A New Focus for a New Century: Availability and Maintainability >> Performance

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www.cs.berkeley.edu/~patterson/talks/keynote.html

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Outline

- **The past:** where we have been
- **The present:** new realities and challenges
- ***A future:*** Recovery-Oriented Computing (ROC)
- **ROC techniques and principles**

The past: research goals and assumptions of last 15 years

- **Goal #1: Improve performance**
- **Goal #2: Improve performance**
- **Goal #3: Improve cost-performance**
- **Assumptions**
  - Humans are perfect (they don't make mistakes during installation, wiring, upgrade, maintenance or repair)
  - Software will eventually be bug free (good programmers write bug-free code, debugging works)
  - Hardware MTBF is already very large (~100 years between failures), and will continue to increase
  - Maintenance costs irrelevant vs. Purchase price (maintenance a function of price, so cheaper helps)

After 15 years of research on price-performance, what's next?

- **Services as model for future of IT**
- **Availability is now the vital metric for servers**
  - near-100% availability is becoming mandatory
    - » for e-commerce, enterprise apps, online services, ISPs
  - but, service outages are frequent
    - » 65% of IT managers report that their websites were unavailable to customers over a 6-month period
      - 25%: 3 or more outages
  - outage costs are high
    - » social effects: negative press, loss of customers who "click over" to competitor

Source: InternetWeek 4/3/2000

Downtime Costs (per Hour)

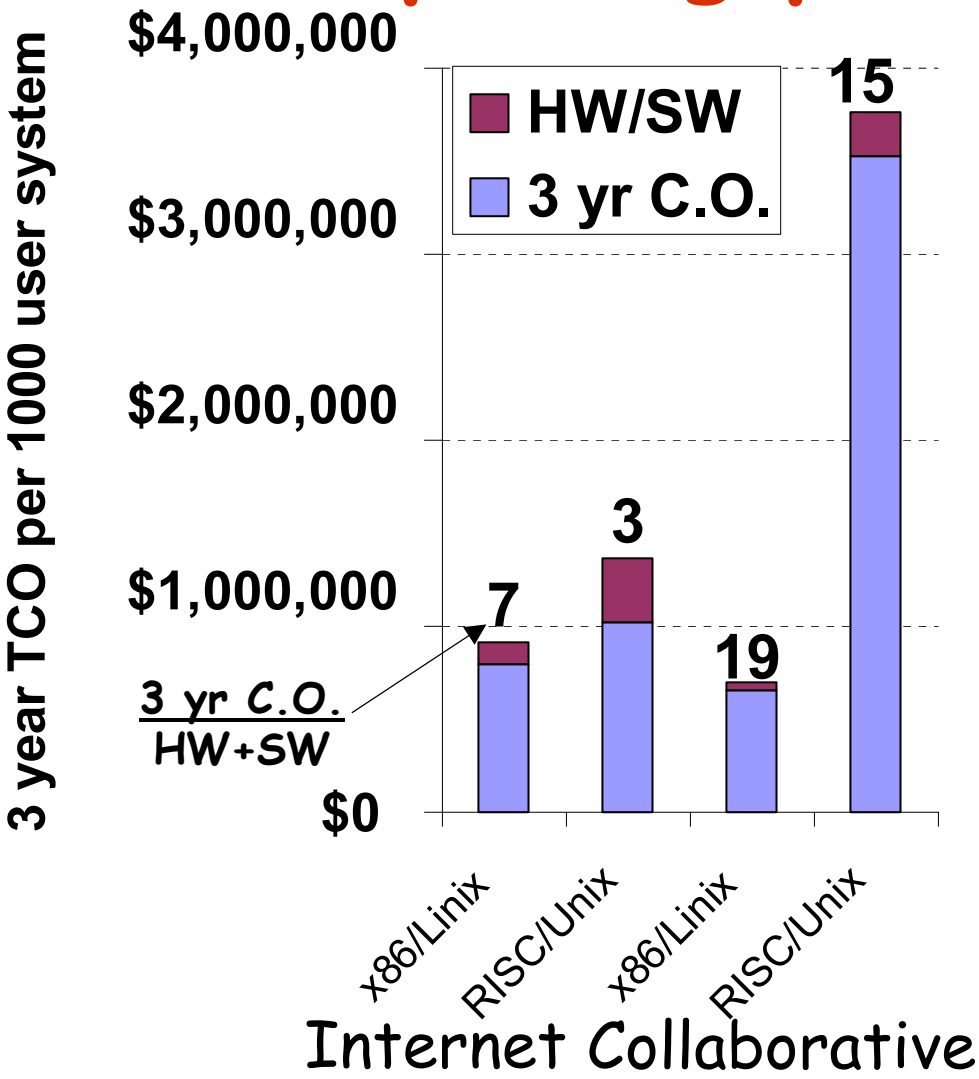
• Brokerage operations	$6,450,000
• Credit card authorization	$2,600,000
• Ebay (1 outage 22 hours)	$225,000
• Amazon.com	$180,000
• Package shipping services	$150,000
• Home shopping channel	$113,000
• Catalog sales center	$90,000
• Airline reservation center	$89,000
• Cellular service activation	$41,000
• On-line network fees	$25,000
• ATM service fees	$14,000

Sources: InternetWeek 4/3/2000 + *Fibre Channel: A Comprehensive Introduction*, R. Kembel 2000, p.8.
"...based on a survey done by Contingency Planning Research."

Total Cost Ownership Hypothesis

- "Moore's Law" + hypercompetitve marketplace improves cost and speed of CPUs,
  cost and capacity of memory and disks
- Morris (IBM) $3M comparison 1984 v. 2001:
  - CPU: Minicomputer to PC, 3000X faster
  - DRAM: Memory boards to DIMMs, 3000X bigger
  - Disks: 8-inch drives to 3.5-inch drives, 4000X bigger
- Unless avg. user demands grow with Moore's Law, a service increases in number of users
- HW/SW costs shrink; salaries go up over time
- Hypothesis: Cost of Ownership is more a function of number of users versus HW/SW $,
  so T.C.O. today is mostly people costs

Cost of Ownership after 15 years of improving price-performance?



- 142 Interviews, 2H01
- $2.4B/yr avg. sales
- Avg. 3 - 12 servers, 1100 - 7600 users/site
- not included: space, power, media, comm., HW/SW support contracts, downtime
- Internet/Intranet: firewall,Web serving, Web caching, B2B, B2C
- Collaborative: calendar, email, file/database,

Source: "The Role of Linux in Reducing the Cost of Enterprise Computing", IDC white paper, sponsored by Red Hat, by Al Gillen, Dan Kusnetzky, and Scott McLaron, Jan. 2002, available at www.redhat.com

What have we learned from past projects?

- **Maintenance of machines (with state) expensive**
  - ~5X to 10X cost of HW/SW
  - Stateless machines can be trivial to maintain (Hotmail)
- **System admin keeps system available; 1/3 to 1/2 of Cost of Ownership?**
  - System + clever human working during failure = uptime (failure often occurs during upgrades, reconfiguration)
  - Also growth plans, user training, fix performance bugs
- **Know how evaluate (performance and cost)**
  - Run system against workload, measure, innovate, repeat
  - Benchmarks standardize workloads, lead to competition, evaluate alternatives; turns debates into numbers
- **What are 21st century research challenges? Says who?**

Jim Gray: Trouble-Free Systems

- **Manager**
  - Sets goals
  - Sets policy
  - Sets budget
  - System does the rest.
- **Everyone is a CIO (Chief Information Officer)**
- **Build a system**
  - Used by millions of people each day
  - Administered and managed by a ½ time person.
    - » On hardware fault, order replacement part
    - » On overload, order additional equipment
    - » Upgrade hardware and software automatically.

"What Next?
A dozen remaining IT problems"
Turing Award Lecture,
FCRC,
May 1999
Jim Gray
Microsoft

Butler Lampson: Systems Challenges

- **Systems that work**
  - Meeting their specs
  - Always available
  - Adapting to changing environment
  - Evolving while they run
  - Made from unreliable components
  - Growing without practical limit
- **Credible simulations or analysis**
- **Writing good specs**
- **Testing**
- **Performance**
  - Understanding when it doesn't matter

"Computer Systems Research -Past and Future"
Keynote address, 17th SOSP, Dec. 1999
Butler Lampson
Microsoft

John Hennessy: What Should the "New World" Focus Be?

