CS 294-8

Principles of Fault Tolerant Computing

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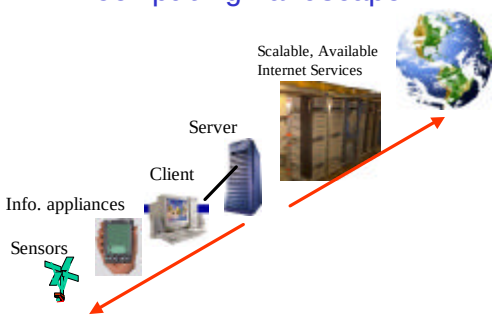
Today's Agenda

- Motivation and trends
- Examples of failures
- Background in reliability computing
- Course Overview
- Administrivia

Ubiquitous Computing

- Computing everywhere:
  - Desktop, Laptop, Palmtop, Cars, Cellphones
- Input devices everywhere:
  - Sensors, cameras, microphones
- Connectivity everywhere:
  - Rapid growth of bandwidth in the interior of the net
  - Broadband to the home and office
  - Wireless technologies such as CMDA, Satelite, laser
- Increased reliance on computers is inevitable
- Computer systems will become invisible only when they are reliable

Computing Landscape



Culler, 1999

The "Post-PC" Era

PostPC Era Divides built on two technologies:

1) Mobile Consumer Electronic Devices
   - e.g., successor to PDA, Cell phone, wearable computers

2) Infrastructure to Support such Devices
   - e.g., successor to Big Fat Web Servers, Databases

The problem space: big data

- Big demand for enormous amounts of data
  - today: enterprise and internet applications
    - online applications: e-commerce, mail, web, archives
    - enterprise decision-support, data mining databases
  - future: richer data and more of it
    - computational & storage back-ends for mobile devices
    - more multimedia content
    - more use of historical data to provide better services
- Two key application domains:
  - storage: public, private, and institutional data
  - search: building static indexes, dynamic discovery

Application: Tornado Response

- CAPS at University of Oklahoma
- Currently 12 radars in Oklahoma area
  - Improve warning time: saved 800 lives?
- Two problems:
  - Real-time computation and response
    - Some local to one radar
    - Better algorithms involve coordination
  - Archival of data for experimentation and long term analyses ("data mining")
    - Petabytes per year

Application: Smart Buildings

- Buildings adapt to occupants and save energy
  - Save $55 billion in the U.S.
  - Reduce carbon emissions by 35 million metric tons
- Sensors with wireless connections
- Integrated with server to record history information and do prediction

Application: Earthquakes

- Reduce the risk and improve response to earthquakes
- Use millions of MEMS sensors in buildings, ground, bridges, etc.
- Front-end processing in sensor
- Tied to backend data bases and computational models
- Building will "self-diagnose" after an earthquake.

Application: Transportation

- Traveler information service
  - Limited for exists in Europe
  - Prototype from Path project in LA
- "Mine" sensor data from roads to predict travel times
- Traffic manage apply controls (traffic ramp meters) in real time
- Improve long term highway planning

Summary of Post-PC Era

- Computing and data in the extremes: tiny devices and enormous "utility-style" servers
- Applications entertainment and business will continue
- New applications that make computing transparent in the environment require reliability

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eBay Crash

- eBay: giant internet auction house
  - A top 10 internet business
  - Market value of $22 billion
  - 3.8 million users as of March 1999
  - Bidding allowed 24x7
- June 6, 1999
  - eBay system is unavailable for 22 hours with problems ongoing for several days
  - Stock drops by 6.5%, $3-5 billion lost revenues
  - Problems blamed on Sun server software
    - Similar to EECS server downtime?
- Shorter downtimes common

EECS Servers Crash

- Department servers are offline for 3-7 days
  - Cause is disk failure coupled with incompatible RAID software
- Power failure also resulted in lost data in a separate event
  - UPS not purchased due to staff turnover

Ariane 5 Rocket Crash

- Ariane 5 and its payload destroyed about 40 seconds after liftoff
- Error due to software bug:
  - Conversion of floating point to 16-bit int
  - Out of range error generated but not handled
- Testing of full system under actual conditions not done due to budget limits
- Estimated cost: 120 million DM

The Therac-25 Failure

- Therac-25 is a linear accelerator used for radiation therapy
- More dependent on software for safety than predecessors (Therac-20, Therac-6)
- Machine reliably treated thousands of patients, but occasionally there were serious accidents, involving major injuries and 1 death.
- Software problems:
  - No locks on shared variables (race conditions).
  - Timing sensitivity in user interface.
  - Wrap-around on counters.

