# The Challenge of Scale (Reprised)

## Fault Tolerance, Scaling and Adaptability

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http://lacsi.rice.edu/review/slides_2006/

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# Acknowledgments


- **Staff**
  - —Kevin Gamiel
  - —Mark Reed
  - —Brad Viviano
  - —Ying Zhang
- **Graduate students**
  - —Charng-da Lu
  - —Todd Gamblin
  - —Cory Quamman
  - —Shobana Ravi
- **LANL and ASC insights**
  - —a long, long list of people


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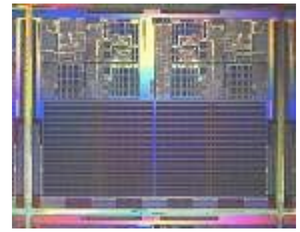
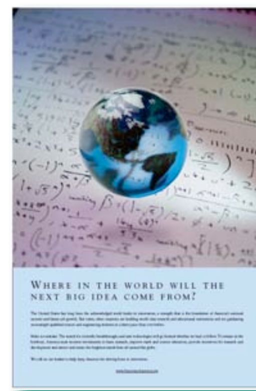
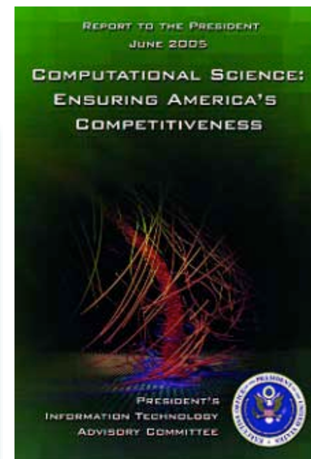
# LACSI Impacts



- **Market forces and laboratory needs**
  - —multicore chips and massive parallelism
    - – capability and capacity systems
  - —power budgets ($) and thermal stress
    - – economics and reliability
- **Tools and systems haven't kept pace**
  - —scale, complexity, reliability and adaptation
- ***Making large systems more usable (our focus)***
  - —*scale, measurement and reliability*
  - —*power management and cooling*
  - —*prediction and adaptation*

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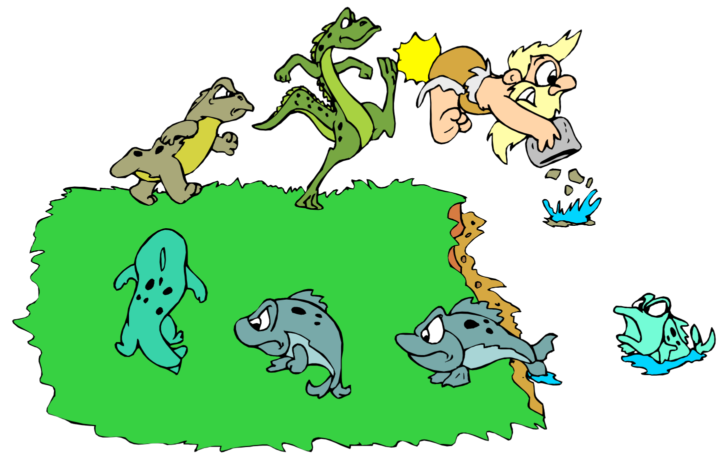
# LACSI Research Evolution

- **At last year's review**
  - —application fault resilience
  - —large-scale system failure modes
  - —HAPI health monitoring toolkit
  - —uniform population sampling
- **This year**
  - —AMPL stratified sampling toolkit
  - —Failure Indicator Toolkit (FIT)
  - —extended temperature/power measurements
  - —SvPablo application signature integration
  - —power-driven batch scheduling



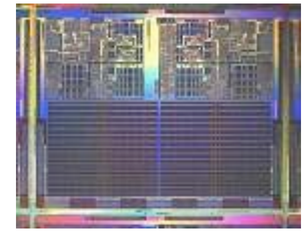
- **Research agenda driven by ASC challenges**
  - —scale, performance and reliability

# You Know You Are A Big System Geek If …

- **You think a $2M cluster**
  - —is a nice, single user development platform
- **You need binoculars**
  - —to see the other end of your machine room
- **You order storage systems**
  - —and analysts issue "buy" orders for disk stocks
- **You measure system network connectivity**
  - —in hundreds of kilometers of cable/fiber
- **You dream about cooling systems**
  - —and wonder when fluorinert will make a comeback
- **You telephone the local nuclear power plant**
  - —before you boot your system

# The Rise of Multicore Chips

- **Intrachip parallelism**
  - —dual core is here
    - – Power, Xeon, Opteron, UltraSPARC
  - —quad core is coming in just months …
    - – Intel, AMD, IBM, SUN
  - —Justin Ratter (Intel)
    - – “100’s of cores on a chip in 2015”

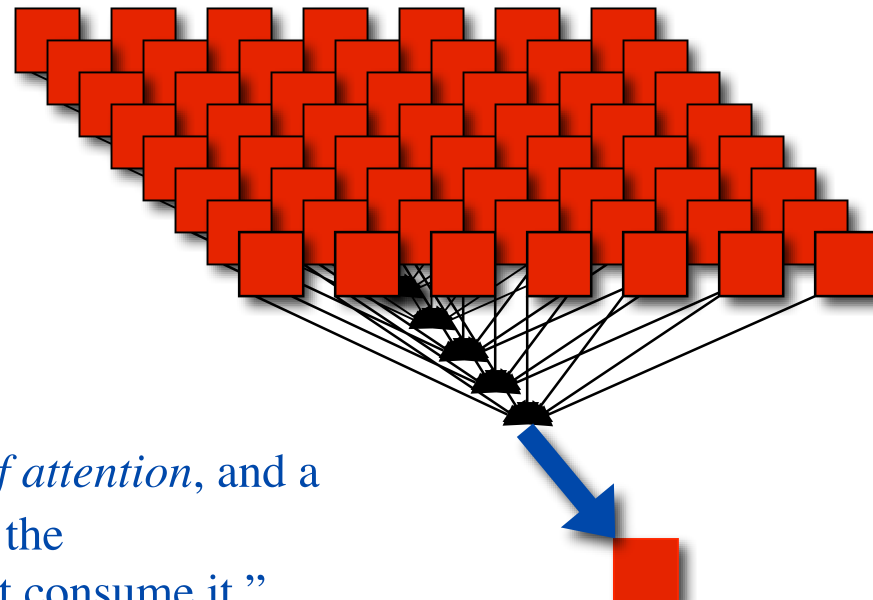


- **“Ferrari in a parking garage”**
  - —high top end, but limited roadway

- **Massive parallelism is finally here**
  - —tens and hundreds of thousands of tasks

# Scalable Performance Monitoring

- **Scalable performance monitoring**
  - **—summaries, space efficient but lacking temporal detail**
  - **—event traces, temporal detail but space demanding**
- **At petascale, even summaries are challenging**
  - **—exorbitant data volume (100K tasks)**
  - **—high extraction costs, with perturbation risk**
- **Tunable detail and data volume**
  - **—application signatures (tasks)**
    - **selectable dynamics**
  - **—stratified sampling (system)**
    - **adaptive node subset**



"*… a wealth of information creates a poverty of attention*, and a need to allocate that attention efficiently among the overabundance of information sources that might consume it."