- **Availability**
  - Both appliance & service
- **Maintainability**
  - Two functions:
    - » Enhancing availability by preventing failure
    - » Ease of SW and HW upgrades
- **Scalability**
  - Especially of service
- **Cost**
  - per device and per service transaction
- **Performance**
  - Remains important, but its not SPECint

"Back to the Future: Time to Return to Longstanding Problems in Computer Systems?"
Keynote address, FCRC, May 1999
John Hennessy
Stanford

IBM Research (10/15/2001)

- Overview: Computing is too hard. It's time we stop our preoccupation with faster and more powerful and start making them smarter.
- The Solution: "Autonomic Computing" a systemic view of computing modeled after a self-regulating biological system; largely self-managing, self-diagnostic. User perspective:
  - Flexible The system will be able to sift data via a platform- and device-agnostic approach
  - Accessible The nature of the autonomic system is that it is always on
  - Transparent The system will perform its tasks and adapt to a user's needs without dragging the user into the intricacies of its workings

Source: www.research.ibm.com/autonomic/

Bill Gates M/S (1/15/2002): "Trustworthy Computing"

- Trustworthiness is a fundamental challenge that spans entire computing ecosystem, from individual chips to global Internet services
  - Availability: System outages should become a thing of the past because of SW architecture that supports redundancy and automatic recovery
  - Privacy: Users should be in control of how their data is used
  - Security: should be easy for developers to understand and build into their apps
- 7000 M/S programmers stop development for February 2002 to get special security training

Source: "Microsoft Makes Software Safety a Top Goal," by John Markoff, N.Y. Times, 1/17/02

New research goals for a New Century: ACME

- **Availability**
  - 24x7 delivery of service to users
- **Changability**
  - support rapid deployment of new software, apps, UI
- **Maintainability**
  - reduce burden on system administrators
  - provide helpful, forgiving SysAdmin environments
- **Evolutionary Growth**
  - allow easy system expansion over time without sacrificing availability or maintainability
- **(Also Security/Privacy, but I don't know much about it, so I'll leave out of this talk)**

Where does ACME stand today?

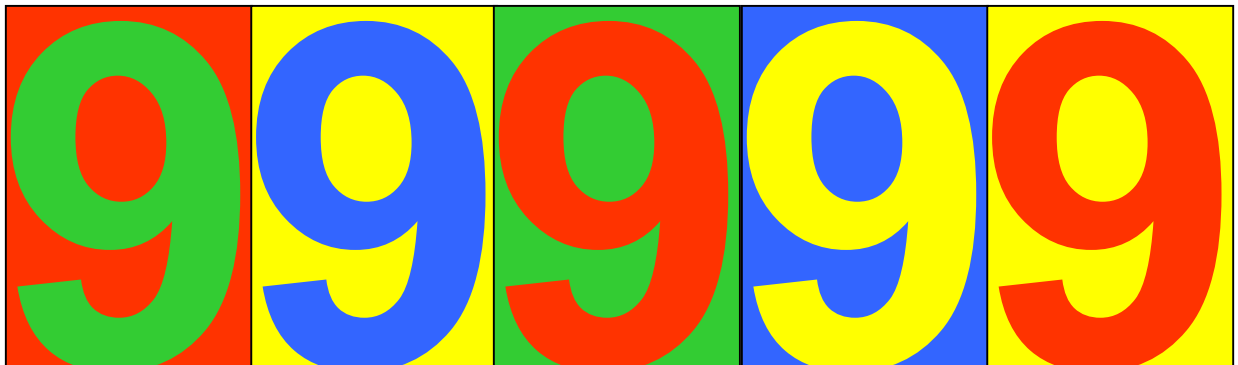
- **Availability: failures are common**
  - Traditional fault-tolerance doesn't solve the problems
- **Changability**
  - In back-end system tiers, software upgrades difficult, failure-prone, or ignored
  - For application service over WWW, daily change
- **Maintainability**
  - system maintenance environments are unforgiving
  - human operator error is single largest failure source
- **Evolutionary growth**
  - 1U-PC cluster front-ends scale, evolve well
  - back-end scalability difficult, operator intensive

ACME: Availability

- **Availability: failures are common**
  - Well designed and manufactured HW: >1% fail/year
  - Well designed and tested SW: > 1 bug / 1000 lines
  - Well trained people doing difficult tasks: up to 10%
  - Well run co-location site (e.g., Exodus):
    1 power failure per year, > 1 network outage per year
  - Denial of service attacks => routine event

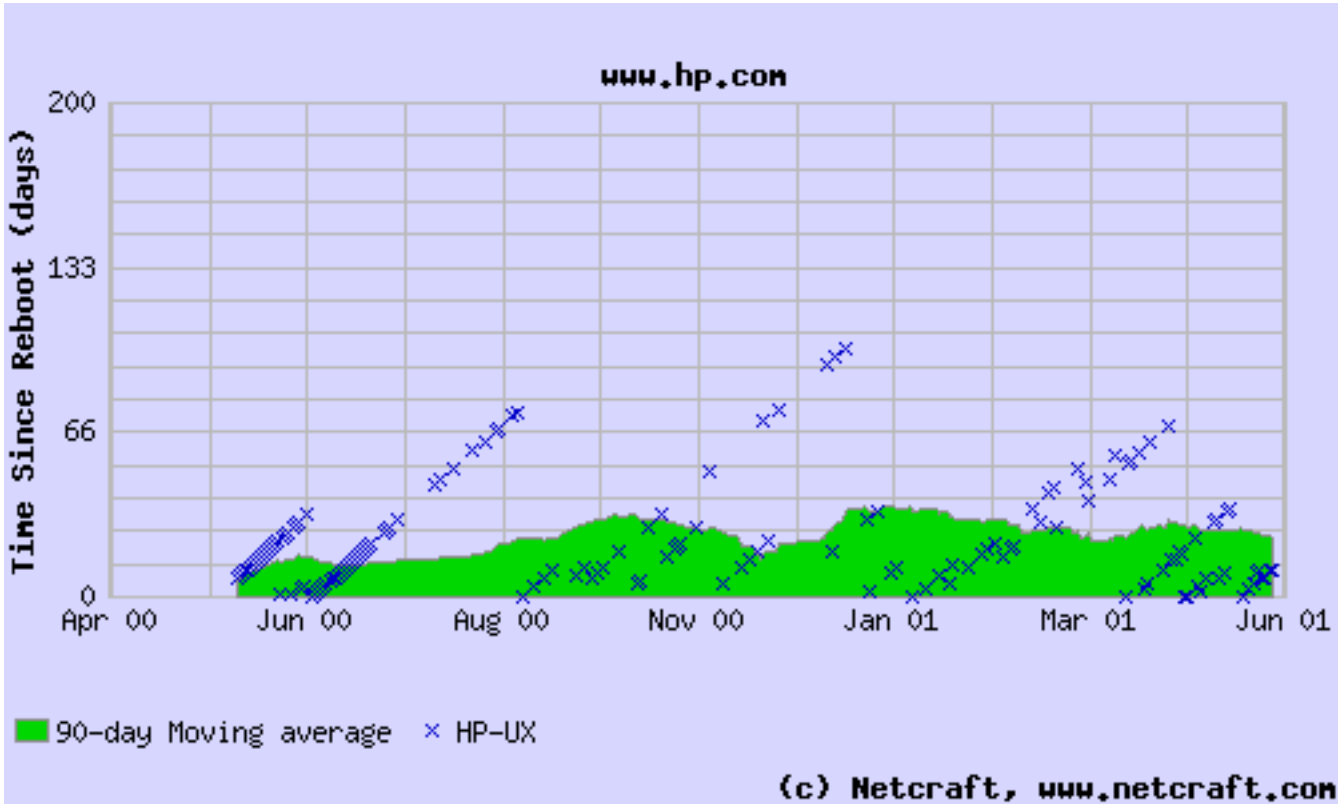
ACME: Claims of 5 9s?

- 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?**

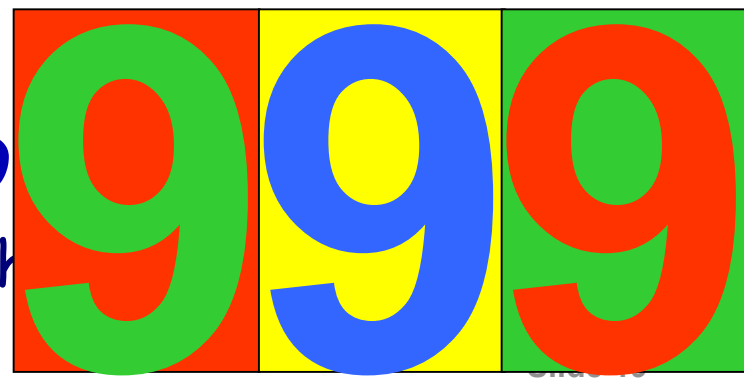


5 9s from Jim Gray's talk:
"Dependability
in the Internet Era"

ACME: Uptime of HP.com?