Tele Denmark

- Tele Denmark Internet, ISP
- August 31, 1999
  - Internet service down for 3 hours
  - Truck drove into the power supply cabinet at Tele Denmark
  - Where were the UPSs?
    - Old ones had been disconnected for upgrade
    - New ones were on the truck!

Lampson: Systems Challenges

- Systems that work
  - Meet their specs
  - Always available
  - Adapt to environment & evolve over time
  - Made from unreliable components
  - Grow without practical limit
- Credible simulations or analysis
- Writing good specs
- Testing
- Performance
  - Understanding when it doesn't matter

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

Hennessy: The "New World" Focus

- 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?" -John Hennessy, Stanford FCRC Keynote, May 1999

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Aspects of Reliability

- Safety: "First, do no harm"
- Fault tolerance: faults should (at worst) result in graceful degradation
- Predictability: behavior should be a function of inputs and environment; should be reproducible
- Timeliness: real-time constraints, Quality of Service (QoS) guarantees

Availability vs. Reliability

- Jim Gray's 85 paper (see class web page) distinguishes these
  - Reliability is measured by mean time between failures (MTBF)
  - Availability is a function of MTBF and mean time to recover (MTTR)

    MTBF/(MTBF+MTTR)
  - A system may have a high MTBF, but low availability

Fault Recovery

- How quickly is the fault detected?
- How soon can recovery begin?
  - Does is require human intervention
  - How is the sysadmin notified?
- How long does recovery take?
  - Restore from backup?
  - Purchase new HW?

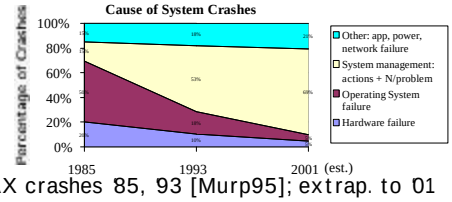
Two Keys to Availability

- Redundancy
  - "The one good idea"
  - May be in software, hardware, data structures (state), programmers, etc.
- Modularity
  - Reduce the size of the failure unit (FRU)
  - Change failure model from continuous to discrete
    - 90% of client machines available 90% time

Causes of Faults: Tandem

- In Gray's 85 survey of Tandem customers
  - 30% were "infantile" failures
  - The rest were broken into (roughly):
    - Administration 42%
    - Software 25%
    - Hardware 18%
    - Environment (power, etc.) 14%
    - Unknown 3%

Causes of Faults: Vax



- VAX crashes '85, '93 [Murp95]; extrap. to '01
- System Management includes:
  - Multiple crashes per problem
  - Sysadmin Actions: set params, config, bad app install
- HW/OS 70% in '85 to 28% in '93. In '01, 10%?
  - Sysadmin increasingly important

The Fail-Fast Principle

- Reliable systems should be built from components that fail fast
  - No answer is better than the wrong answer
  - Improves latency of fault detection
  - Fault containment is better if modules stop

The Heisenbug Hypothesis

- Software faults can be divided into
  - Bohrbugs – easily reproduced
  - Hiesenbugs – transient, hard to produce
- Conventional wisdom is that most bugs in running systems are Heisenbugs
  - Is this true? SW and HW? Open source too?
- HW redundancy (processor pairs) can help with Hiesenbugs

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What is Fault Tolerance?

- A better title might have been "reliable" or "available" computing
- We will be looking at:
  - The "classics" (Gray, Lamport, Birman,…) in distributed computing
  - Recent results (Coding-based replication, practical byzantine fault tolerance,…)
- Avoid overlap with 262AB (Coda and Bayou possible exceptions)
- Not software verification/quality: See Wolfgang Pree's course instead

What is Meant by "Principles"?

- We will study
  - Models of distributed systems and faults
  - Distributed algorithms
  - Reasoning techniques
- Things that every system designer should know, aside from the experience papers

Course Goals

- Prepare for research in reliability
  - Put structure on past work
- Identify major open problems and possible approaches
  - Can cheap hardware be used in place of expensive humans? Bugs? Maintenance?
  - What is the user's view? Are "weak" consistency models acceptable?
  - To what extent can self-monitoring, self-healing systems help?

Administrivia

- Class times:
  - Tuesday 3:30-5:00 here in 380
  - Thursday: seminar in 306 3:30-4:30
    - Except this week: Thursday 3:30 in 380
  - Thursday: discussion 4:30-5:30 in 380
- Work
  - Readings (some write-ups)
    - Read ISTORE paper for Thursday
  - Small homework assignments
  - Project: presentations/poster + paper

This Week

- Read ISTORE paper for Thursday
- Homework 1 due next Tuesday:
  - Anatomy of a failure
- Read Grapevine and Porcupine papers for next Tuesday
- Read M. Baker paper for 9/7