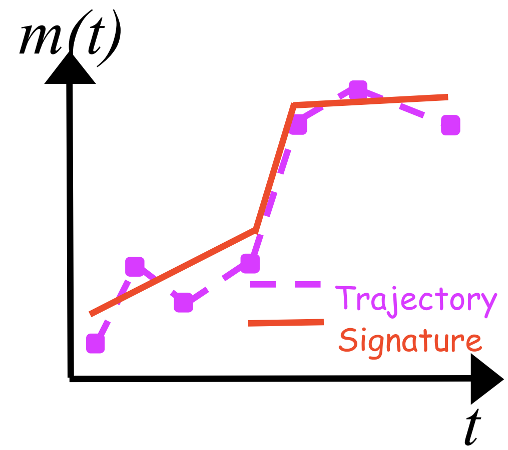
*Herbert Simon*

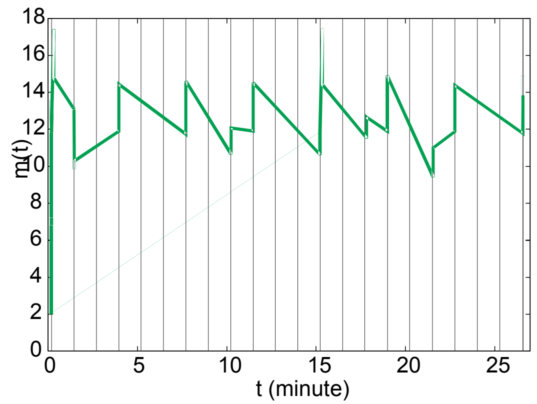
# Compact Application Signatures

- **Motivations**
  - compact dynamic representations
  - multivariate behavioral descriptions
  - adaptive volume/accuracy balance
- **Polyline fitting**
  - based on least squares linear curve fitting
    - measurement at user markers
  - curves are computed in real-time
- **Signature comparison**
  - degree of similarity (DoS) of q wrt p

$$\max\left(1-\frac{\int |p(t)-q(t)|\,dt}{\int p(t)\,dt},0\right)$$

- **SvPablo integration**
  - marker selection inside GUI
  - data capture library (DCL) signature generation
  - signature browsing and comparison
- **Adaptive measurement control**




Source: Charng-da Lu (SC02 Best Student Paper Finalist)

# Sampling Theory: Exploiting Software

- **SPMD models create behavioral equivalence classes**
  - —domain and functional decomposition
- **By construction, …**
  - —most tasks perform similar functions
  - —most tasks have similar performance
- **Sampling theory and measurement**
  - —extract data from "representative" nodes
  - —compute metrics across representatives
  - —balance volume and statistical accuracy


Sampling Must Be Unbiased!

- **Estimate mean with confidence 1-$\alpha$ and error bound *d***
  - —select a random sample of size *n* from population of size *N*

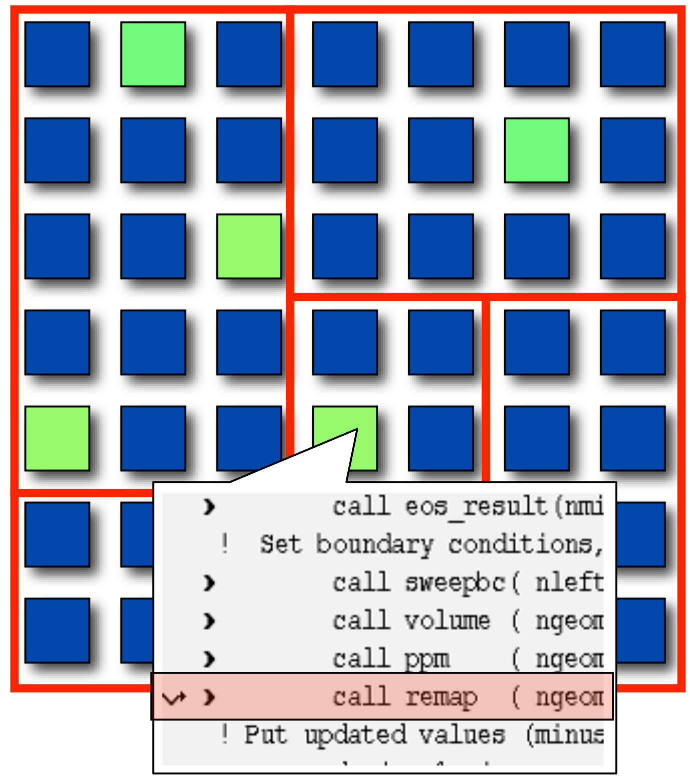
$$n \geq N\left[1 + N\left(\frac{d}{z_\alpha S}\right)^2\right]^{-1}$$

  - —approaches $\frac{z_\alpha S}{d}$ for large populations

Source: Todd Gamblin

# Adaptive Performance Data Sampling

- **Simple case**
  - select subset *n* of N nodes
  - collect data from the *n*
- **Stratified sampling (multiple behaviors)**
  - identify low variance subpopulations
  - sample subpopulations independently
  - reduced overhead for same confidence
- **Metrics vary over time**
  - samples must track changing variance
    - number and frequency
  - number of subpopulations also vary
- **Sampling options**
  - fixed subpopulations (time series)
  - random subpopulations (independence)
- **Adaptive measurement control**
  - fix data volume (variable error)
  - fix error (variable data volume)




Source: Todd Gamblin

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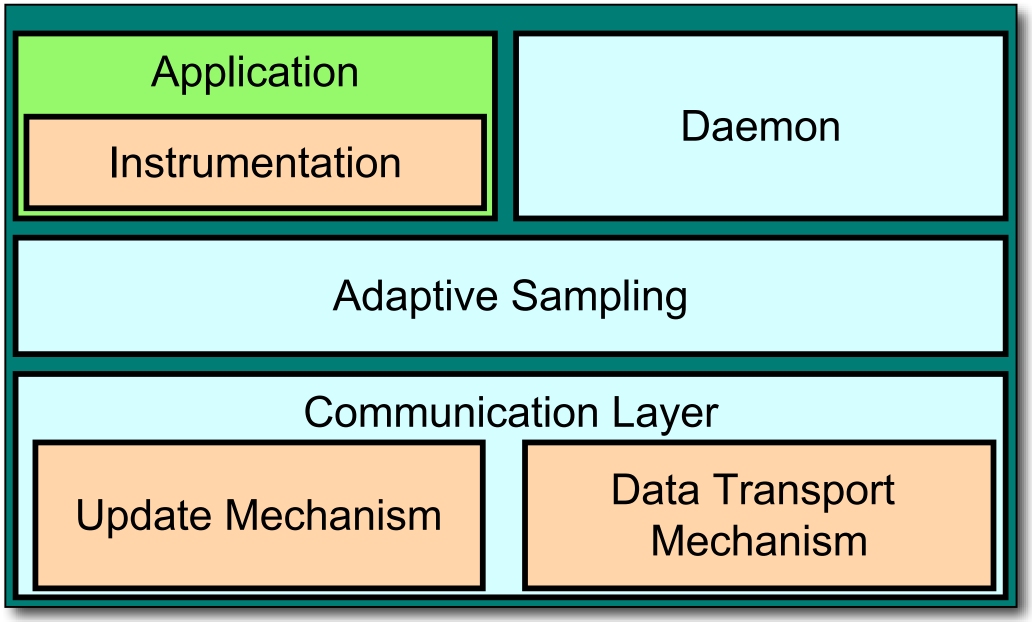
# AMPL Framework

