Recovery Oriented Computing (ROC)

Dave Patterson and a cast of 1000s:

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Outline

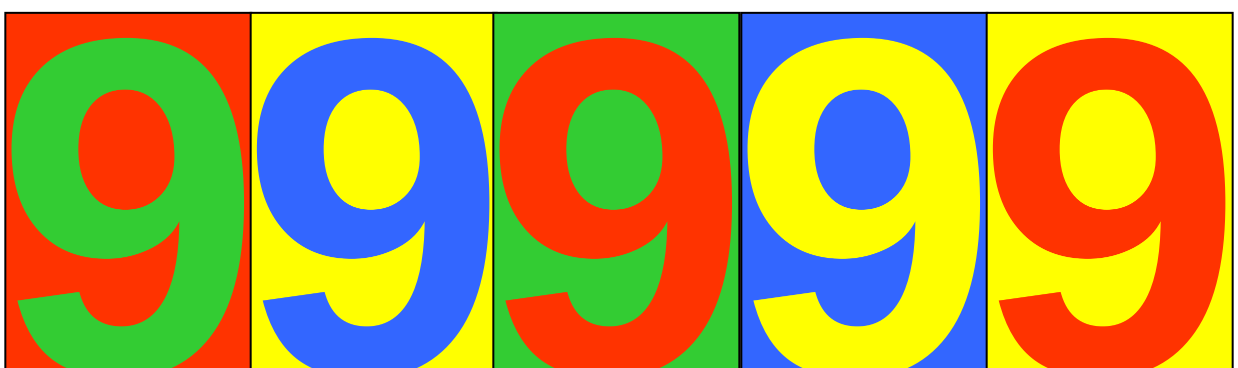
- Recovery-Oriented Computing: Motivation
- What Can We Learn from Other Fields?
- ROC Principles and Lessons in Retrospect
- ROC => AMP Lab (if time permits)

The past: research goals and assumptions of last 20 years

- **Goal #1: Improve performance**
- **Goal #2: Improve performance**
- **Goal #3: Improve cost-performance**
- **Simplifying Assumptions**
  - Humans are perfect
  - Software will eventually be bug free
  - Hardware MTBF very large
  - Maintenance costs irrelevant vs. Purchase price

Dependability: Claims of 5 9s?

- 99.999% availability from telephone company?
  - **AT&T switches < 2 hours of failure in 40 years**
- Cisco, HP, Microsoft, Sun … claim 99.999% availability claims (5 minutes down / year) in marketing/advertising
  - **HP-9000 server HW and HP-UX OS can deliver 99.999% availability guarantee "in certain pre-defined, pre-tested customer environments"**
  - **Environmental? Application? Operator?**

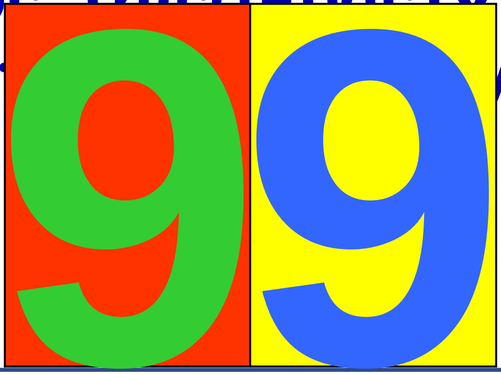


5 9s from Jim Gray's talk: "Dependability in the Internet Era"

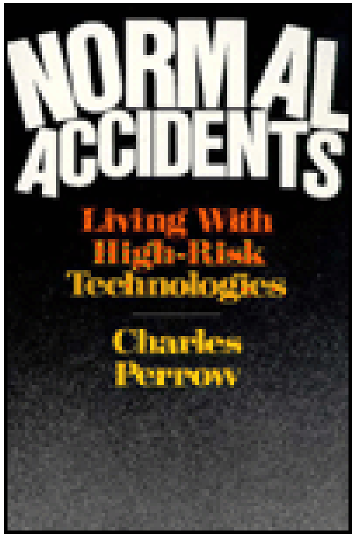
"Microsoft fingers technicians for crippling site outages"

By Robert Lemos and Melanie Austria Farmer, ZDNet News, January 25, 2001

- Microsoft blamed its own technicians for a crucial error that crippled the software giant's connection to the Internet, almost completely blocking access to its major Web sites for nearly 24 hours… a "router configuration error" had caused requests for access to the company's Web sites to go unanswered…
- "This was an operational error and not the result of any issue with Microsoft or third-party products, nor with the securi[illegible] works," a Microsoft spokesman said.



