# Fault Tolerant Computing

CS 530

## Lecture Notes 1
## Introduction

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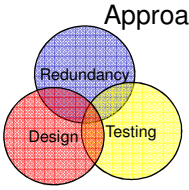
## What We Will Study

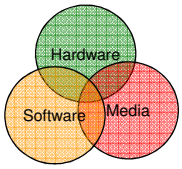
- Essential terms
- How defects arise
- Fault taxonomies
- Fault handling
- Reliability attributes and measures
- Redundancy types
- Deterministic vs probabilistic approaches

# Fault-tolerant Computing

- Objective: to achieve very high reliability in computing
- How:
  - Design for high reliability
  - Test to find and remove potential faults
  - Use redundancy to tolerate faults
- In hardware, software & media
  - Some approaches are common
  - Some not

Approaches




Systems



# About this course

- Texts (and courses) generally focus on
  - Reliability or Testing or Redundancy
  - Hardware or software
- This course attempts to address
  - different aspects of highly reliable computing
  - Relationships among Reliability, Testing and Redundancy
  - Similarities and differences between hardware & software issues
- No single book used. Study based on
  - Course notes
  - Articles (including some by instructor)
  - Various sources

# Murphy's Law

- Anything that can go wrong, will.
  - (Actually not by Murphy but by Finagle)
- To every law there is an exception.
- Cs530 laws:
- Anything that can go wrong, it eventually will, but
  - It may not go wrong for a while
  - It may not go wrong the next time
  - Only one thing may go wrong at a time



# Reliability: increasing concern

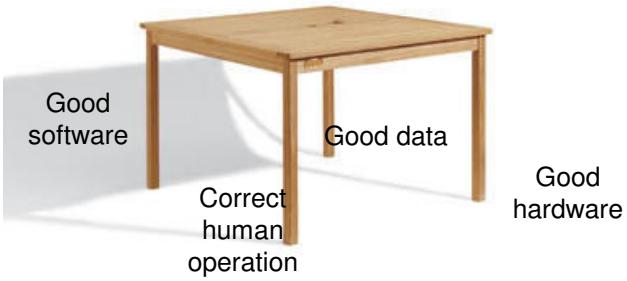
## Historical

- High reliability in computers was needed in critical applications: space missions, telephone switching, process control etc.

## Contemporary

- Extraordinary dependence on computers: on-line banking, commerce, cars, planes, communications etc.
- Hardware is increasingly more fault-prone
- Software is increasingly more complex
- Things simply will not work without special reliability measures

# Correct Operation in Computing



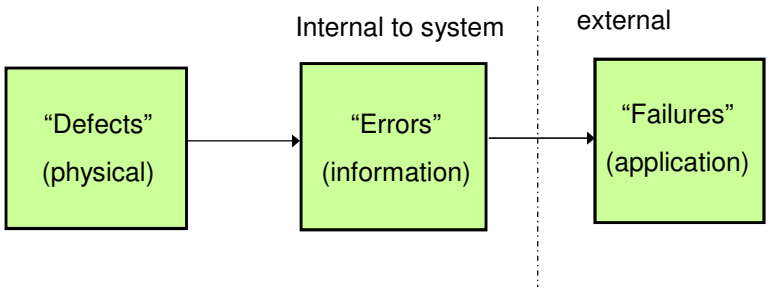

These are the system components. All are needed for proper operation



# Reliability approaches: Fault Avoidance Vs. Tolerance

- **Fault avoidance: eliminate problem sources**
  - **Remove defects: Testing and debugging**
  - **Robust design: reduce probability of defects**
  - **Minimize environmental stress: Radiation shielding etc**
  - **Impossible to avoid faults completely**
- **Fault tolerance: add redundancy to mask effect**
  - **Additional resources needed (more later)**
  - **Examples:**
    - **Error correction coding**
    - **Backup storage**
    - **Spare tire etc**

# Terminology




- **Latent fault: which has not yet produced error**
  - **Faulty component will produce error only when used by a process.**
- **Latent error: which has not yet produced failure.**
  - **An infected person may not show symptoms of a disease.**
- **Unfortunately terminology is not standard.**
  - **You need to ensure you have understood author's intent.**



# Origin of Defects in Objects

**(in hardware or software)**

Increasing human responsibility

- **Good object wearing out with age**
  - **Hardware (software can *age* too)**
  - **Incorrect maintenance/operation**
- **Good object, unforeseen hostile environment**
  - **Environmental fault**
- **Marginal object: occasionally fails in target environment**
  - **Tight design/bad inputs**
- **Implementation mistakes**
- **Specification mistakes**



Object: refers to a piece of hardware or software

# Fault Taxonomies

- Cause (a previous slide)
- Nature:
  - Software
  - Hardware
    - Digital: causing a change in binary (logic) behavior
    - Analog: Ex: high supply current
- Duration of the fault:
  - Permanent: You have to throw away the unit
  - Temporary
    - Intermittent: marginal system: Ex: a loose connection
    - Transient: environmental: Ex: charged particles causing soft errors
    - Permanent with repair: repair makes the fault go away