- **AMPL**
  - —Adaptive Performance Monitoring and Profiling On Large Scale Systems
  - —SvPablo and TAU integration
  - —Multiple performance data sources (PAPI and others)




```
SampleWindow = 5.0
WindowsPerUpdate = 4
UpdateMechanism = Subset

Group {
     Name = "Adaptive"
     Members = 0-127
     Confidence = .90
     Error = .03
}
Group {
     Name = "Static"
     SampleSize = 30
     Members = 128-255
     PinnedNodes = 128-137
}
```

Source: Todd Gamblin

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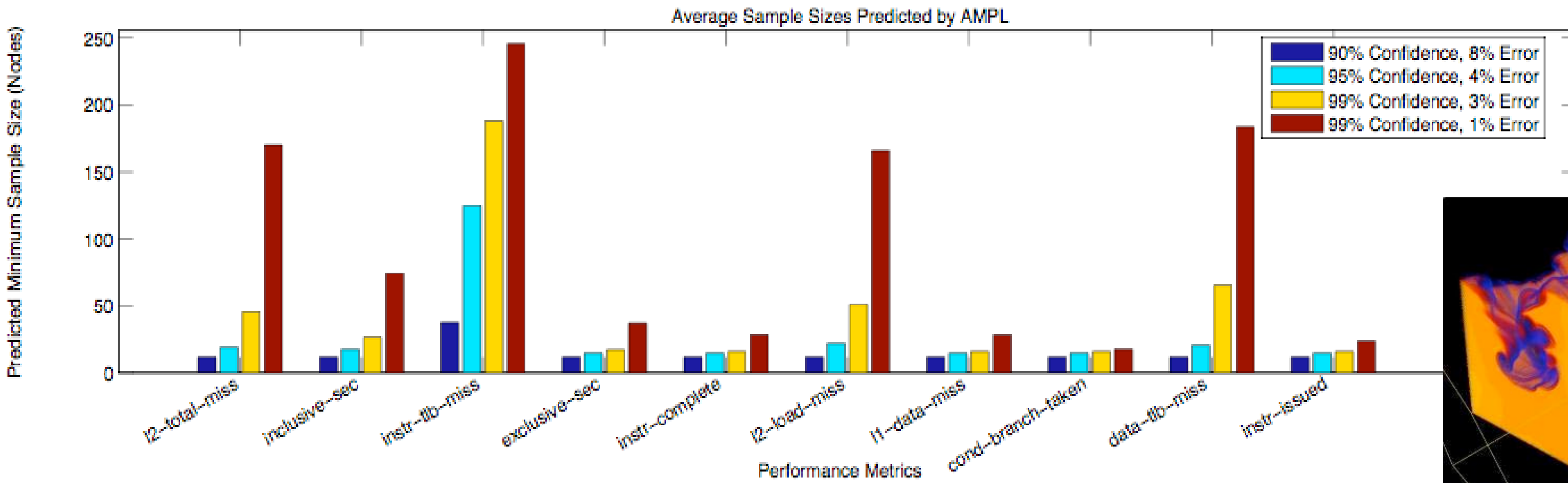
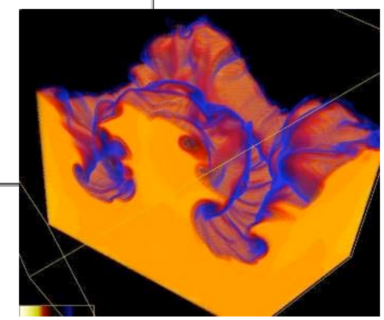
# sPPM Sampling Results



- **PAPI counter sampling**
  - **—5-14% overhead at 90% confidence and 8% accuracy**
  - **—7-14% overhead at 99% confidence and 1% error**
    - **low variance metrics**

**Source: Todd Gamblin**

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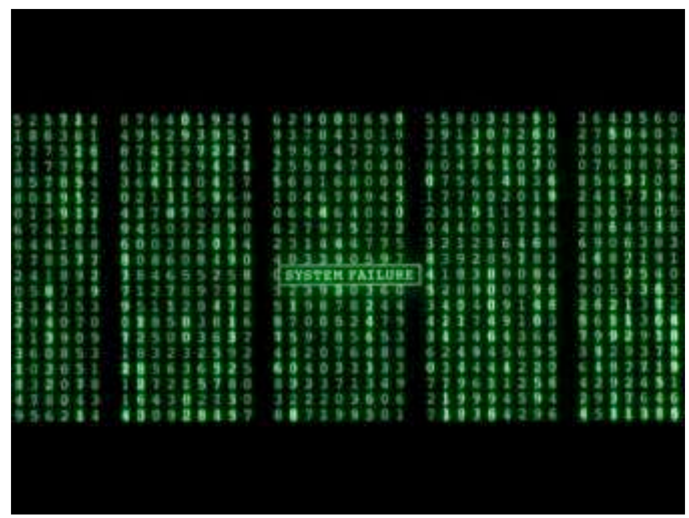
# Execution Models and Reliability

- **There are many execution models**
  - —parameter space exploration
  - —single program, multiple data (SPMD)
  - —master/worker and functional decomposition
  - —dynamic workflow
    - – data and condition dependent execution
- **Each amenable to different reliability strategies**
  - —need-based resource selection
  - —over-provisioning
    - – SETI@Home model
  - —checkpoint/restart
  - —algorithm-based fault tolerance
  - —library-mediated over-provisioning



# Machine Room Microclimate

- Sensors for machine rooms
  - multiple locations
    - air ducts, racks, servers, …
  - multiple modes
    - vibration, temperature and humidity
- Sensor options
  - UC Berkeley/Crossbow motes
  - WxGoos network sensors
- Infrastructure coupling
  - HAPI for integrated data capture
  - AMPL for statistical sampling
  - FIT for failure model generation
  - SvPablo for application instrumentation
- Rationale
  - micro-environment analysis
  - thermal gradients and equipment placement

