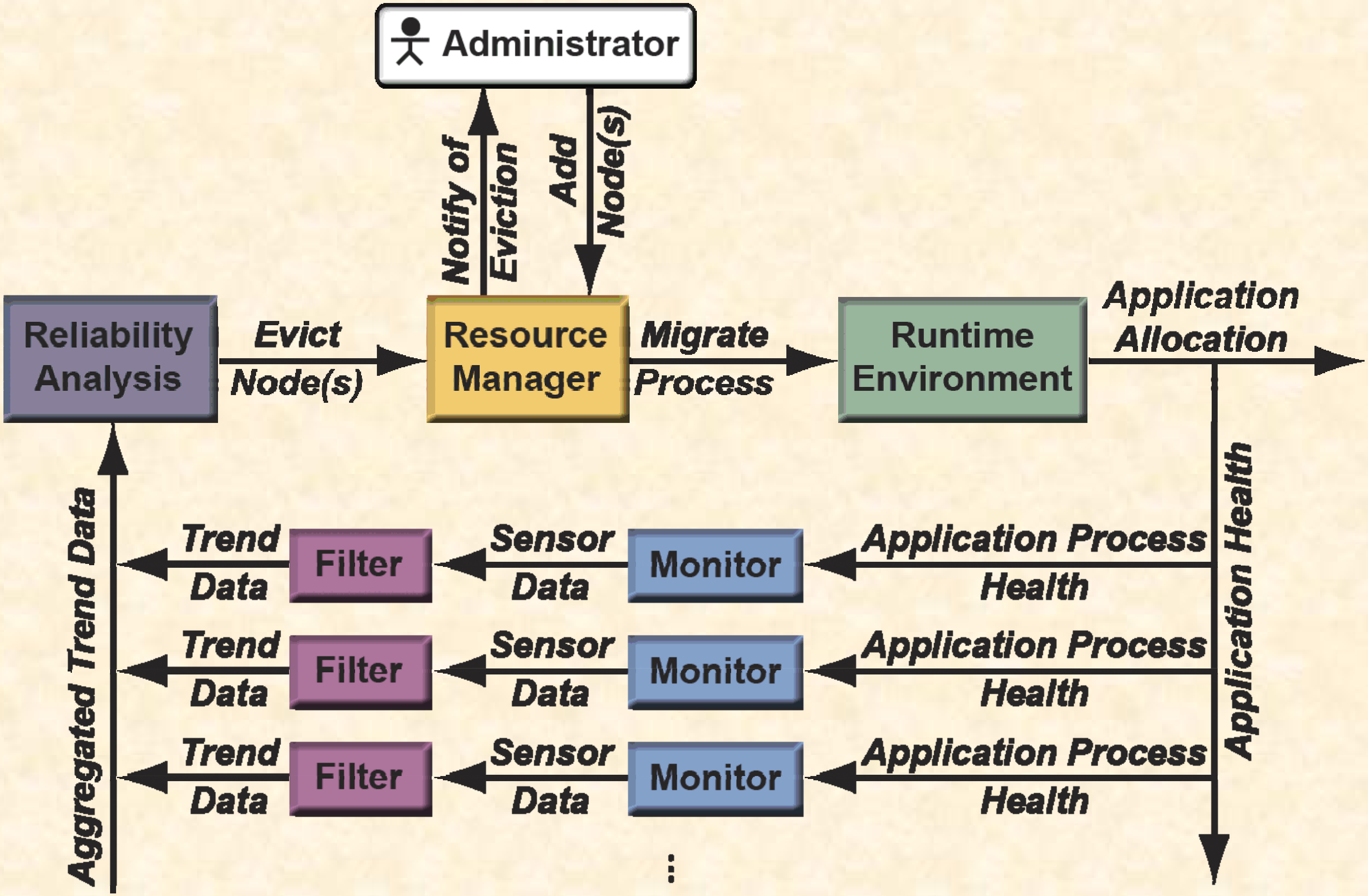
Type 2 Feedback-Loop Control Architecture



Type 2 Feedback-Loop Control Properties

- **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 heath through migration**
  - **No correlation of health context (space) or history (time)**

