EDA122/DIT061 Fault-Tolerant Computer Systems

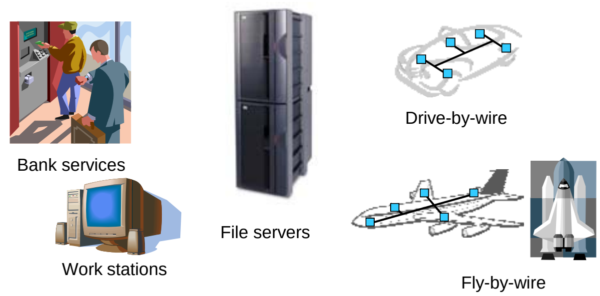
DAT270 Dependable Computer Systems

Welcome to Lecture 1

Johan Karlsson

Why fault tolerance?

We *depend* on computer systems!



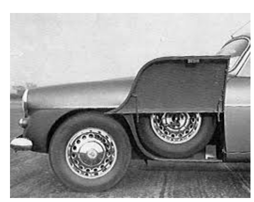
Definition of *fault tolerance*

Fault tolerance *means to* ***avoid service failures*** *in the* ***presence of faults****.*

Avizienis, et al., "Basic Concepts and Taxonomy of Dependable and Secure Computing"

Fault-Tolerance – How?

- By introducing ***redundancy*** (extra resources)
- Forms of redundancy
  - hardware redundancy
  - software redundancy
  - time redundancy
  - information redundancy

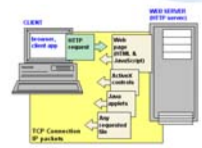


Fault tolerance vs. Fault prevention

- Fault tolerance – to avoid service failure during operation
  - Requires fault and error handling mechanisms, e.g.,
    - Error detection
    - System recovery
    - Fail-over
- Fault prevention – to prevent or reduce the occurrence of faults
  - Fault prevention is applied during development, e.g.,
    - Robust design
    - Testing
    - Formal verification

Applications Areas for Fault Tolerance (1)
Business-critical applications

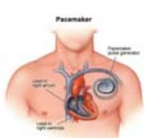
- Web servers
- Cloud computing
- Financial transaction system
- E-business
- General-purpose file servers
- …



Applications Areas for Fault Tolerance (2)
Embedded systems


Active safety systems for road vehicles


Fly-by-wire systems


Medical devices


Factory automation


Railway signaling

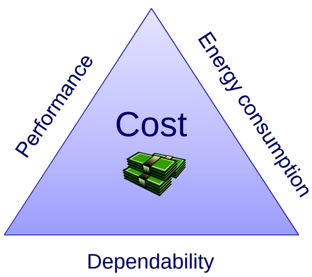
Applications Areas for Fault Tolerance (3)
Cyber-physical systems

- Smart grids (smart electrical power grids)
- Cooperative active safety systems for road vehicles
- Remote surgery
- …

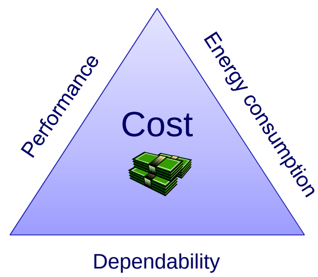

Smart Grid

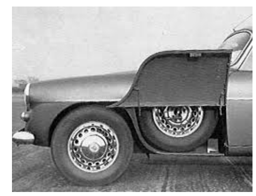

Surgical robot system

Important Trade-offs in System Design

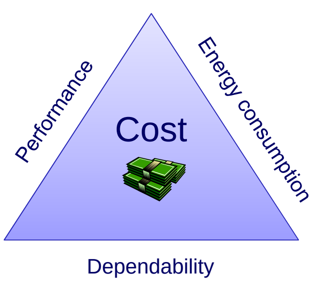


Important Trade-offs in System Design





Important Trade-offs in System Design



Redundancy in HP's NonStop System

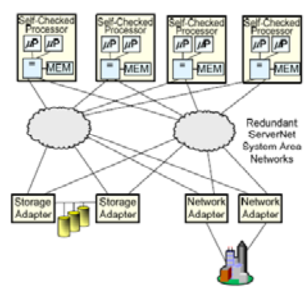
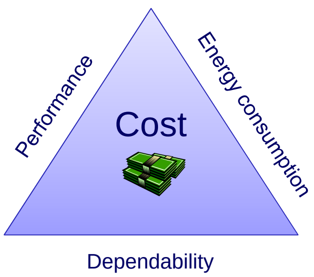