Source: Shobana Ravi/Brad Vivano

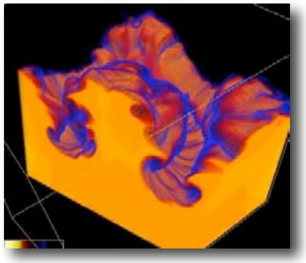
# A Tale of Three Clusters

- Old, homemade (Dell)
  - —standard Dell towers
  - —1 GHz Pentium III dual processor nodes
  - —multiple rows of eight nodes
  - —GigE interconnect
- Clustermatic (Linux Labs)
  - —one 42U rack
  - —2 GHz Opteron dual processor nodes
  - —16 nodes plus head node
  - —Infiniband and GigE interconnects
- Vendor (Dell)
  - —17 standard racks, plus 4 network racks
  - —512 3.6 GHz Xeon dual processor nodes
  - —Infiniband interconnect

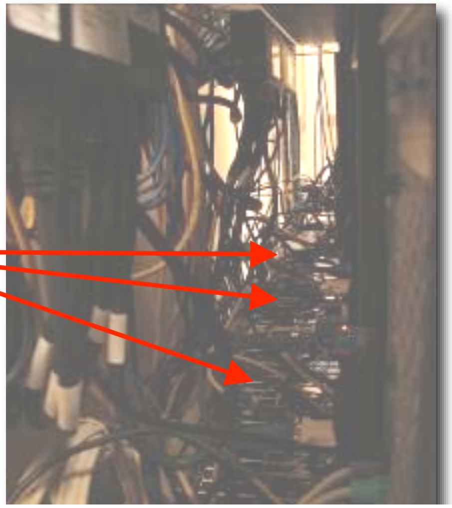
Source: Shobana Ravi

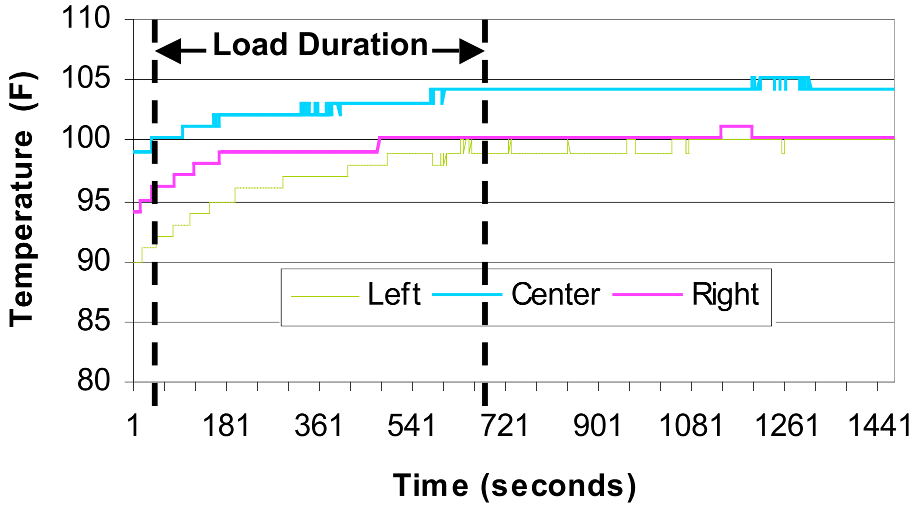
# Loading and Monitoring Details

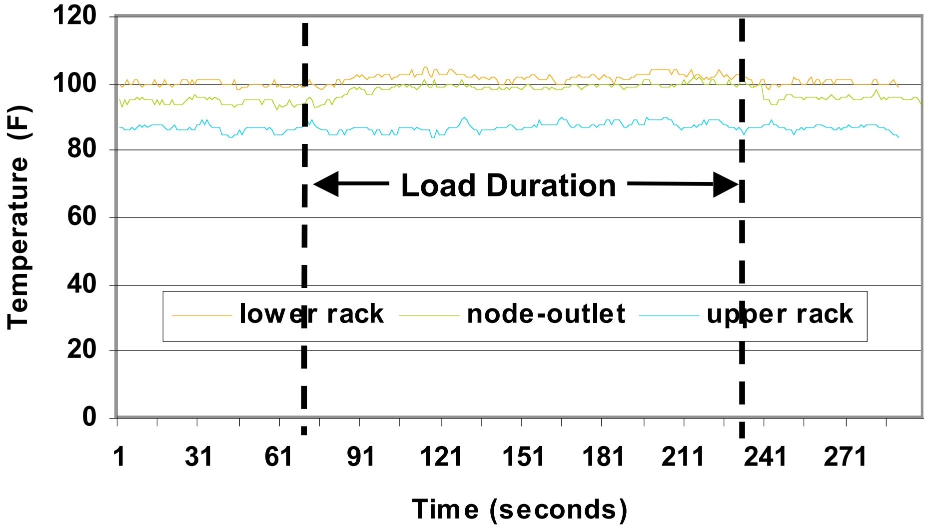
- UC Berkeley/Crossbow motes
  - —temperature measurements
- Measurement locations
  - —air outlet on each node
- Benchmark
  - —sPPM
- Observations
  - —rack cooling (or its lack) really matter