Learning from other fields: disasters

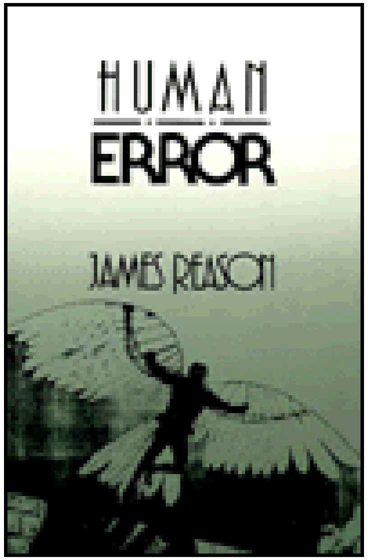


Common threads in accidents ~3 Mile Island

1. Latent errors accumulate
2. Operators cannot fully understand system
3. Tendency to blame operators afterwards
4. Systems never working fully properly
5. Emergency Systems often flawed
   - Facility running under normal operation masks errors in error handling

Source: Charles Perrow, *Normal Accidents: Living with High Risk Technologies*, Perseus Books, 1990

Learning from other fields: human error



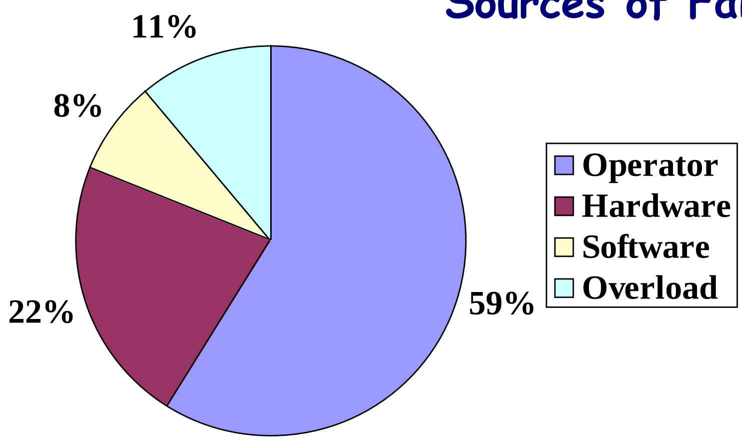
- **Two kinds of human error**
  1) **slips/lapses:** errors in execution
  2) **mistakes:** errors in planning
- **Human errors are inevitable**
  - "humans are furious pattern-matchers"
    - » sometimes the match is wrong
  - cognitive strain leads brain to think up least-effort solutions
- **Humans can self-detect errors**
  - 75% errors immediately detected

Source: J. Reason, <u>Human Error</u>, Cambridge, 1990.

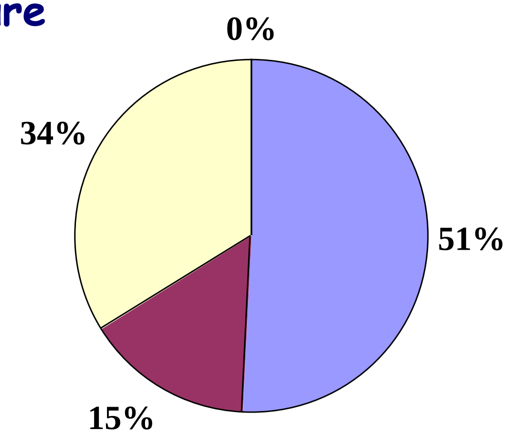
Human error

- **Human operator error is the leading cause of dependability problems in many domains**

Sources of Failure



Public Switched Telephone Network



Average of 3 Internet Sites

- **Operator error cannot be eliminated**
  - humans inevitably make mistakes: "to err is human"
  - *automation irony* tells us we can't eliminate the human

Source: D. Patterson et al. Recovery Oriented Computing (ROC): Motivation, Definition, Techniques, and Case Studies, UC Berkeley Technical Report UCB//CSD-02-1175, March 2002.

