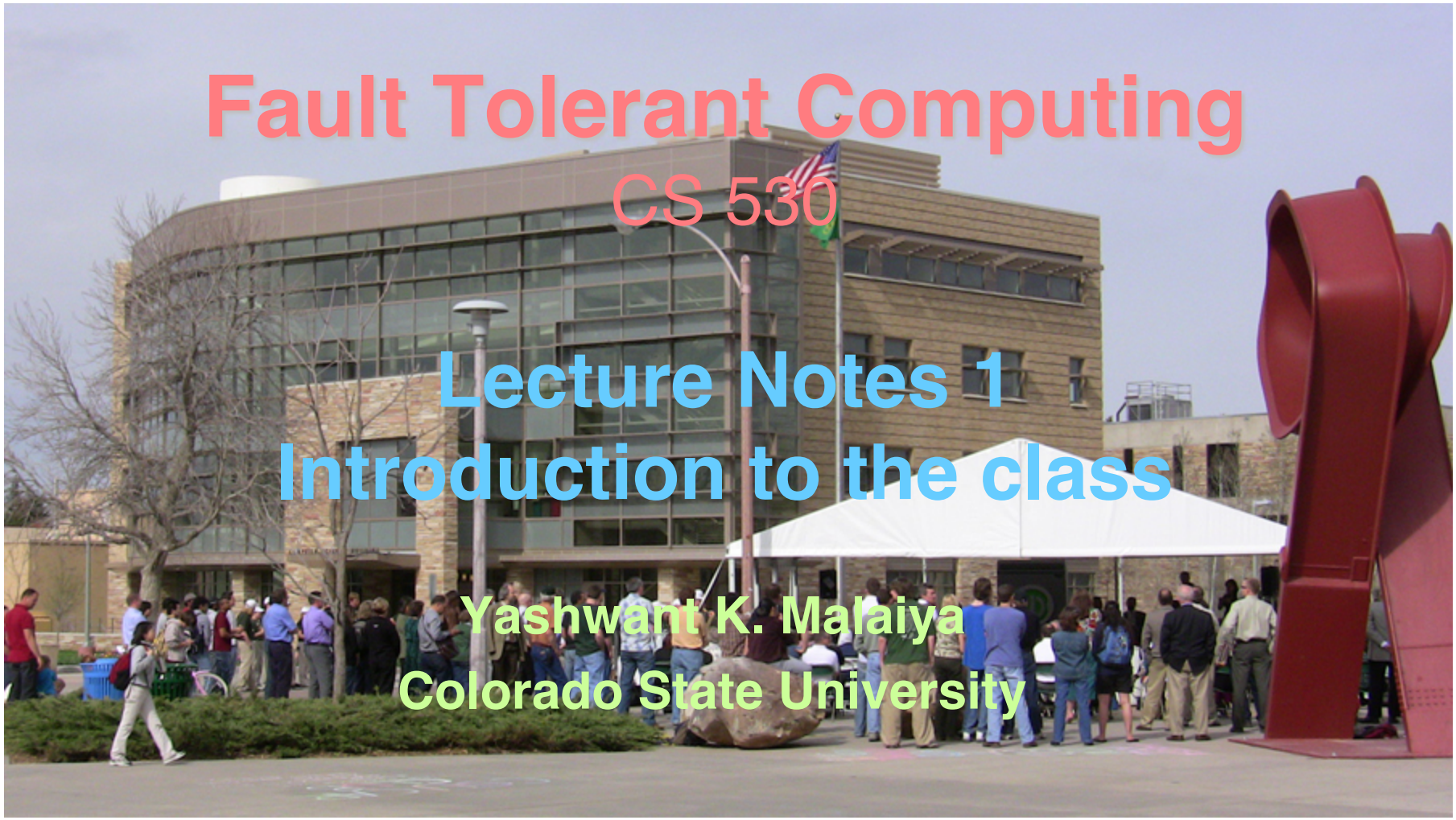


Fault Tolerant Computing

CS 530

Lecture Notes 1
Introduction to the class

Yashwant K. Malaiya
Colorado State University

Instructor

- **Instructor: Yashwant K. Malaiya, Professor**
  - **malaiya @ colostate.edu**
  - **Office: ~~356 CS~~ MS Teams**
  - **Hours: W 3:30-4:30 PM**
- **Textbook: None. Various sources, mostly available on course website**
- **Canvas: Discussions, submissions, quizzes etc.**