Mote Sensor Locations



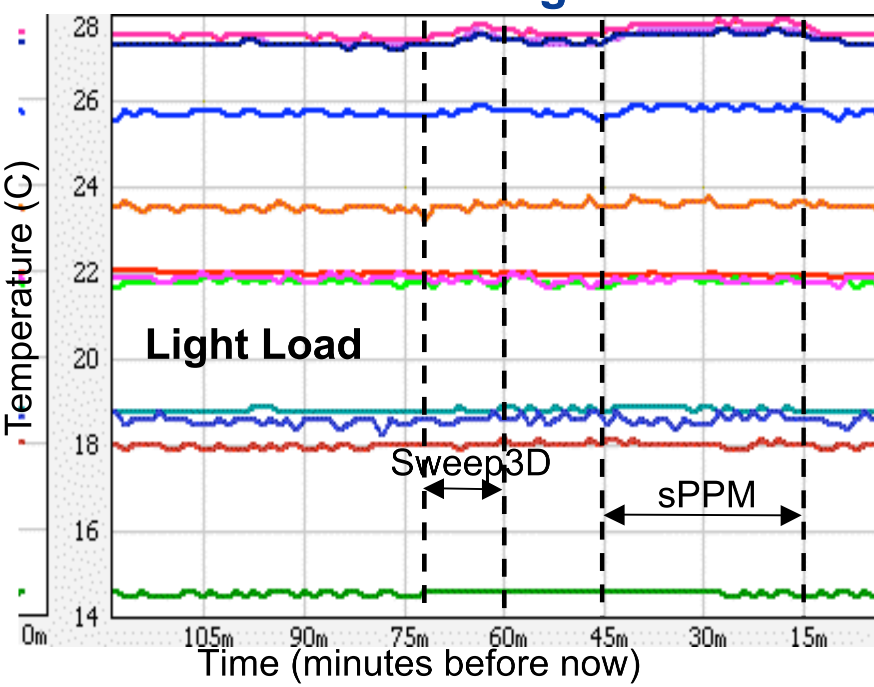


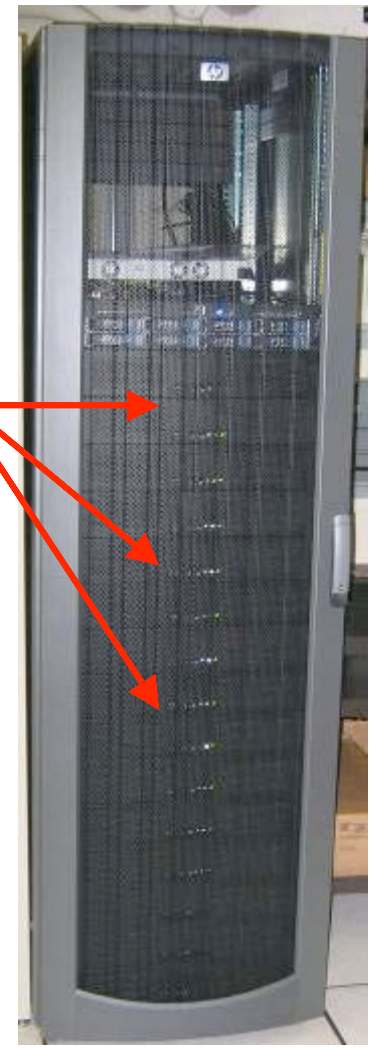

Source: Shobana Ravi

# Clustermatic Temperature Profile

- **WxGoos hardware**
  - —temperature, power, humidity, …
- **Measurement locations**
  - —air outlets, sensors on rack door
- **Multiple benchmarks**
  - —sPPM and Sweep3D (multiple data sets)
  - —~10 minute lag on cool down (larger data)



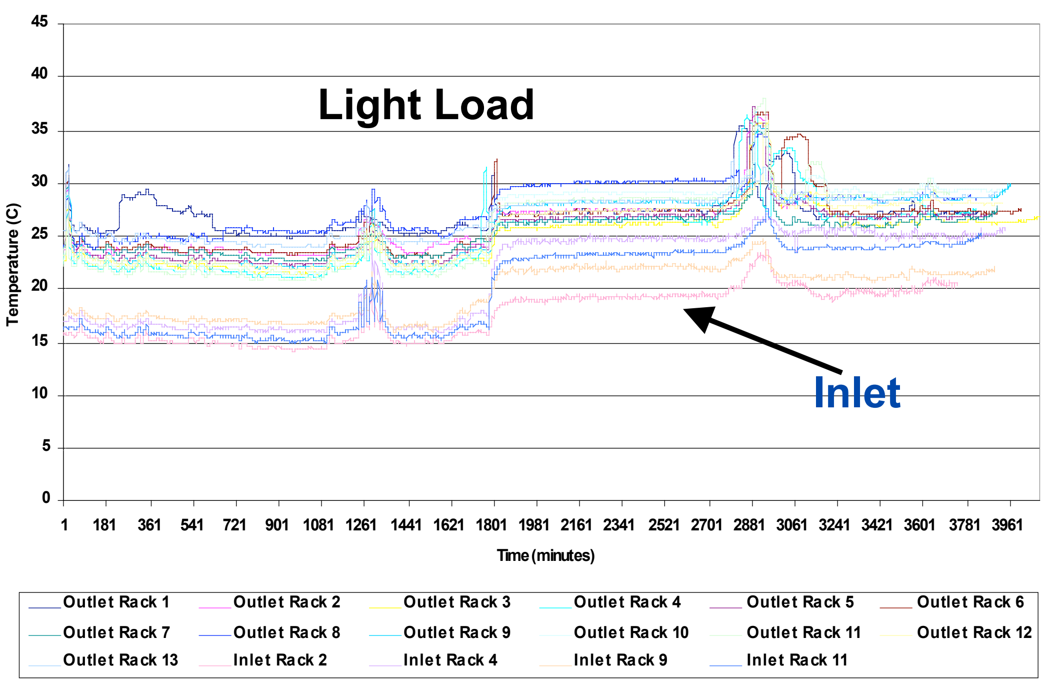

WxGoos Sensors



Source: Shobana Ravi

# Large Cluster: Top500 Benchmarking

- UC Berkeley/Crossbow motes
  - —temperature measurements
- Measurement locations
  - —air inlets and outlets
- Multiple benchmarks
  - —primarily Top500 (HPL)