# Why We Need High Reliability?

- High availability systems:
  - Telephone
  - Transaction processing: banks/airlines
- Long life missions:
  - Unscheduled maintenance too costly
  - Long outages, manual reconfiguration OK
  - Critical applications
- Critical applications:
  - Real-time industrial control
  - Flight control
- Ordinary but widespread applications:
  - CDs: encoding
  - Internet: packet retransmission

## What to do about faults

**Finding & identifying faults:**

- **Fault detection: is a fault there?**
- **Fault location: where?**
- **Fault diagnosis: which fault it is?**

**Automatic handling of faults**

- **Fault containment: blocking error flow**
  - **Fault masking: fault has no effect**
- **Fault recovery: back to correct operation**

Remember the terms in **blue.**



## Reliability Measures: formal defs

- **Failure rate: fraction of units failing/unit time**
  - **1000 units, 3 failed in 2 hours**
  - **Failure rate=3/1000x2=1.5x10$^{-3}$ per hour**
- **Mean time to failure (MTTF): expected time before unit fails**
  - **Corresponds to inverse of failure rate**
- **"Reliability"= probability system will survive to time t**
- **Availability: probability that system is operational at time t**
  - **Corresponds to fraction of time system is operational**

## Common Reliability Attributes 1

- **Dependability**: combination of several measures
- **Safety**: attribute of a system which either operates correctly or fails in a safe manner.
  - "Fail-safe": ex: traffic light blinks red upon failure
- **Performability**: combination of reliability & performance
  - "Graceful degradation": loss of performance due to minor failures

Some of the terms are not defined in a way to be quantifiable.



## Common Reliability Attributes 2

- **Security**: authentication, confidentiality, integrity etc.
- **Survivability**: combination of dependability and security
- **Testability**: ease of detecting presence of a fault
  - Controllability and observability
- **Maintainability**: ease of repairing a system after failure

Quantitative measures for testability have been proposed, but not widely accepted.

## System Response to Faults

- **Error on output:** may be acceptable in non-critical systems if happens only rarely
- **Fault masking:** output correct even when fault from a specific class occurs
  - **Critical applications: air/space/manufacturing**
- **Fault-secure:** output correct or error indication
  - **Retryable: banking, telephony, payroll**
- **Fail safe:** output correct or in *safe* state
  - **Flashing red traffic light, disabled ATM**



## Need for fault tolerance: Universal & Basic

**Natural objects:**

- **Fat deposits in body: survival in famines**
- **Clotting of blood: self repair**
- **Duplication of eyes: graceful degradation upon failure**

**Man-made objects**

- **Redundancy in ordinary text**
- **Asking for password twice during initial set-up**
- **Duplicate tires in trucks**
- **Coin op machines: check for bad coins**

# Redundancy

- Spatial (hardware) Redundancy
  - Replication (higher level)
  - Encoding (low level)
- Temporal (time) Redundancy
  - Rollback and retry
  - Encoding
  - Retransmission in networks (ARQ)
- Procedural Redundancy
  - Checking (small overhead)
  - Software redundancy: n-version
  - Design verification



# Redundancy (Cont.)

- Analog Redundancy
  - Use of slack or margin,
  - Ex: allow for extra delays in chips due to temp rise
- Information (or Data) Redundancy: already included in
  - Spatial (Ex: bus with 8 bits + 1 bit parity) or
  - Temporal (Ex: packet transmitted serially, with party bit at the end)
- Exact classification is sometimes hard
- Disadvantages:
  - Overhead
  - Difficulty of testing
  - Unmanaged/excessive redundancy: increase unreliability

# Fault-tolerant Computing

- Deterministic approaches
  - Based on simplifying assumptions: "fault model"
  - Obtain methods using the models: test generation
  - Evaluation of effectiveness
  - Used for Testing & combinatorial fault-tolerance
- Probabilistic approaches
  - We can't predict exactly when a person will die, but we can get "life expectancy = 77.2 years", if we have data
  - Used for evaluating, achieving and optimizing reliability
  - Random testing



# Course Topics

**Testing**
- Fault-modeling, test generation
- Testability and black-box testing

**Reliability**
- Permanent and temporary faults
- Replication and retry
- Pursuit of ultra-reliability

**Software reliability**
- Defects, factors, reliability growth
- Reliability strategies

**Other topics**

# References

http://hissa.nist.gov/chissa/SEI_Framework/framework_1.html

**A Conceptual Framework for System Fault Tolerance**

- A detailed introduction to Fault Tolerance

http://www.eventhelix.com/RealtimeMantra/FaultHandling

**Fault Handling and Fault Tolerance**

- Introduction to how fault tolerance is achieved

http://rodin.cs.ncl.ac.uk/Publications/avizienis.pdf

**Dependability And Its Threats: A Taxonomy" by Algirdas Avizienis, Jean-Claude Laprie, B. Randell**

- Advanced intro by distinguished researchers