Introduction

- Please introduce yourself on Canvas Discussions
- Yashwant K. Malaiya
  - Professor of Computer Science
    - Interact with ECE, also supervise System Eng PhDs
  - Background
    - VLSI defects, fault modeling, testing
    - Software testing, test effectiveness, test coverage
    - Security Vulnerability discovery, economics, risk evaluation

Evaluation

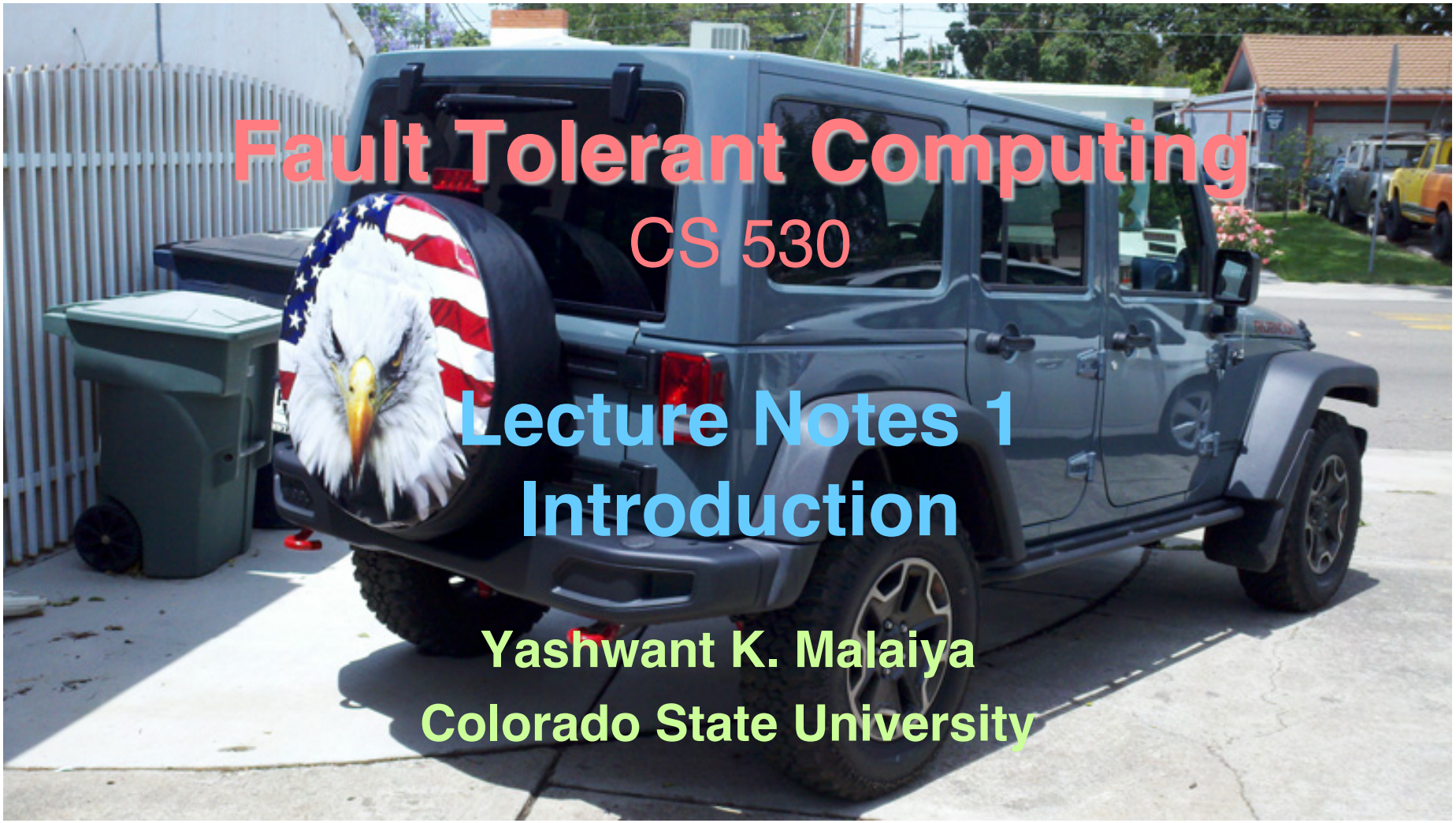
- **Distribution**
  - **20% Midterm (Th March 11) Respondus LDB**
    5% Participation
    25% Final (M May 11) Respondus LDB
    20% Research Project
    30% Assignments and quizzes
- **S 001 & local S 801 students:**
  - **Midterm, Final at announced time**
- **Non-local S 801 students:**
  - **Must be taken during the speciified time window**
- **The two groups will be evaluated separately,**
  - **but with the same overall standard**