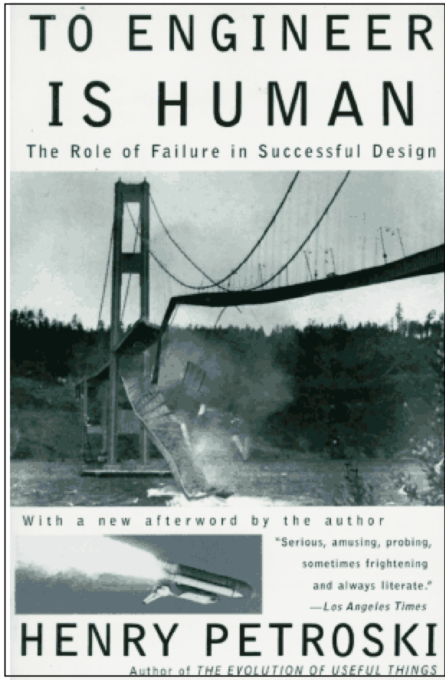
The ironies of automation

- **Automation doesn't remove human influence**
  - shifts the burden from operator to designer
    - » designers are human too, and make mistakes
    - » unless designer is perfect, human operator still needed
- **Automation can make operator's job harder**
  - reduces operator's understanding of the system
    - » automation increases complexity, decreases visibility
    - » no opportunity to learn without day-to-day interaction
  - uninformed operator still has to solve exceptional scenarios missed by (imperfect) designers
    - » exceptional situations are already the most error-prone
- **Need tools to help, not replace, operator**

Source: J. Reason, Human Error, Cambridge University Press, 1990.

Learning from others: Bridges

- 1800s: 1/4 iron truss railroad bridges failed!
- Safety is now part of Civil Engineering DNA
- Techniques invented since 1800s:
  - Learn from failures vs. successes
  - Redundancy to survive some failures
  - Margin of safety 3X-6X vs. calculated load
  - (CS&E version of safety margin?)



Margin of Safety in CS&E?

- **Like Civil Engineering, never make dependable systems until add margin of safety ("margin of ignorance") for what we don't (can't) know?**
  - Before: design to tolerate expected (HW) faults
- **RAID 5 Story**
  - Operator removing good disk vs. bad disk
  - Temperature, vibration causing failure before repair
  - In retrospect, suggested RAID 5 for what we anticipated, but should have suggested RAID 6 (double failure OK) for unanticipated/safety margin?
- **CS&S Margin of Safety: Tolerate human error in design, in construction, and in use?**

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Recovery-Oriented Computing Philosophy

"If a problem has no solution, it may not be a problem, but a fact, not to be solved, but to be coped with over time"

— Shimon Peres ("Peres's Law")

- **People/HW/SW failures are facts, not problems**
- **Recovery/repair is how we cope with them**
- **Improving recovery/repair improves availability**
  - UnAvailability = $\frac{MTTR}{MTTF}$ *(assuming MTTR much less than MTTF)*
  - 1/10th MTTR just as valuable as 10X MTTF
- **ROC helps Operators**
  - Less stress with faster repair times
- **ROC enables use of Statistical Machine Learning**
  - False positives OK if repair times fast

"ROC Solid" Principles

1. **Given errors occur, design to recover rapidly**
2. **Given humans make errors, build tools to help operator find and repair problems**
3. **Extensive sanity checks during operation**
   – To discover failures quickly (and to help debug)
4. **Recovery benchmarks to measure progress**
   – Recreate performance benchmark competition?
   – (Skip in interest of time)

Lessons and Observations from ROC

- Fast recovery makes mistakes OK

Observations:

- The power of Statistical Machine Learning
- Visualization to help convince operator of value of Statistical Machine Learning
- REST (Representational State Transfer)
  - Skip for time constraints

Lesson: MTTR more valuable than MTTF???

- **Originally: low MTTR allows MTTR<<MTTF so Avail-->1.0**
- **Now: other advantages of low MTTR**
- **If MTTR is below "human threshold", failure effectively didn't occur**
  - Example: microrebooting - if can serve a request in <8sec, user doesn't see the failure
- **Tolerates false positives**
  - Enables aggressive automatic techniques
  - If Administrator believes there's a problem, can try "recovery" without incurring high cost if he's wrong

MTTR more valuable than MTTF???

- **MTTF normally predicted vs. observed**
  - Include environmental error operator error, app bug?
  - Much easier to verify MTTR than MTTF!
- **If 99% to 99.9% availability, no change in prep**
  - 1-3 months => 10-30 months MTTF, still see failures
- **Threshold => non-linear return on improvement**
  - 8 to 11 second abandonment threshold on Internet
  - 30 second NFS client/server threshold
  - Satellite tracking and 10 minute vs. 2 minute MTTR
- **Ebay 4 hour outage, 1st major outage in year**
  - More people in single event worse for reputation?
  - One 4-hour outage/year => NY Times => stock?
  - What if 1-minute outage/day for a year?
    (250X improvement in MTTR, 365X worse in MTTF)