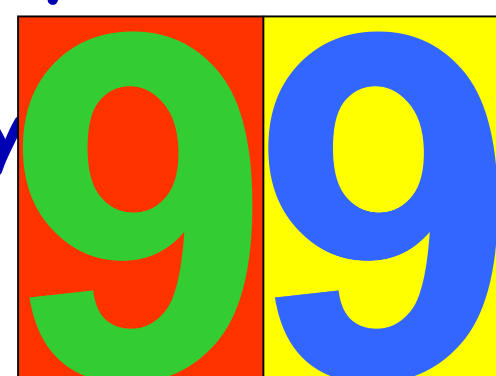
- **Average reboot is about 30.8 if 10 minutes per reboot => 9**
  - See uptime.netcraft.com/up/graph



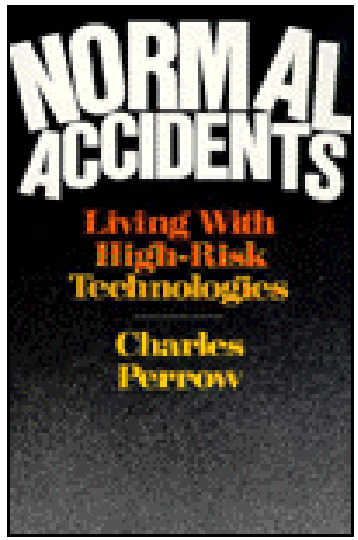
“Microsoft fingers technicians for crippling site outages”

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 security of our networks," a Microsoft spokesman said.
    - (5 9s possible if site stay … rs!)



ACME: Learning from other fields: disasters

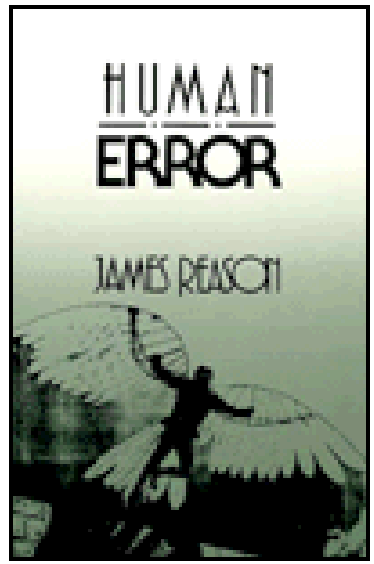


Common threads in accidents ~3 Mile Island

1. More multiple failures than you believe possible, because latent errors accumulate
2. Operators cannot fully understand system because errors in implementation, measurement system, warning systems. Also complex, hard to predict interactions
3. Tendency to blame operators afterwards (60-80%), but they must operate with missing, wrong information
4. The systems are never all working fully properly: bad warning lights, sensors out, things in repair
5. Emergency Systems are often flawed. At 3 Mile Island, 2 valves left in the wrong position; parts of a redundant system used only in an emergency. Facility running under normal operation masks errors in error handling

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

ACME Learning from other fields: human error



- **Two kinds of human error**
  1) **slips/lapses**: errors in execution
  2) **mistakes**: errors in planning
  - errors can be **active** (operator error) or **latent** (design error, management error)
- **Human errors are inevitable**
  - "humans are furious pattern-matchers"
    - » sometimes the match is wrong
  - cognitive strain leads brain to think up least-effort solutions first, even if wrong
- **Humans can self-detect errors**
  - about 75% of errors are immediately detected

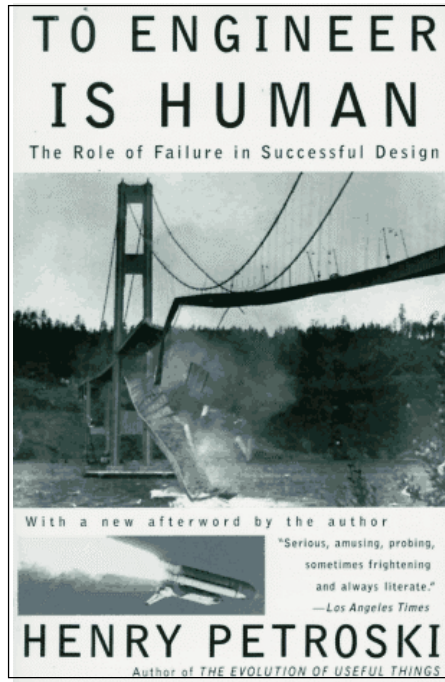
Source: J. Reason, Human Error, Cambridge, 1990.

ACME: The Automation Irony

- **Automation does not cure human error**
  - Automation shifts some errors from operator errors to design errors
    - » harder to detect/tolerate/fix design errors
  - Automation addresses the easy tasks, leaving the complex, unfamiliar tasks for the human
    - » humans are ill-suited to these tasks, especially under stress
  - Automation hinders understanding and mental modeling
    - » decreases system visibility and increases complexity
    - » operators don't get hands-on control experience
    - » prevents building mental rules and models for troubleshooting

Learning from other fields: Bridges

- 1800s: 1/4 iron truss railroad bridges failed!
- Safety is now part of Civil Engineering DNA
  - "Structural engineering is the science and art of designing and making, with economy and elegance, buildings, bridges, frameworks, and similar structures so that they can safely resist the forces to which they may be subjected"
- Techniques invented since 1800s:
  - Learn from failures vs. successes
  - Redundancy to survive some failures
  - Margin of safety 3X-6X vs. calculated load
- What is CS&E version of safety margin?



Summary: the present

- **We have invented a brittle technology, and the world depends on it more every day (story)**
- **After 15 years of working on performance, 21st Century research needs new, relevant goals**
  - **ACME:** Availability, Changability, Maintainability, Evolutionary growth (+ Security/Privacy)
- **Challenges in achieving ACME:**
  - HW, SW, network failures continue to plague us
  - Human operator errors continue to plague us
    - » Automation Irony tells us that we can't eliminate human
  - Untested emergency systems, latent errors remain
  - Traditional high-availability/fault-tolerance techniques don't solve the problem
  - Software in Internet services evolves rapidly

Outline

- **The past:** where we have been
- **The present:** new realities and challenges
- ***A future:*** Recovery-Oriented Computing (ROC)
- **ROC techniques and principles**

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")