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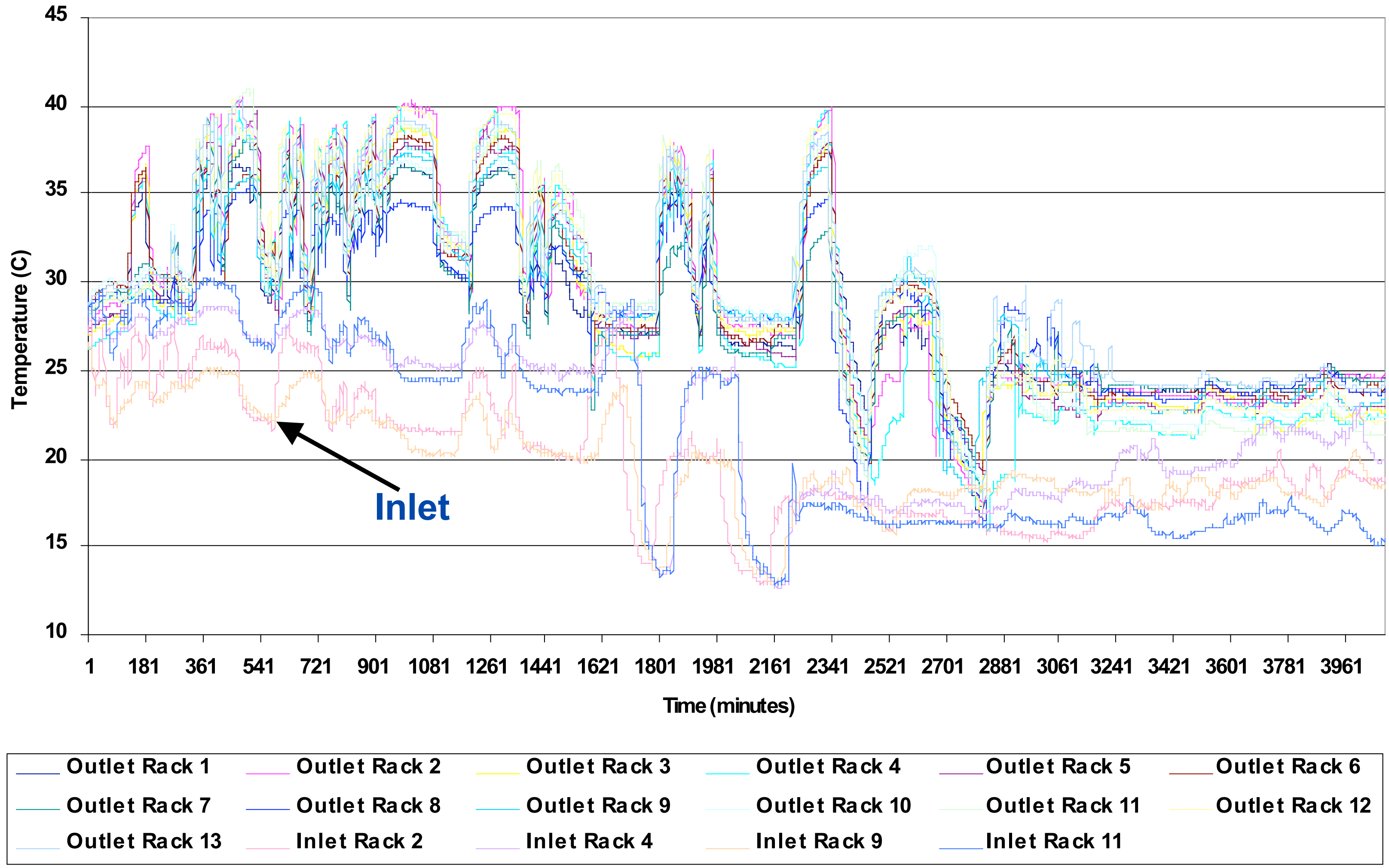
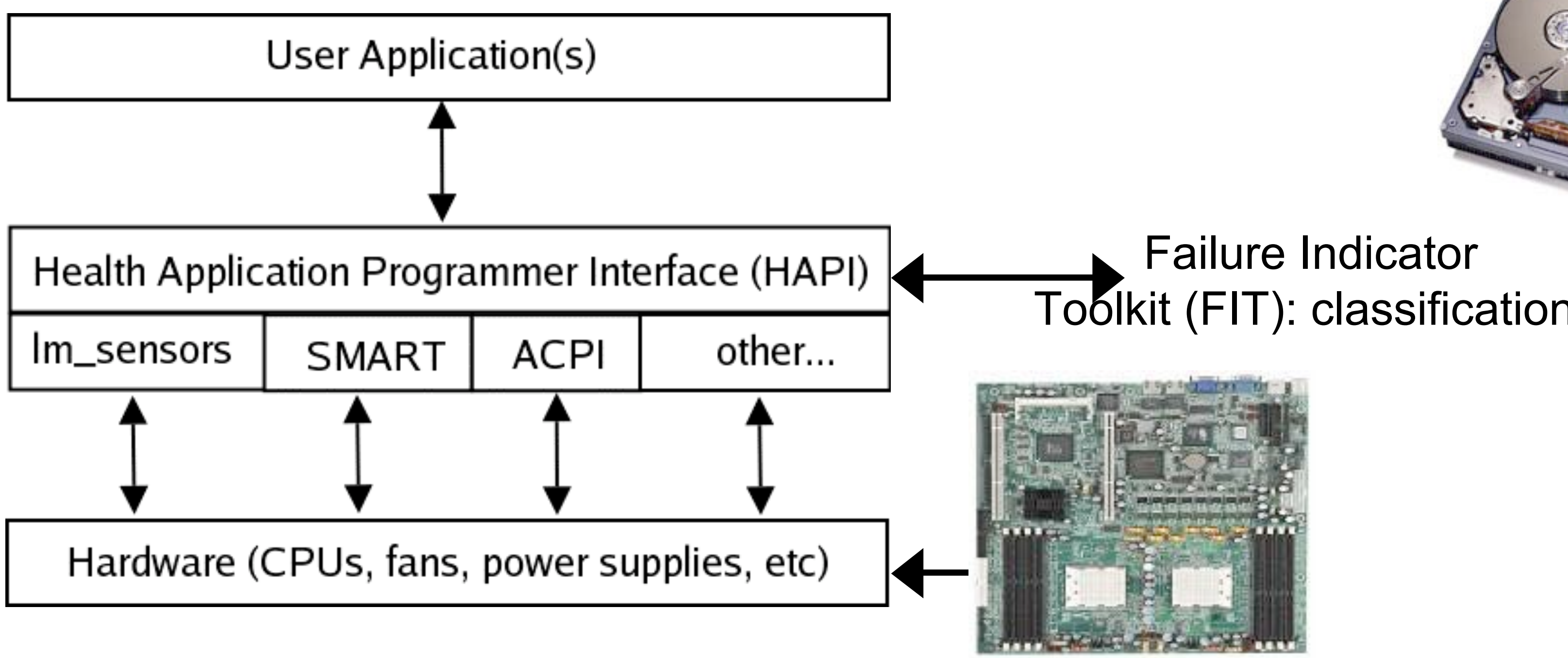



Source: Shobana Ravi

# UNC HAPI Implementation

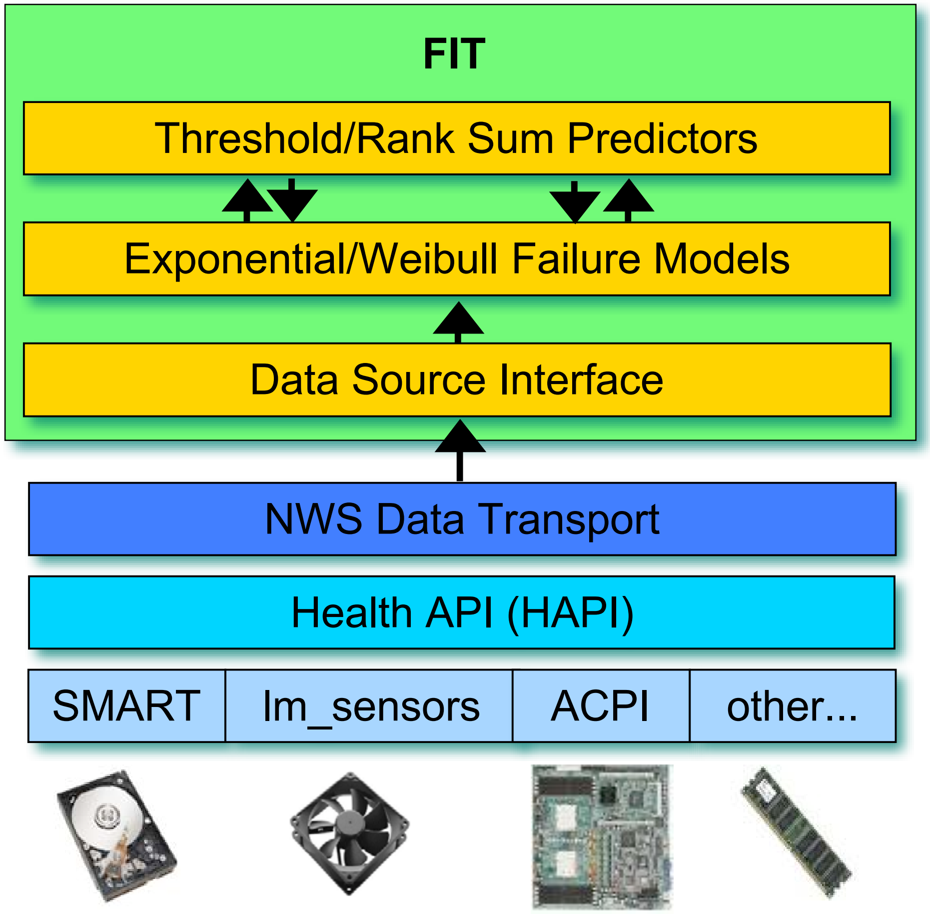
- **Health Application Programming Interface (HAPI)**
  - —**standard interface for health monitoring (by analogy with PAPI)**
  - —**ACPI (Advanced Configuration and Power Management)**
  - —**SMART (Self Monitoring, Analysis and Reporting Technology)**
- **Release available at www.renci.org**