Some ROC Accomplishment

- **Crash-only software design philosophy + 3 prototypes**
  - Separation of data recovery from program recovery, and specially-designed crash-only state stores
  - Insight: crash-only-ness simplifies failure detection and recovery
- **Microrebooting components in J2EE applications**
  - "Selective recovery" of bad J2EE components in tens of ms to hundreds of ms (2-3 orders of magnitude faster than restart)
  - Insight: Fast recovery makes mistakes OK
  - Insight: Short transient failures can be completely masked
  - REST (Representational State Transfer) is 2010 version of ideas

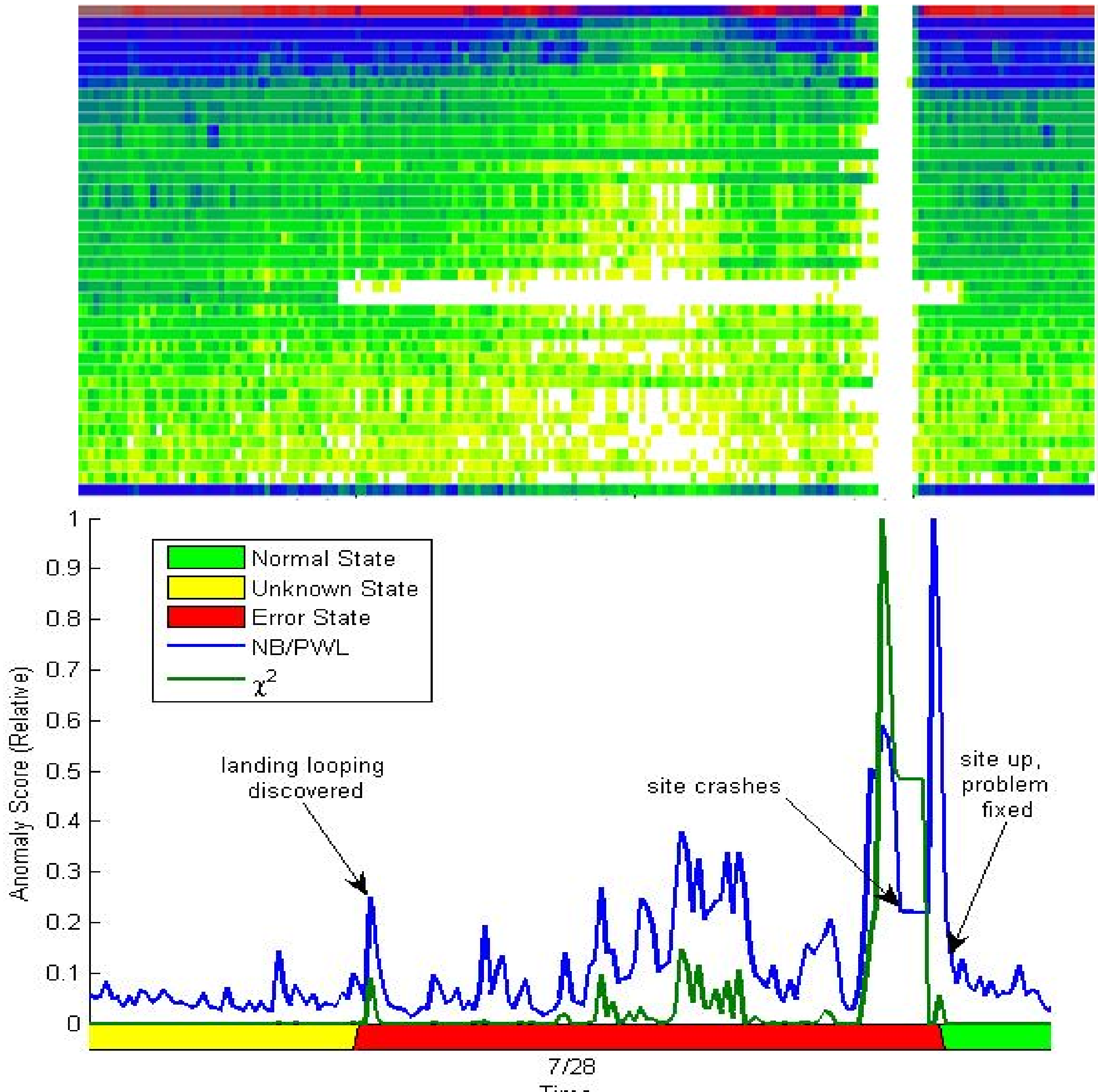
Crash Only Software

- Crash-only software refers to code that handle failures by simply restarting, without attempting any sophisticated recovery
- Components can microreboot into known good state without help of user
- Failure handling and normal startup use same methods => more likely failure handling code is debugged
- Managing state: try to have persistent state match running state for quick crash recovery
- Influenced design of several software products, including Apple OS X