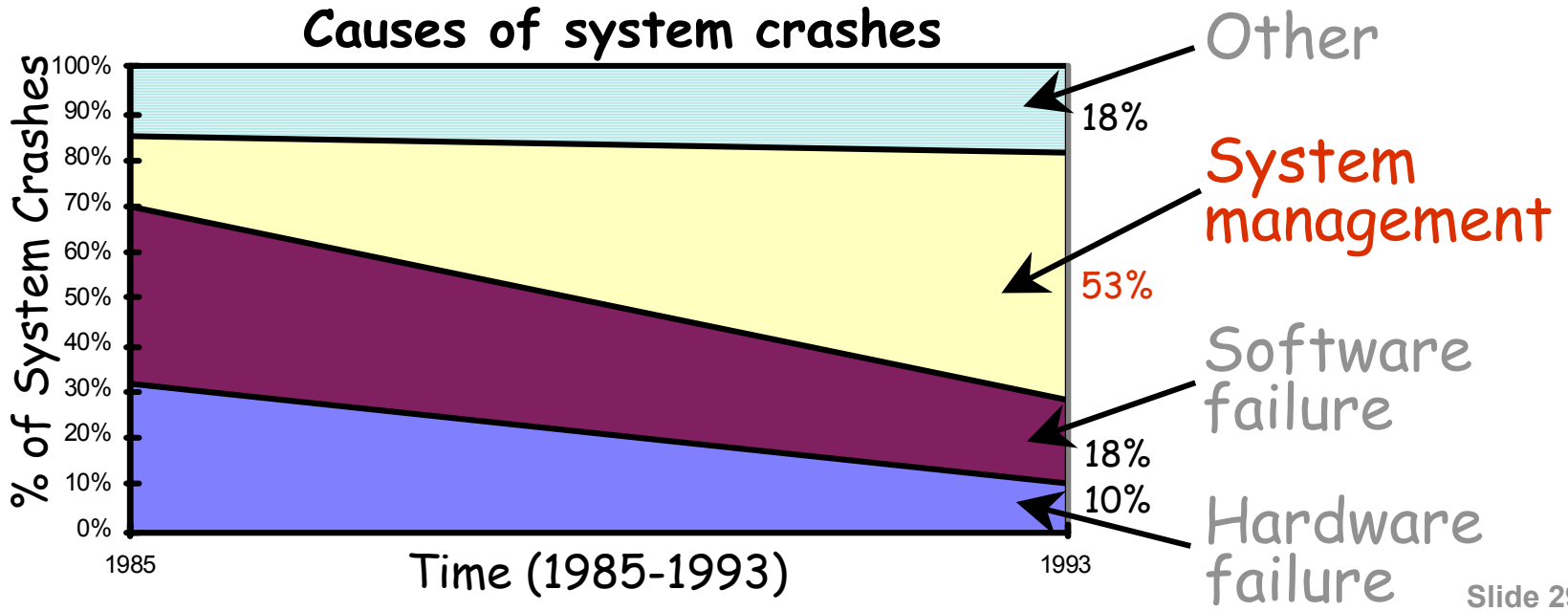
- **People/HW/SW failures are facts, not problems**
- **Improving recovery/repair improves availability**
  - UnAvailability = $\frac{\text{MTTR}}{\text{MTTF}}$ *(assuming MTTR much less than MTTF)*
  - 1/10th MTTR just as valuable as 10X MTBF
- **Recovery/repair is how we cope with above facts**
- **Since major Sys Admin job is recovery after failure, ROC also helps with maintenance/TCO**
- **Since Cost of Ownership is 5-10X HW/SW, if necessary, sacrifice disk/DRAM space and processor performance for ACME**

ROC approach

1. **Collect data to see why services fail**
2. **Create benchmarks to measure ACME**
   - Use failure data as workload for benchmarks
   - Benchmarks inspire researchers / humiliate companies to spur improvements in ACME
3. **Apply Margin of Safety from Civil to Availability target: Need more 9s?**
4. **Create and Evaluate techniques to help ACME**
   - Identify best practices of Internet services
   - Make human-machine interactions synergistic vs. antagonistic
   - ROC focus on fast repair (they are facts of life) vs. FT focus longer time between failures (problems)

ROC Part I: Failure Data Lessons about human operators

- **Human error is largest single failure source**
  - HP HA labs: human error is #1 cause of failures (2001)
  - Oracle: half of DB failures due to human error (1999)
  - Gray/Tandem: 42% of failures from human administrator errors (1986)
  - Murphy/Gent study of VAX systems (1993):

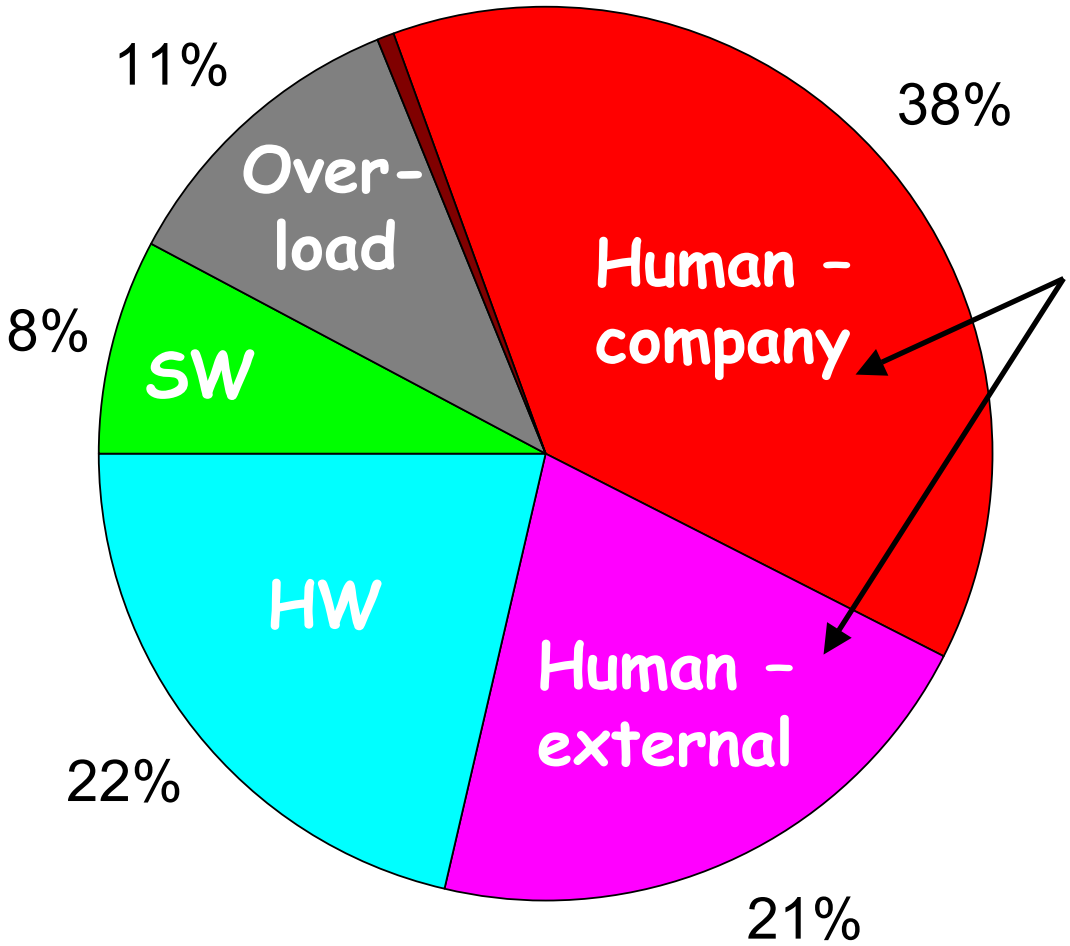


Failure Data: Public Switched Telephone Network (PSTN) record

- **Detailed telephone service failure data available from the Federal Communications Commission (FCC)**
  - Required by law for outages affecting 30,000 people or lasting at least 30 minutes
  - 3 ways to report

1. **Outage and reason (direct vs. root cause)**
   - But how big an outage?
2. **Length of outage * potential customers affected**
   - But what if 2 AM vs. 2 PM?
3. **Blocked calls: actual calls tried but unsuccessful due to outage (!)**

Blocked Calls: PSTN in 2000



Human error accounts for **59%** of all blocked calls

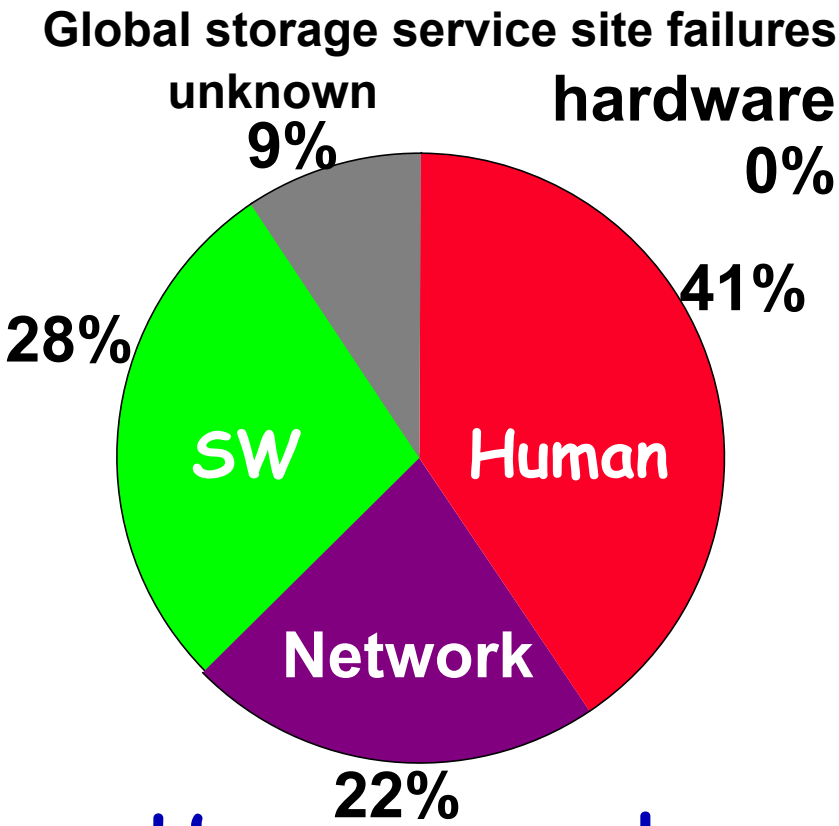
Source: Patty Enriquez, U.C. Berkeley, in progress.