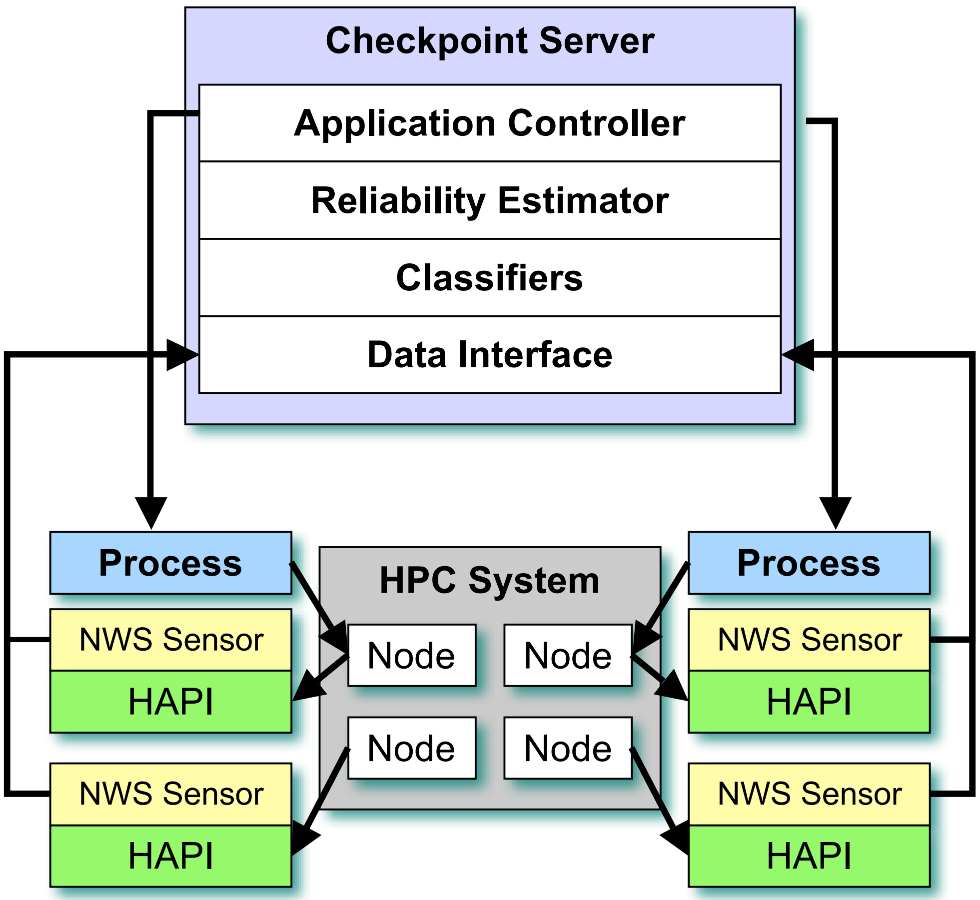

**Source: Mark Reed/Kevin Gamiel**

# Failure Indicator Toolkit (FIT)

- **Concept**
  - **measure failure indicators**
    - **disks, networks, …**
    - **memory, motherboards**
  - **predict likely failures**
  - **adapt based on MTBF**
    - **checkpoint frequency**
    - **batch scheduling, …**
- **Approach**
  - **standard data interfaces**
  - **statistical classifiers**
    - **failure prediction**
  - **application controller**
    - **adaptation**



# FIT Adaptive Checkpointing




- Checkpointing frequency
  - — application driven
    - – susceptibility to faults
  - — reliability driven
    - – application needs
    - – system capabilities

- *Adaptive checkpointing*
  - — *FIT MTBF estimate*
  - — *application controller*
- *Experiments beginning …*

Source: Cory Quammen

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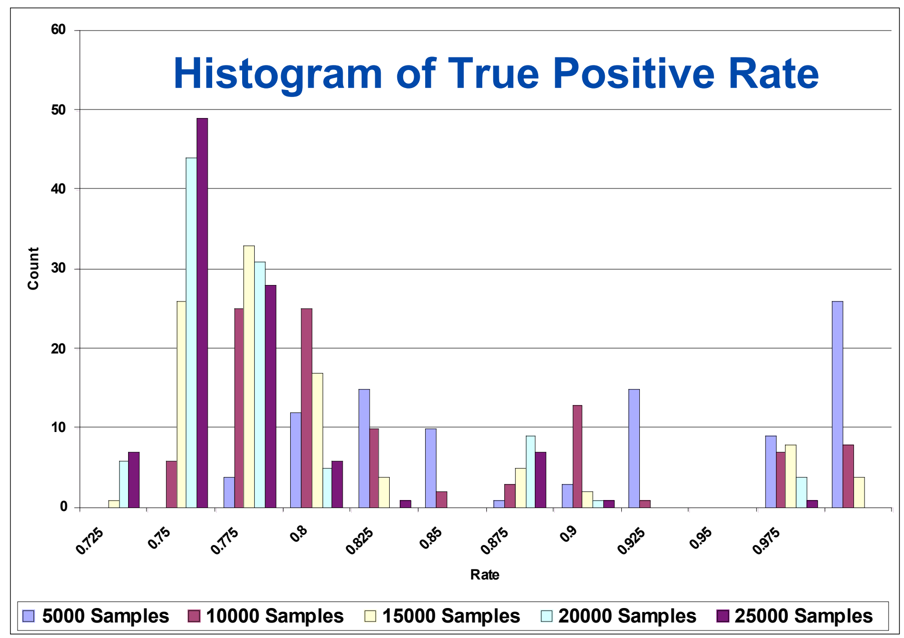
# Failure Assessment Experiments

- **Disk data (from Murray et al)**
  - —177 good disks (tested at manufacturer)
  - —191 failed disks (customer returns)
  - —64 attributes (55 usable)
  - —observations every two hours
    - – up to 300 observations/disk