Visualizing & Mining User Behavior During Site Failures*

- **Idea: when site misbehaves, users notice, and change *their* behaviors; use this as a "failure detector"**
  - Partially-supervised learning, since ground truth data often incomplete
- **Approach: does distribution of hits to various pages match the "historical" distribution?**
  - each minute, compare hit counts of top N pages to hit counts over last 6 hours using Bayesian networks and χ^2 test
  - combine with visualization so operator can spot anomalies corresponding to what the algorithms find
- **Evaluation:**
  - Which site problems could have been avoided, or to what extent could they have been mitigated, with these techniques in place?
  - Ground truth evaluation of model findings: *very hard*

* P. Bodik, G. Friedman, H.T. Levine (Ebates.com), A. Fox, et al. In Proc. ICAC 2005.



RECOVERY-ORIENTED

Potential Impact: Gaining Operator Trust

- **Combining SML with *operator centric* visualization**
  - faster adoption (since skeptical sysadmins can turn off the automatic actions and just use the visualization to cross-check results)
  - earlier visual detection of potential problems, leading to faster resolution or problem avoidance
  - faster classification of false positives
  - Leveraging sysadmin's existing expertise, and augmenting her understanding of its behavior by combining "visual pattern recognition" with SML
- **Increasing operators' *trust* in automated techniques**

Crisis identification is difficult, time consuming, costly, & lengthen MTTR

- Frequent SW/HW failures cause downtime

- Timeline of a typical crisis
  - detection: automatic, easy
  - identification: manual, difficult
    - » takes minutes to hours
  - resolution: depends on crisis type
  - root cause diagnosis, documentation
- Web apps are complex and large-scale
  - app used for evaluation: 400 servers, 100 metrics

Insight: performance metrics help identify recurring crises

Performance crises recur

- incorrect root cause diagnosis
- takes time to deploy the fix
  - » other priorities, test new code

System state is similar during similar crises

- but not easily captured by fixed set of metrics
- 3 operator-selected metrics not enough

“Fingerprinting the datacenter: automated classification of performance crises,” Peter Bodík, Moises Goldszmidt, Armando Fox, Dawn Woodard, Hans Andersen, Eurosys 2009.

Definition and examples of performance crises

Performance crisis = violation of service-level objective (SLO)

- based on business objectives
- captures performance of whole cluster
- example: >90% servers have latency < 100 ms during 15-minute epoch