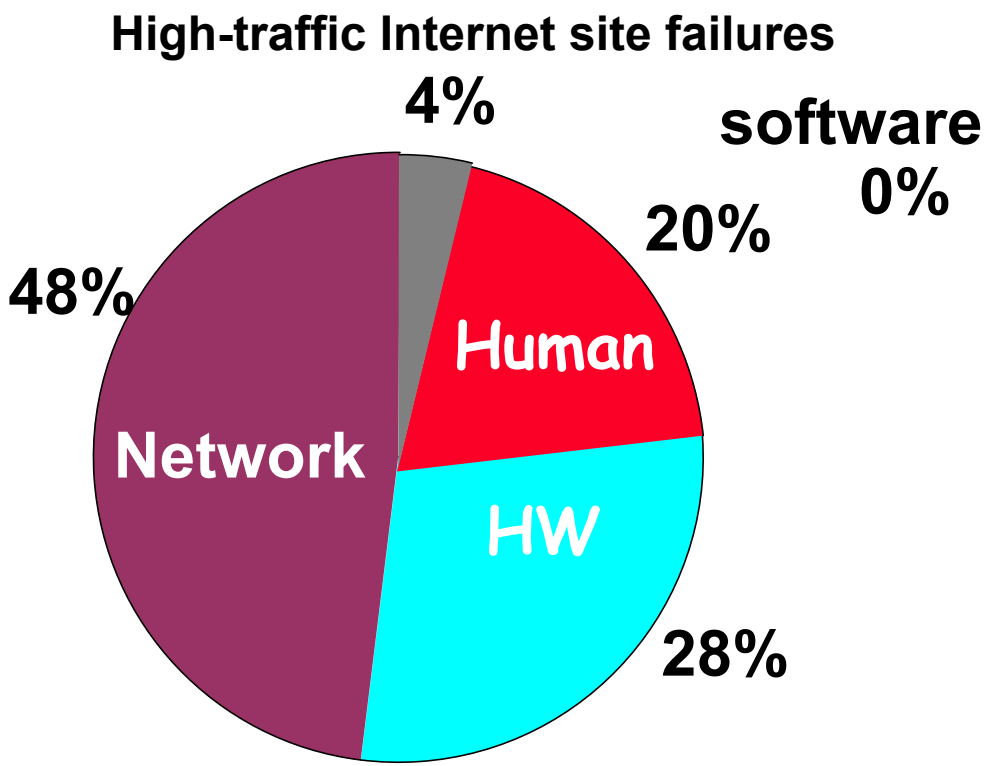
Failure Data: 2 Internet Sites

- **Global storage service**
  - ~500 machines, 4 colo. facilities + customer sites
  - all service software custom-written (x86/free OS)
  - Read/Write, more complex workload
- **High-traffic Internet site**
  - ~5000 of machines, 4 collocation facilities
  - ~100 million hits/day
  - all service software custom-written (x86/free OS)
  - Read mostly
  - Read, More HW, Software more mature
- **Looked at trouble tickets over 3-6 months**

Source: David Oppenheimer, U.C. Berkeley, in progress.

Internet Site Failures





Human error largest cause of failure in the more complex service, significant in both

Network problems largest cause of failure in the less complex service, significant in both

ROC Part 1: Failures Data Collection (so far)

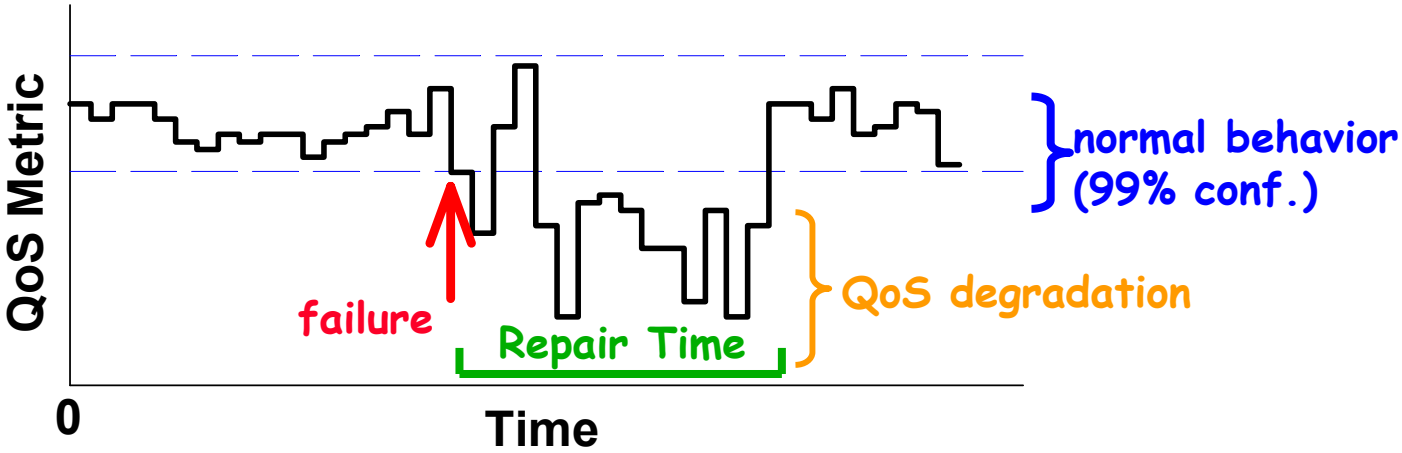
- **Humans substantial cause of failures**
  - As end users
  - As operators
- **Internet sites also challenged by network outages**
  - Significant outages due to relying on collocation site facilities
  - Problem diagnosis/repair difficult when components maintained by independent entities
- **Very interested in getting more data (under NDA) if you know of some**

ROC Part 2: ACME benchmarks

- **Traditional benchmarks focus on performance**
  - ignore ACME goals
  - assume perfect hardware, software, human operators
- **20th Century Winner: fastest on SPEC/TPC?**
- **21st Century Winner: fastest to recover from failure?**
- **New benchmarks needed to drive progress toward ACME, evaluate ROC success**
  - for example, *availability* and *recovery* benchmarks
  - How else convince developers, customers to adopt new technology?
  - How else convince researchers to find new challenges?