Research Project

- **Will have a list of suggested topics later.**
- **March 6: a *one-page* proposal**
  - **motivation, brief scope of study and *some specific references*.**
- **April 1: progress report**
- **April 21: slides needed**
  - **A presentation will be required.**
- **May 6: final report (two column format, TurnItIn)**

Topics: Testing, Reliability, Redundancy

- **Introduction:** Terminology, redundancy
- **Digital systems:** overview, fault models, testing, test effectiveness
- **Probabilistic concepts:** random variables and stochastic processes, probabilistic testing
- **Reliability Theory:** simple and redundant systems, implementation issues, time redundancy
- **Software Reliability:** Static and dynamic approaches
- **Coding theory and applications: Parity,** CRC, RAIDs
- **Quantitative Security:** vulnerabilities and risk
- **Emerging topics**: Hadoop file systems etc.



Fault Tolerant Computing

CS 530

Lecture Notes 1
Introduction

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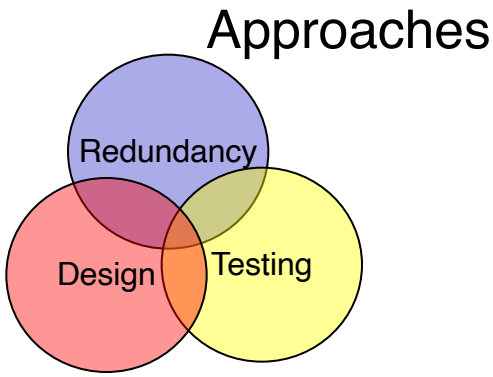
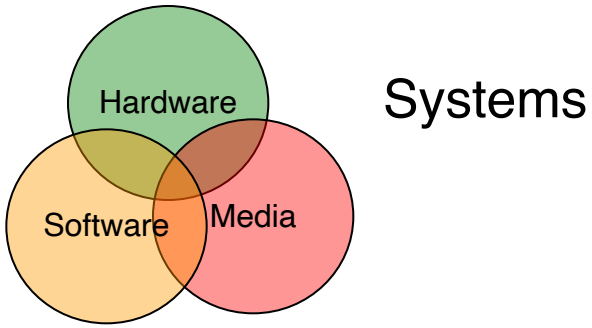
What We Will Study

- Essential terms
- How defects arise
- Fault taxonomies
- Fault handling
- Reliability attributes and measures
- Redundancy types

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**





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
  - Some quantitative aspects of security
- 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