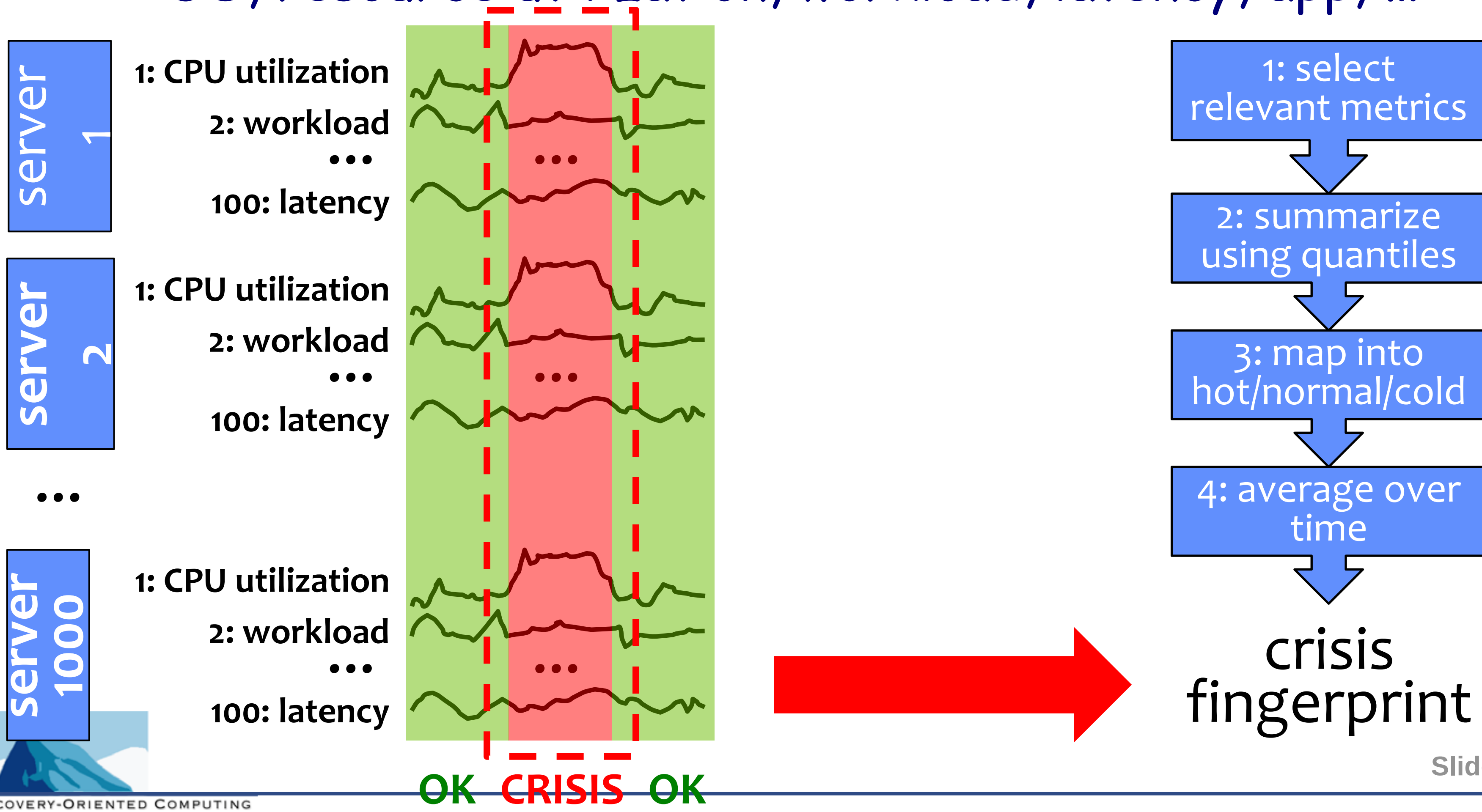
Crises Bodik et al analyzed

- app config, DB config, request routing errors
- overloaded front-end, overloaded back-end

Fingerprints capture state of performance metrics during crisis

Metrics as arbitrary time series

- OS, resource utilization, workload, latency, app, …



System under study

24 x 7 enterprise-class user-facing application at Microsoft

- 400 machines
- 100 metrics per machine, 15-minute epochs
- operators: "Correct label useful during first hour"

Definition of a crisis

- operators supplied 3 latency metrics and thresholds
- 10% servers have latency > threshold during 1 epoch

19 operator-labeled crises of 10 types

- 9 of type A, 2 of type B, 1 each of 8 more types
- 4-month period

Evaluation results

- **Previously-seen crises:**
  - identification accuracy: 77%
  - identified when detected or 1 epoch later
- **For 77% of crises, average time to ID 10 minutes**
  - Could save up to 50 minutes; more if shorter epochs
- **Accuracy for previously-unseen crises: 82%**
- **Suggested metrics operators didn't realize were important**
- **Being deployed inside Microsoft**

ROC Summary

- **Peres's Law more important than Moore's Law?**
  - Must cope with fact that people, SW, HW fail
- **Recovery Oriented Computing is one path for operator synergy, dependability for servers**
  - Significantly reducing MTTR (people/SW/HW)
    => Better Dependability (reduce MTTR/MTBF)
    => Reduce Operator Stress (less risk with fast repair)
    => Enable Machine Learning (live with false positives)
  - Compete on recovery time vs. performance?
  - Careful isolation of state for crash only, quick MTTR

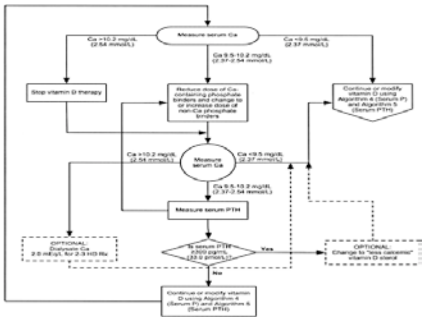
http://ROC.cs.berkeley.edu

AMP: Big Data Scalability Dilemma

- Data Analytics frameworks can't handle lots of incomplete, heterogeneous, dirty data
- State-of-the Art Machine Learning techniques do not scale to large data sets
- Processing architectures struggle with increasing diversity of programming models and job types
- Adding people to a late project makes it later

Exactly Opposite of what we Expect and Need

Algorithms, Machines, People (AMP)