Availability benchmarking 101

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



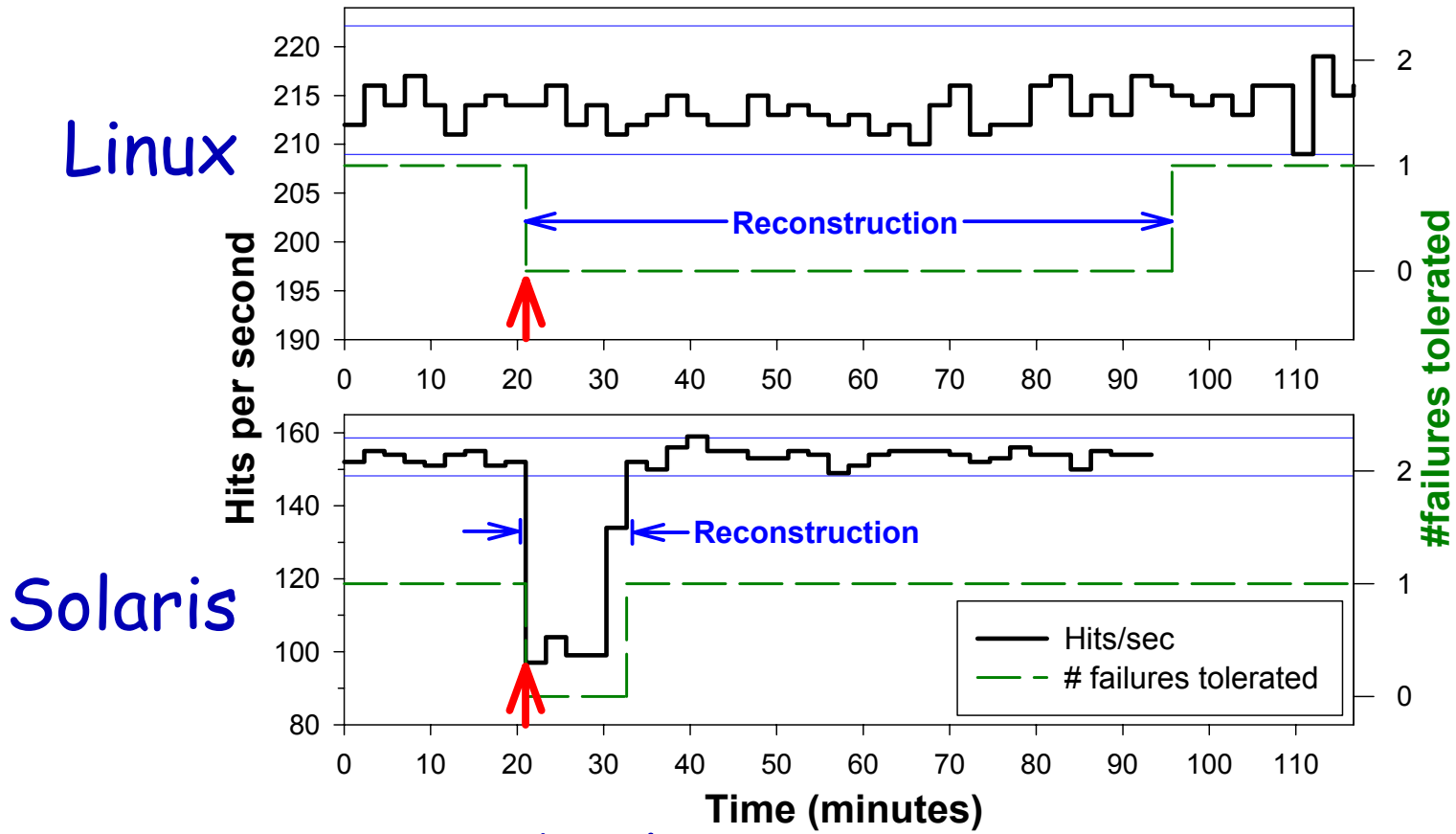
- **They require**
  - A realistic workload for the system
  - Quality of service metrics and tools to measure them
  - Fault-injection to simulate failures
  - Human operators to perform repairs

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

Availability Benchmarking Environment

- **Fault workload**
  - Must accurately reflect failure modes of real-world Internet service environments
    - » plus random tests to increase coverage, simulate Heisenbugs
  - But, no existing public failure dataset
    - » we have to collect this data
    - » a challenge due to proprietary nature of data
  - major contribution will be to collect, anonymize, and publish a modern set of failure data
- **Fault injection harness**
  - build into system: needed anyway for online verification

Example: 1 fault in SW RAID



- Compares Linux and Solaris reconstruction
  - **Linux**: minimal performance impact but longer window of vulnerability to second fault
  - **Solaris**: large perf. impact but restores redundancy fast
  - **Windows**: does 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

ROC Part 2: ACME Benchmarks (so far)

- Race to recover vs. race to finish line
- Many opportunities to compare commercial products and claims, measure value of research ideas, … with availability benchmarks
- Maintainability benchmarks involve people, but so do most research by social scientists
- Partial failures: Evaluate "Service level" benchmarks that insert faults that do not bring down entire service for all users?
- Even initial Availability benchmarks find peculiarities of systems measured
- Lots of low hanging fruit (~ early RAID days)

ROC Part 3: Margin of Safety in CS&E?

- Today marketing claims of 5 9s of availability (99.999%) but customers achieving 2-3 9s (99% to 99.9%)
- Like Civil Engineering, perhaps we will never make systems dependable until we add a margin of safety ("margin of ignorance") for things we don't (or can't) know
  - No more "that failure doesn't count"
- Perhaps we need to "over engineer" by a 1-2 9's to deliver in practice what we claim in theory?

ROC Part 4: Create and Evaluate Techniques to help ACME

- **Need a theory on constructing dependable, maintainable sites for networked services**
  - Document best practices of successful sites?
- **Need a theory on good design for operators as well as good design for end users**
  - Airplane Analogy: user interface to passengers (747) vs. user interface to pilots (Cessna)
- **Need new definition of failure**
  - Need IT equivalent of PSTN "blocked calls"?
    - » PSTN switches required to collect blocked calls; why not Internet switches too?
  - Failure > unavailable for 100% of users: (e.g., available to 10% of users is not "up")

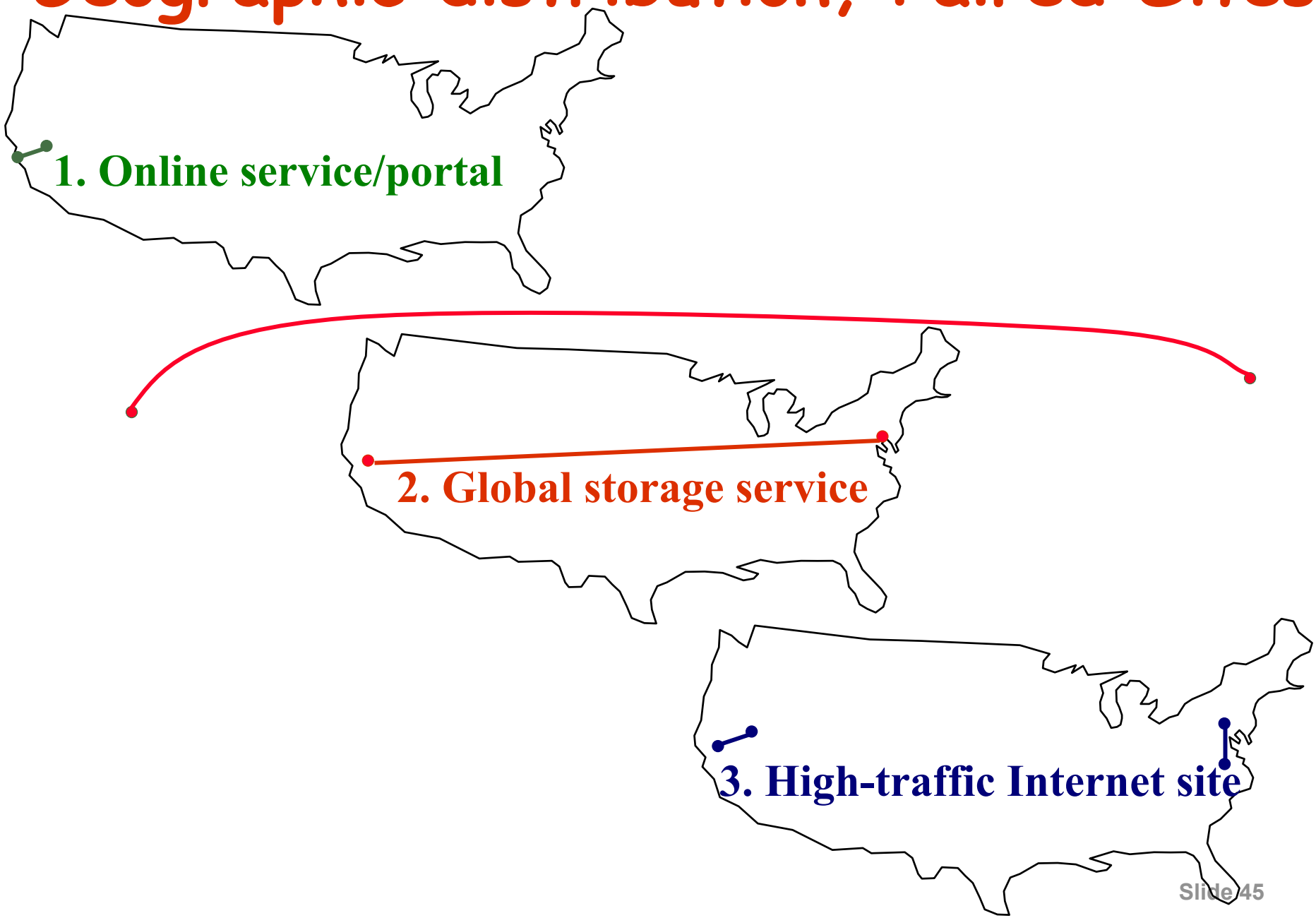
Safe, forgiving space for operator?