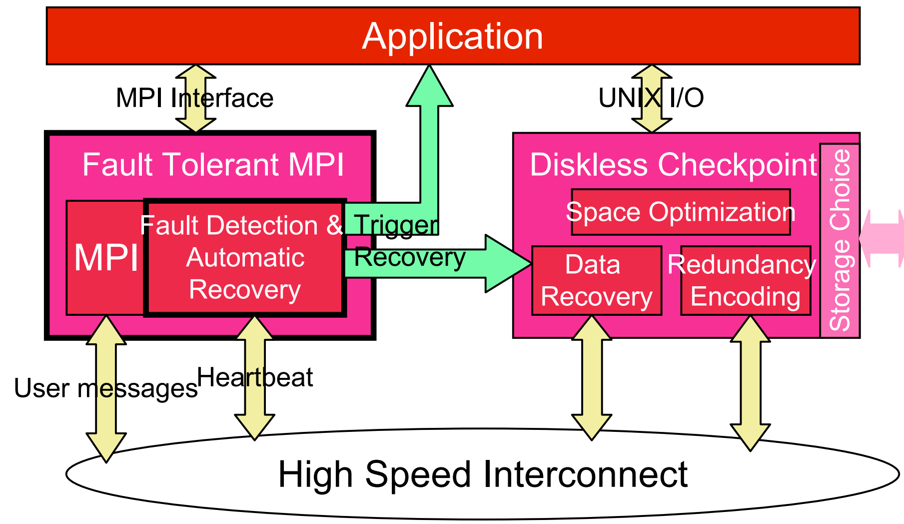
- **Assessment approach**
  - —randomly sample the population
    - – all observations from good disks
  - —determine min/max of attributes, e.g.,
    - – read head flying height (min)
    - – write errors (max)
  - —test each good and bad disk
    - – violation of threshold definitions
- **Preliminary results**
  - —71% accurate prediction
    - – with no false positives




Source: Cory Quammen

# Large Scale Adaptation Examples

- ***Batch queue selection***
  - *—application fault sensitivity*
  - *—predicted partition reliability*
  - *—power/temperature constraints*
- **Checkpoint frequency**
  - **—application fault sensitivity**
  - **—predicted partition reliability**
- **Redundancy application**
  - **—spare nodes for reliable execution**
- **Power aware code optimization**
  - **—tuning for power/performance/reliability**
- **OS suicide hotline**
  - **—adaptive personality management**

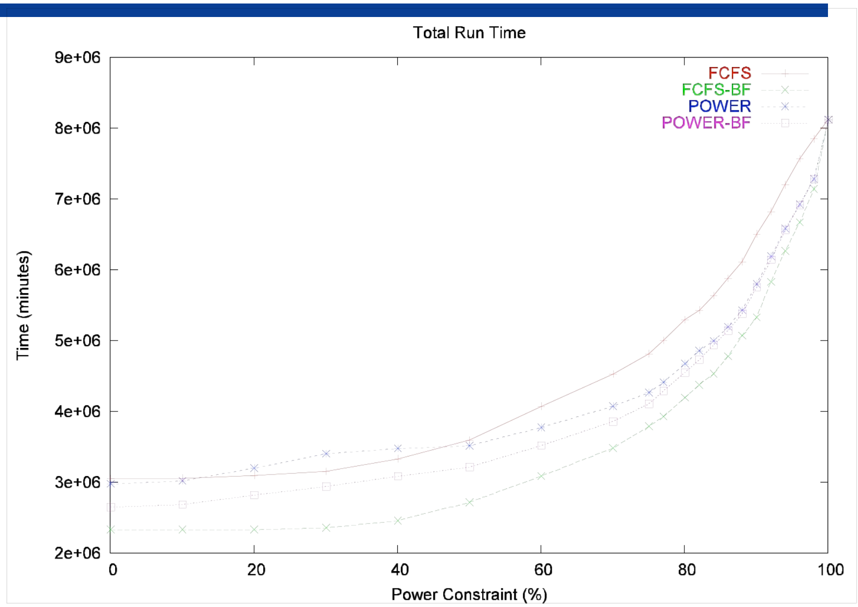


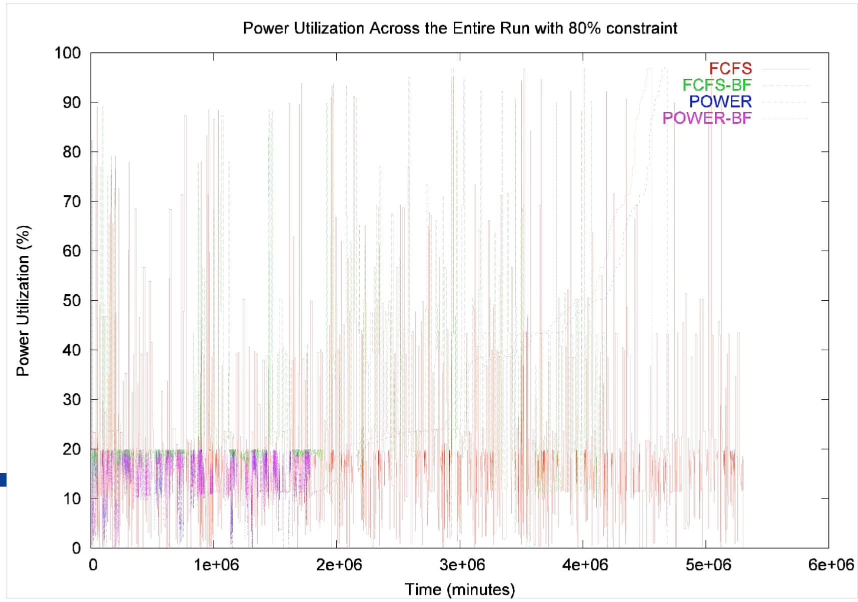

# Job Scheduling Policies and Power

- Today, batch scheduling is largely power oblivious
  - utilization and delay metrics dominate
  - predominantly First Come First Serve (FCFS)
    - backfilling to improve utilization
- Power and temperature implications
  - temperature transients lag job completion
    - cooling costs
  - power budgets are increasingly important
    - fluctuating demands on power infrastructure
- Goals
  - bound total power consumption
  - minimize utilization and delay impact

# Very Preliminary Evaluation

- **LANL CM-5 workload**
  - —122,055 jobs on 1024 nodes
  - —24 month period
- **POWER**
  - —scheduled ranked on power
- **POWER-BF**
  - —scheduled ranked on power
  - —backfilling ranked on power
- **FCFS**
  - —scheduled ranked on submit time
- **FCFS-BF**
  - —scheduled ranked on submit time
  - —backfilling ranked on submit time

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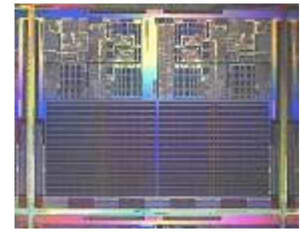

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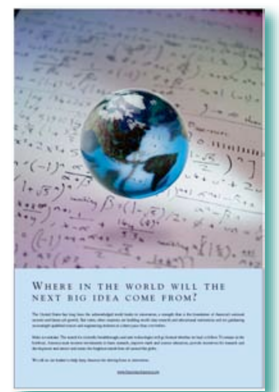


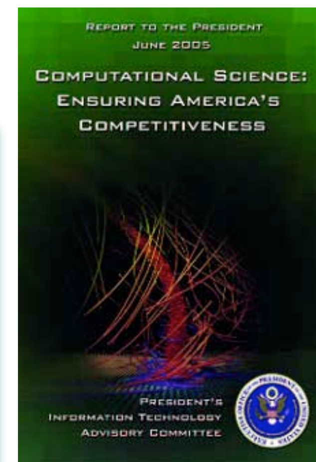


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