Adaptive/Active Machine Learning and Analytics

Massive and Diverse Data

CrowdSourcing

Cloud Computing

Team of experts in ML, Systems, & Crowds build ≈Real Time Big Data Analyzer

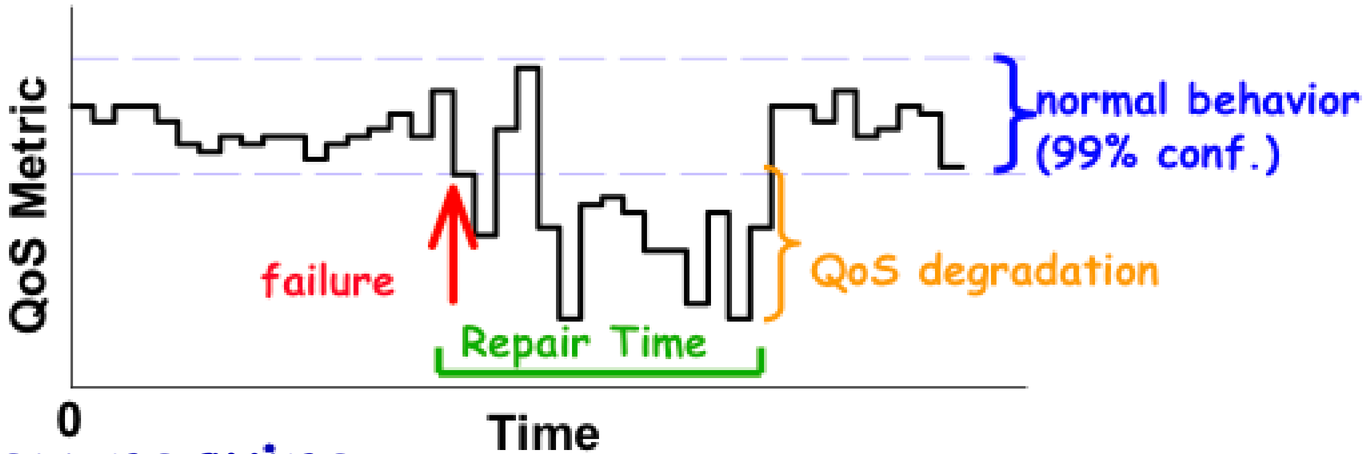
Extra Slides

Traditional Fault-Tolerance vs.ROC

- **>30 years of Fault-Tolerance research**
- **FT greatest success in HW; ignores operator error?**
  - ROC holistic, all failure sources: HW, SW, and operator
- **Key FT approach: assumes accurate model of hardware and software, and ways HW and SW can fail**
  - Models to design, evaluate availability
- **Success areas for FT: airplanes, satellites, space shuttle, telecommunications, finance (Tandem)**
  - Hardware, software often changes slowly
  - Where SW/HW changes more rapidly, less impact of FT research
- **ROC compatible with SW Productivity Tools, SW Churn of Internet Sites**
- **Much of FT helps MTTF, ROC helps MTTR**
  - Improving MTTF and MTTR synergistic (don't want bad MTTF!)