- **Expect human error and tolerate it**
  - protect system data from human error
  - allow mistakes to be easily reversed
- **Allow human operator to learn naturally**
  - "mistakes are OK": design to encourage exploration, experimentation
- **Make training on real system an everyday process**
- **Match interfaces to human capabilities**
- **Automate tedious or difficult tasks, but retain manual procedures**
  - encourage periodic use of manual procedures to increase familiarity

Partitioning and Redundancy?

- **System is Partitionable**
  - To isolate faults
  - To enable online repair/recovery
  - To enable online HW growth/SW upgrade
  - To enable operator training/expand experience on portions of real system without fear of system failure
  - Techniques: Geographically replicated sites, Virtual Machine Monitors
- **System is Redundant**
  - Sufficient HW redundancy/Data replication => part of system down but satisfactory service still available
  - Enough to survive 2nd (n^{th}?) failure during recovery
  - Techniques: RAID-6, N-copies of data

Geographic distribution, Paired Sites



Input Insertion for Detection?

- **System enables input insertion, output check of all modules (including fault insertion)**
  - To check module sanity to find failures faster
  - To test correctness of recovery mechanisms
    - » insert (random) faults and known-incorrect inputs
    - » also enables availability benchmarks
  - To expose and remove latent errors from system
  - To train/expand experience of operator
    - » Periodic reports to management on skills
  - To discover if warning systems are broken
    - » How else tell?
  - To simplify use of ACME benchmarks

Aid Diagnosis?

- **System assists human in diagnosing problems**
  - Root-cause analysis to suggest possible failure points
    - » Track resource dependencies of all requests
    - » Correlate symptomatic requests with component dependency model to isolate culprit components
  - "health" reporting to detect failed/failing components
    - » Failure information, self-test results propagated upwards
  - Don't rely on things connected according to plans
    - » Example: Discovery of network, power topology
- **Not a major focus of Berkeley or Stanford ROC projects**

Automation vs. Aid?

- **Two approaches to helping**

1) Automate the entire process as a unit

- the goal of most research into "self-healing", "self-maintaining", "self-tuning", or more recently "introspective" or "autonomic" systems
- What about Automation Irony?

2) ROC approach: provide tools to let human SysAdmins perform job more effectively

- If desired, add automation as a layer on top of the tools
- What about number of SysAdmins as number of computers continue to increase?

Refresh via Restart?

- Many Internet services refresh system by periodic restart
- "Recursive Restart" (Candea, Fox) restarts optimal number of components of system
- Reduces time to repair by 5X or more, depending on system
- Major focus of Stanford ROC project

Source: G. Candea and A. Fox, "Recursive Restartability: Turing the Reboot Sledgehammer into a scalpel," *8th Workshop on Hot Topics in Operating Systmes (HotOS-VIII)*, May 2001

Support Operator Trial and Error?

- **Provide an Undo for system administration**
  - to create an environment that forgives operator error
  - to let SysAdmins fix latent errors even after they're manifested
    - » this is no ordinary word processor undo!
- **The Three R's: undo meets time travel**
  - **Rewind:** roll system state backwards in time
  - **Repair:** fix latent or active error
    - » automatically or via human intervention
  - **Redo:** roll system state forward, replaying user interactions lost during rewind
- **Major focus of Berkeley ROC project**

Source: Aaron Brown, U.C. Berkeley, in progress.

Undo for Sysadmin

- **3 cases needing Undo**
  - Reverse the effects of a mistyped command (rm –rf *)
  - Roll back a software upgrade without losing user data
  - "Go back in time" to retroactively install virus filter on email server; effects of virus are squashed on redo
- **The 3 R's vs. check pointing, reboot, logging**
  - Check pointing gives Rewind only
  - Reboot may give Repair, but only for "Heisenbugs"
  - Logging can give all 3 R's
    - » but need more than RDBMS logging, since system state changes are interdependent and non-transactional
    - » 3R-logging requires careful dependency tracking, and attention to state granularity and externalized events
- **(Undo may help with security systems)**

Summary: from ACME to ROC

- 21st Century Research challenge is Availability, Changability, Maintainability, Evolutionary Growth
- Peres's Law vs. Moore's Law:
  Cope with fact that people, SW, HW fail
- Industry: may soon compete on recovery v. SPEC
- Need theory for design of Internet services
- Recovery Oriented Computing is one path
  - Failure data collection + Benchmarks to evaluate ACME
  - Partitioning, Redundancy, Input Insertion, Diagnosis
  - Undo (3 R's), Fast Restart lowers MTTR
  - Margin of Safety via More 9s in target?
- Significantly reducing MTTR (people/SW/HW)
  => better Availability & Cost of Ownership

Interested in ROCing?

- **More research opportunities than 2 university projects can cover. Many could help with:**
  - Failure data collection, analysis, and publication
  - Create/Run Availability, Maintainability benchmarks: compare (by vendor) databases, files systems, routers, …
  - Invent, evaluate techniques to reduce MTTR and TCO in computation, storage, and network systems
  - (Low hanging fruit)

"If it's important, how can you say if it's impossible if you don't try?"

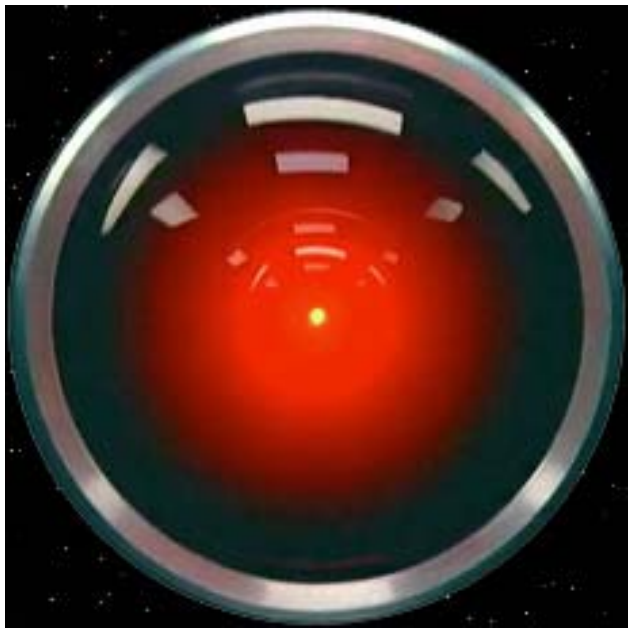
Jean Monnet, a founder of European Union

http://ROC.cs.berkeley.edu

BACKUP SLIDES

A science fiction analogy: Autonomic vs. ROC

- Autonomic approach



HAL 9000 (2001)

- Suffers from effects of the Automation Irony
  - system is opaque to humans
  - only solution to unanticipated failure is to pull the plug?

- ROC approach

Enterprise computer (2365)

- 24th-century engineer is like today's SysAdmin
  - a *human* diagnoses & repairs computer problems
  - aided by diagnostic tools and understanding of system

Outage Report

Company

Time

Explanation

Cause

Date

Place

Number of Customers Affected

Blocked Calls

Duration

WIRE LINE OUTAGE REPORTING TEMPLATE

Box #1: Reporting Carrier — Final
AT&T

Box #2: Date of Incident (mm/dd/yy)
2/5/2001

Box #3: Time of Incident (at outage location; 24-hour clock)
15:47 EST

Box #4: Geographic Area Affected
Orlando, FL

Box #7: Services Affected

- IntraLATA Intraoffice ☐
- IntraLATA Interoffice ☐
- InterLATA Interoffice ☐
- E911 ☐
- Other (specify): International, Intertoll, toll access, toll completing & NCP based