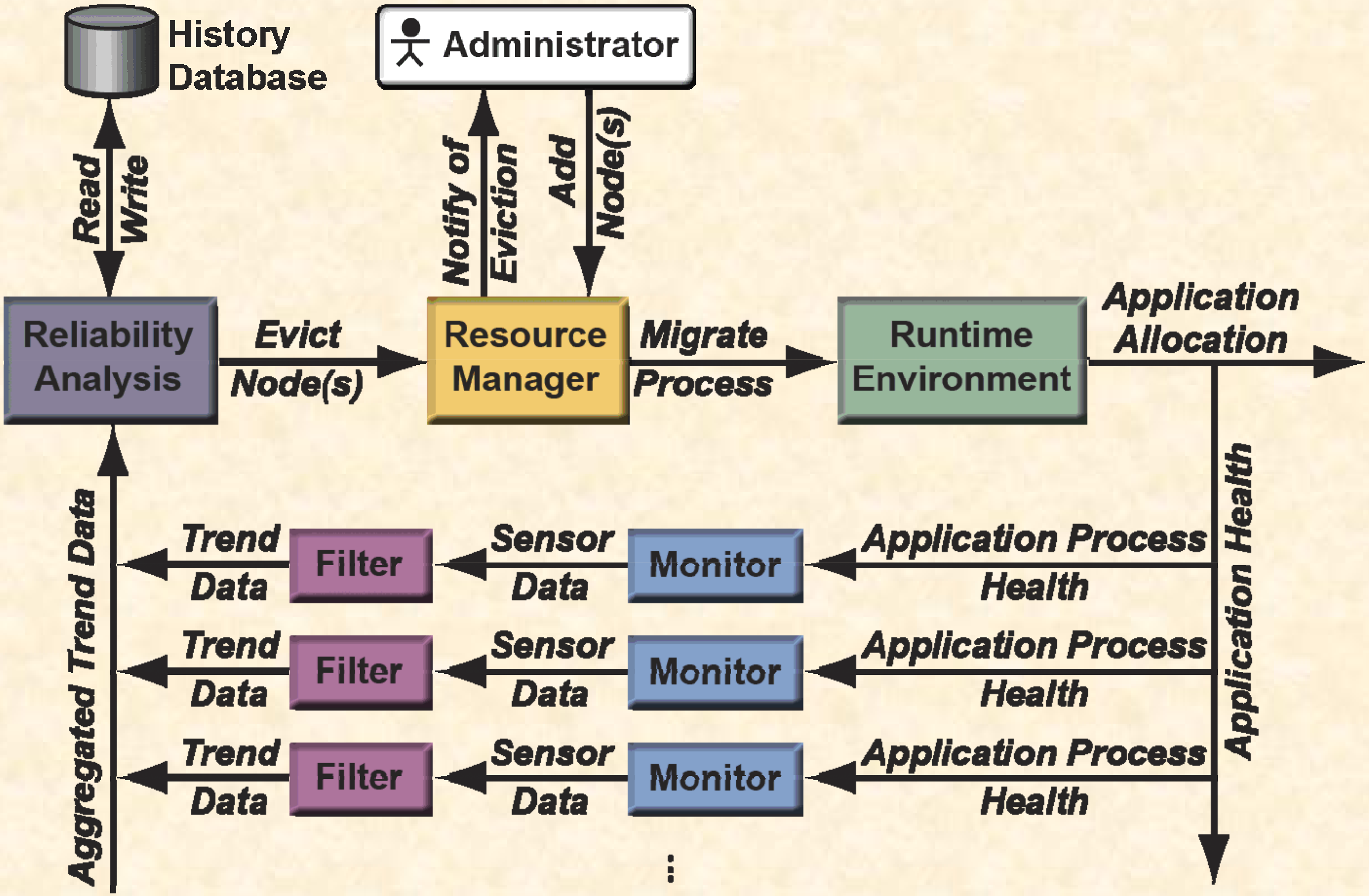
Type 3 Feedback-Loop Control Architecture



Type 3 Feedback-Loop Control Properties

- 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 Feedback-Loop Control Architecture



Type 4 Feedback-Loop Control Properties

- **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 heath through migration**
  - **Correlation of short and long-term health context and history**

Feedback-Loop Control Types Summary

- **Type 1**
  - **Alert-driven coverage for basic failures**
  - **Monitor, resource manager, runtime environment**
- **Type 2**
  - **Trend-driven coverage for basic failures**
  - **Additional filter**
- **Type 3**
  - **Reliability-driven coverage of failures**
  - **Additional reliability analysis**
- **Type 4**
  - **Reliability-driven coverage of failures and anomalies**
  - **Additional history database**

Related Work

- **System monitoring**
  - **OpenIPMI, Ganglia, OVIS 2 and MRNet**
- **System log and reliability analysis**
  - **USENIX Computer Failure Data Repository (CFDR)**
  - **hPREFECTs and Sisyphus**
- **Transparent migration mechanisms**
  - **Xen, BLCR, AMPI, MPI-Mitten**
- **Type 1 proactive fault tolerance frameworks**
  - **Xen + Ganglia**
- **Combining proactive and reactive fault tolerance**
  - **Policy analysis using simulation and failure logs**

Challenges Ahead

- **Health monitoring**
  - **Identifying deteriorating applications and OS conditions**
  - **Coverage of application failures: Bugs, resource exhaustion**
- **Reliability analysis**
  - **Performability analysis to provide extended coverage**
- **Scalable data aggregation and processing**
  - **Key to timeliness in the feedback control loop**
- **Need for standardized metrics and interfaces**
  - **System MTTF/MTTR != Application MTTF/MTTR**
  - **System availability != Application efficiency**
  - **Monitoring and logging is system/vendor dependent**

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Questions?