Recovery benchmarking 101

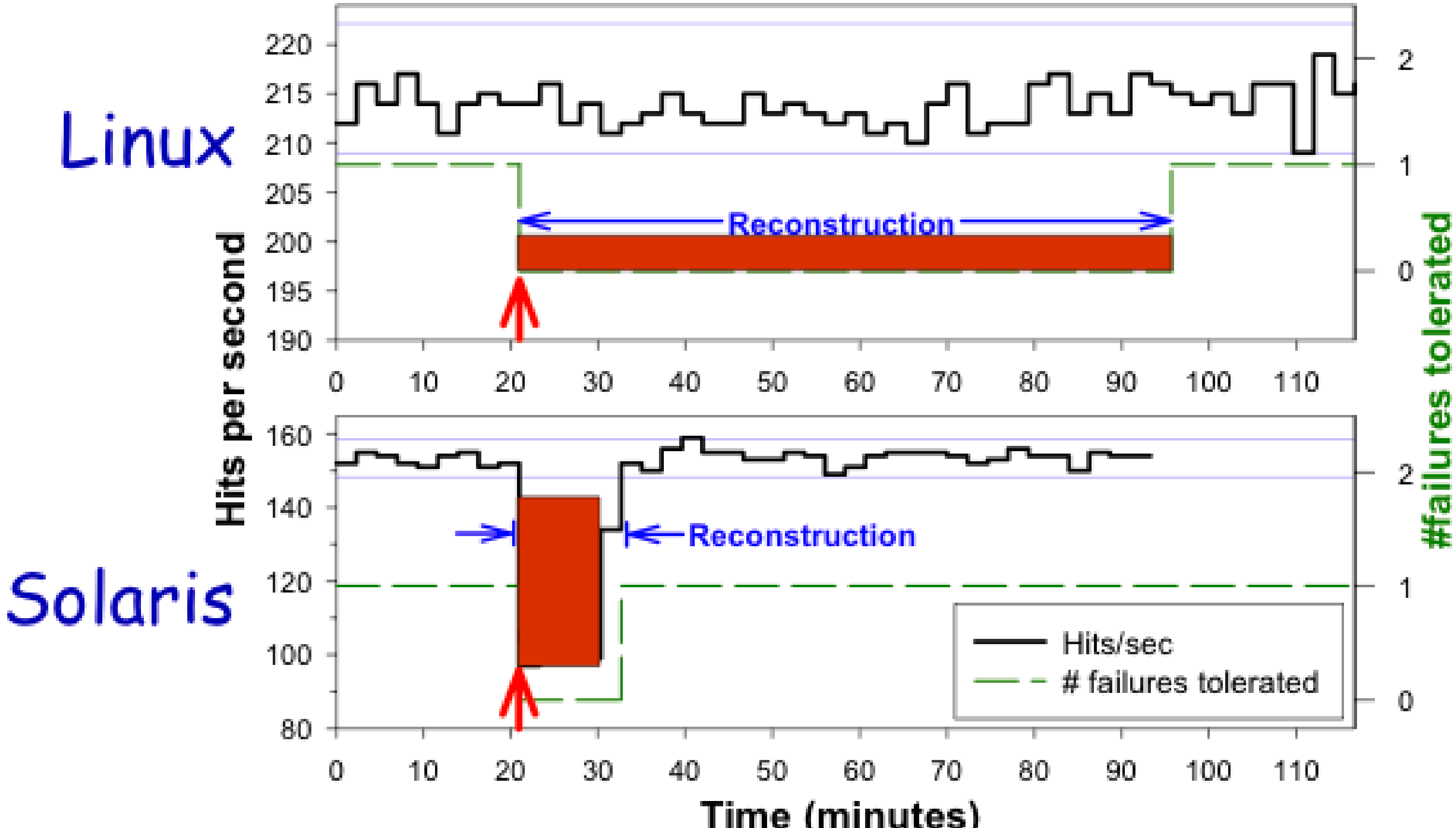
- **Recovery benchmarks quantify system behavior under failures, maintenance, recovery**



- **They require**
  - A realistic workload for the system
  - Quality of service metrics and tools to measure them
  - Fault-injection to simulate failures
  - Human operators to perform repairs

Source: A. Brown, and D. Patterson, "Towards availability benchmarks: a case study of software RAID systems," *Proc. USENIX*, 18-23 June 2000

Example: 1 fault in SW RAID



- Compares Linux and Solaris reconstruction
  - **Linux**: Small impact but longer vulnerability to 2nd fault
  - **Solaris**: large perf. impact but restores redundancy fast
  - **Windows**: did not auto-reconstruct!

Software RAID: QoS behavior

- **Response to double-fault scenario**
  - a double fault results in unrecoverable loss of data on the RAID volume
  - **Linux:** blocked access to volume
  - **Windows:** blocked access to volume
  - **Solaris:** silently continued using volume, delivering *fabricated* data to application!
    - » clear violation of RAID availability semantics
    - » resulted in corrupted file system and garbage data at the application level
    - » this *undocumented* policy has serious availability implications for applications

REST (Representational State Transfer)

- Roy Fielding's PhD thesis, 2000
- Wikipedia: "REST can be considered as a *post hoc description of the features of the Web that made the Web successful*"
- Idea: everything in your system (in this case, the Web) is a *resource*
- Requests specify one of a fixed set of *operations* on some *representation* of that resource

RESTful requirements

- Client-server, with client separated from server by a *uniform interface*
- *Stateless:* each request carries *all* necessary info for server to complete it
- *Cacheable:* responses must specify if representation of resource returned may be cached for future use
- *Layered:* intermediaries can pass on requests, transparently to client or server

REST and Web Services

- **A RESTful web service advertises**
  - a base URI
  - a way to name a specific resource, starting from that base URI
  - MIME types (JSON, XML, XHTML, ...) supported by available representation(s) of resource
  - a set of requests specifying what can be done to the resource
  - well-defined semantics for each request type

REST Summary

- A key difference between SaaS and SWS is *how to encapsulate state*
- REST forces you to think about this up front
- *Highly recommended: Wikipedia article on REST*