Box #5: Number of Customers Affected
Apprx. 777,652

Box #6: Number of Blocked Calls
2,332,957

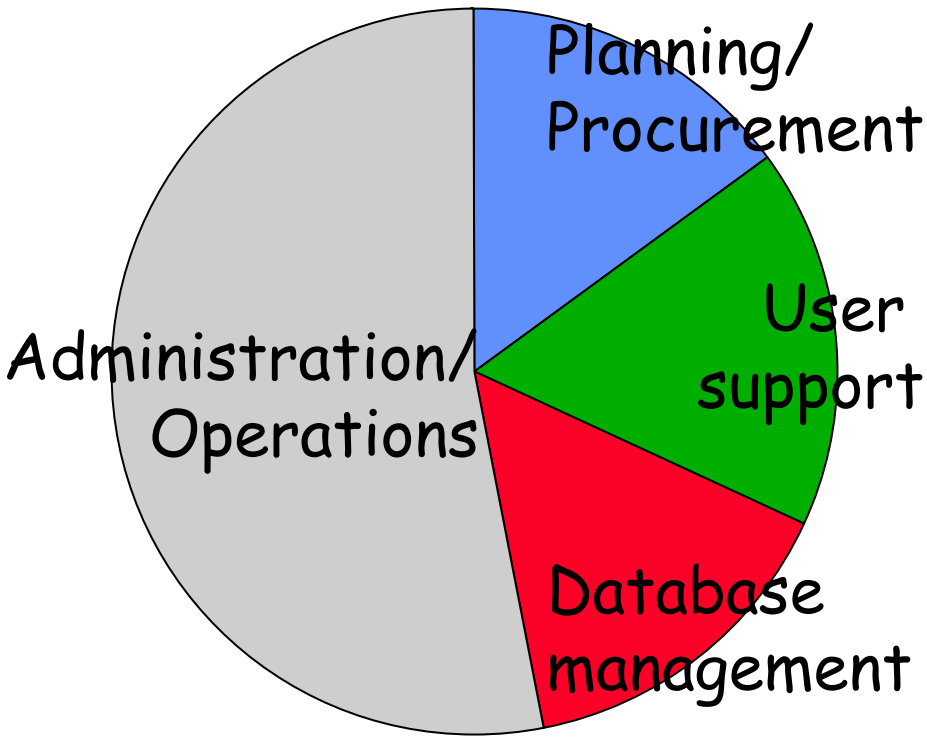
Box #8: Outage Duration
Hrs. 6 Min. 53

Box #9: Background of the Incident
Jones Brothers Contracting was installing a new sewer line as part of a Department of Transportation (DOT) project. This project has been on-going for approximately two years. In the course of two years the AT&T technician has worked with this contractor on several occasions where they have crossed the AT&T fiber cable. Although the cable had been marked, the contractor took it upon himself to expose the cable by potholing without notifying the AT&T Technician. The contractor then resumed digging with the trackhoe and severed the AT&T cable.

Box # 10: Direct Cause
Cable Damage

Box #11: Root Cause
Cable Damage - Digging Error

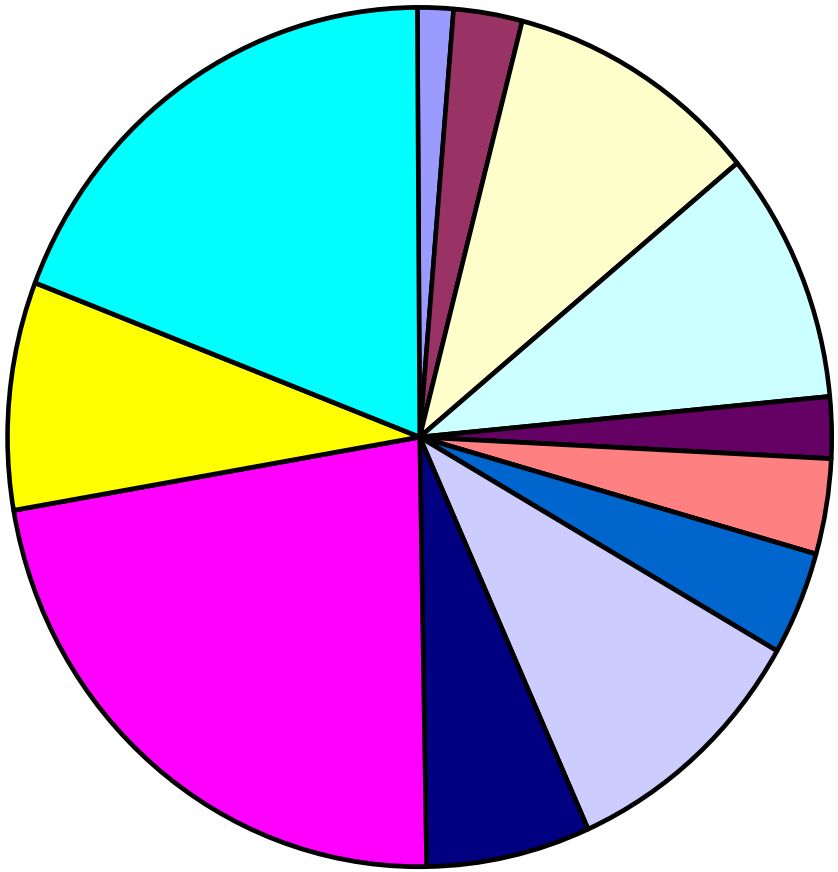
TCO breakdown (average)



- **Administration/Operations**
  - Adding/deleing users
  - Tracking equipment
  - Network, Server management
  - Backup
  - Upgrades, Web site
- **Planning/Procurement**
  - Planning for upgrades
  - Buying new, disposing old
- **User support**
  - Help desk
  - Desktop troubleshooting
- **Database management**
  - Creating, adjusting, allocating DB resources

Source: "The Role of Linux in Reducing the Cost of Enterprise Computing", IDC white paper, sponsored by Red Hat, by Al Gillen, Dan Kusnetzky, and Scott McLaron, Jan. 2002, available at www.redhat.com

Internet x86/Linux Breakdown



- deinstall/disposal desktop sys
- Procurement
- Admininistration
- Web site management
- Asset management admin
- System backup
- Upgrades/moves/adds/changes
- Network Management
- Planning/Management
- Database Management
- Operations
- User support

Evaluating ROC: human aspects

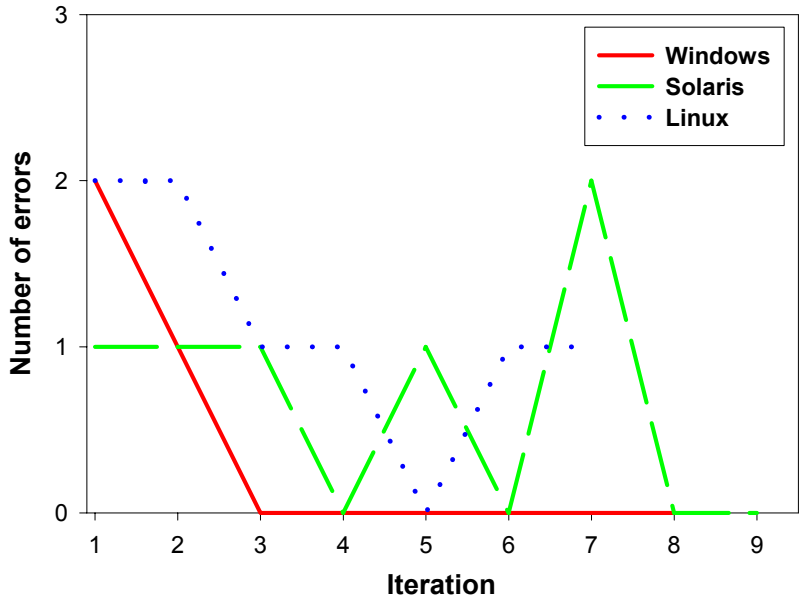
- **Must include humans in availability benchmarks**
  - to verify effectiveness of undo, training, diagnostics
  - humans act as system administrators
- **Subjects should be admin-savvy**
  - system administrators
  - CS graduate students
- **Challenge will be compressing timescale**
  - i.e., for evaluating training
- **We have some experience with these trials**
  - earlier work in maintainability benchmarks used 5-person pilot study

Example results: software RAID (2)

- **Human error rates during repair**
  - 5 trained subjects repeatedly repairing disk failures

Error type	Windows	Solaris	Linux
Fatal Data Loss	1		2
Unsuccessful Repair			1
System ignored fatal input			1
User Error – Intervention Required	1	2	1
User Error – User Recovered	1	4	2
Total number of trials	**35**	**33**	**31**

  - errors rates do not decline with experience
    - » early: mistakes; later: slips & lapses
    - » UI has big impact on slips & lapses



Lessons Learned from Other Cultures

- Code of Hammurabi, 1795-1750 BC, Babylon
  - 282 Laws on 8-foot stone monolith

229. If a builder build a house for some one, and does not construct it properly, and the house which he built fall in and kill its owner, then that builder shall be put to death.

230. If it kill the son of the owner the son of that builder shall be put to death.

232. If it ruin goods, he shall make compensation for all that has been ruined, and inasmuch as he did not construct properly this house which he built and it fell, he shall re-erect the house from his own means.

- Do we need Babylonian quality standards?