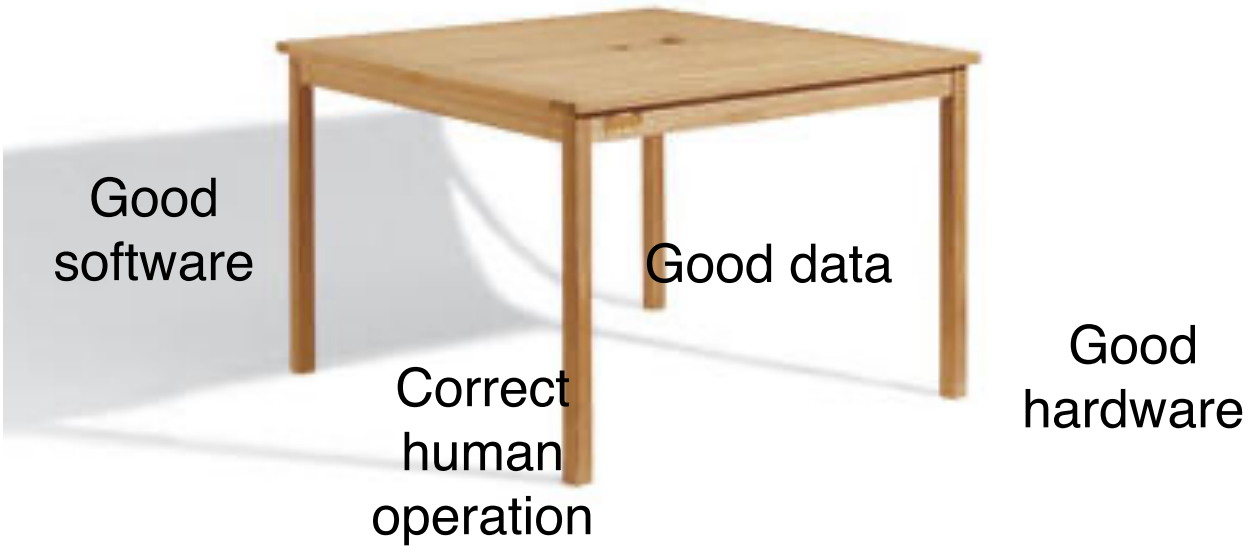
Historical

- 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/Software/Systems are increasingly more complex
- Things simply will not work without special reliability measures

Correct Operation in Computing

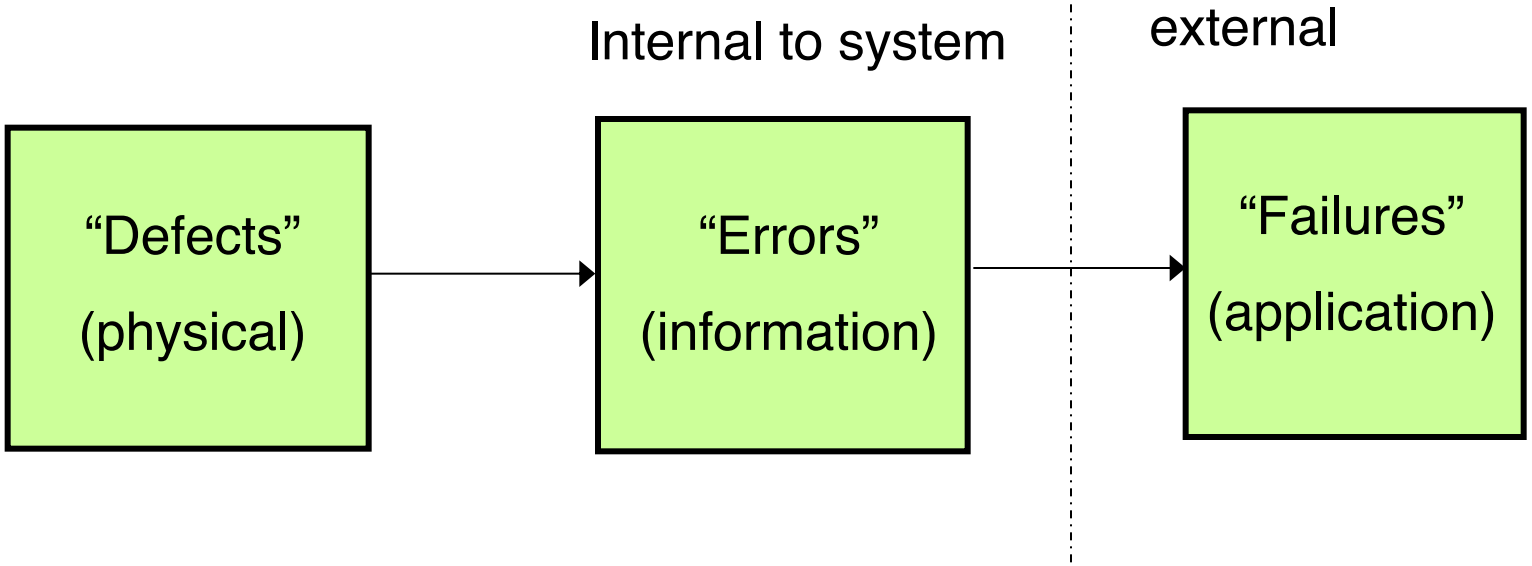


These are the system components. All are needed for proper operation

Reliability approaches: Fault Avoidance Vs. Tolerance

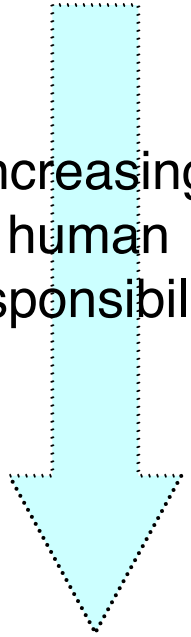
- **Fault avoidance:** eliminate problem sources
  - Remove defects: Testing and debugging
  - Robust design: reduce probability of defects
  - Minimize environmental stress: Radiation shielding etc
  - Impossible to avoid faults completely
- **Fault tolerance:** add redundancy to mask effect
  - Additional 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, the terminology is not standard.**
  - **You need to ensure you have understood author's intent.**

Origin of Defects in Objects
(in hardware or software)



- **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**
- **Intentional actions (security issues)**

Object: refers to a piece of hardware or software

Fault Taxonomies

- **Cause** (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

Fault Taxonomies

"It goes on to say, 'The fault is not with the hardware. It is with you—the software!' "

Introductions

- When I call your name
- Enable microphone and camera and say
  - Your name
  - Where you are from (city, country)
  - What you are doing at CSU and interests

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:
  - Real-time industrial control
  - Flight control
- Ordinary but widespread applications:
  - CDs: encoding
  - Internet: packet retransmission
- Systems needing security

What to do about faults

Finding & identifying faults:

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

Easier problem

Harder problem

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.**

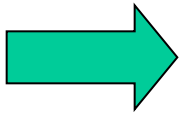
Common Reliability Measures

- **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**: confidentiality, integrity, (availability) authentication, non-reupediation
- **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.

Quantitative measures for security are currently evolving..

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

Security? Thorns, White blood cells

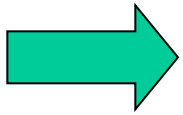
Redundancy

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

Duplex for self-checking
TMR: self-correction
Spare: self repair

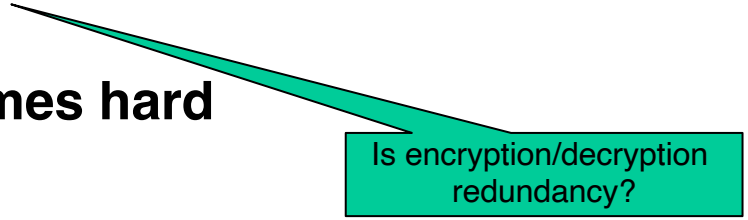
Fewer bits: self-checking
More bits: self-correcting

Both “Backward error recovery” BER



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 & Redundancy

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

Software reliability/security

- Defects, factors, reliability growth
- Reliability strategies

Emerging issues

References

https://resources.sei.cmu.edu/asset_files/TechnicalReport/1992_005_001_16112.pdf **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**