Figure 1: 4 Processor NonStop System with Duplicated and Compared Microprocessors

Important Trade-offs in System Design



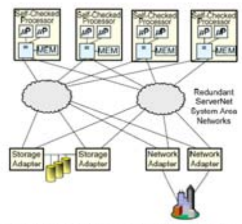
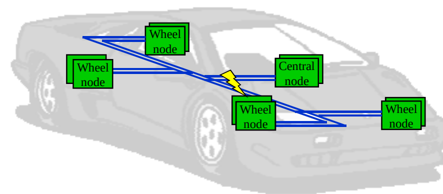
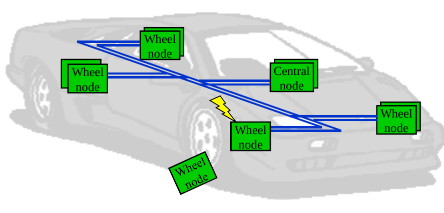


Figure 1: 4 Processor NonStop System with Duplicated and Compared Microprocessors

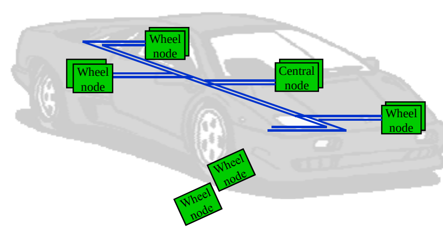
Brake-By-Wire System



Brake-By-Wire System



Brake-By-Wire System



Safety

Safety *is a property of a system that it will not endanger human life or the environment*

A ***safety-related*** *system is one by which the safety of equipment or plant is assured*

The term ***safety-critical system*** *is normally used as a synonym for a safety-related system, although it may suggest a system of high criticality*

(Neil Storey)

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Important concepts

- Fault tolerance
  - To avoid service failures in the presence of faults
- Graceful degradation
  - Gradual reduction of service in the presence of faults

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Course Outline

- 16 lectures (16 x 2 h) including 3 guest lectures
- 9 exercise classes (9 x 2 h)
- 2 laboratory classes (2 x 4 h)

- 7,5 credits (hp)

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Course Homepage

www.cse.chalmers.se/edu/course/EDA122

Also available via the student portal

Here you find:
- The course PM (contains all administrative information)
- Lecture slides
- Messages from the examiner
- Old exams, etc

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Course Homepage

- Username: ftcs2011
- Password: depend2011

Teachers

Johan Karlsson, ext. 1670, room 4107
johan@chalmers.se (examiner and lecturer)

Negin Fathollah Nejad, ext. 5404, room 4127
negin@chalmers.se (teaching assistant)

Examination

- Written examination
- Grades: Failed, 3, 4, 5 (Chalmers),
  Failed, G, VG (GU)
- Exam dates: 19 October, 2010, afternoon
  9 January, 2011, afternoon
  21 August, 2011, afternoon
- Participation in laboratory classes + approved laboratory reports

Literature

- Course book: Neil Storey, "Safety-Critical Computer Systems", Prentice Hall, ISBN 0-201-42787-7
- Reprints of articles on selected topics in fault-tolerant computing (available on the course homepage)
- Lecture slides
- Compendium of exercise problems
- PMs for laboratory classes (Lab PM)

Course Evaluation

- ***Two to six student representatives***, representing different programmes.
- Student representatives will receive a voucher valid for 200 SEK at Cremona.
- Three meetings:
  Week 2, Week 3 and after the course.
- Student representatives are expected to
  1. ***Provide feedback from all students***
  2. ***Review and help design the course questionnaire***
  3. ***Participate in all meetings***

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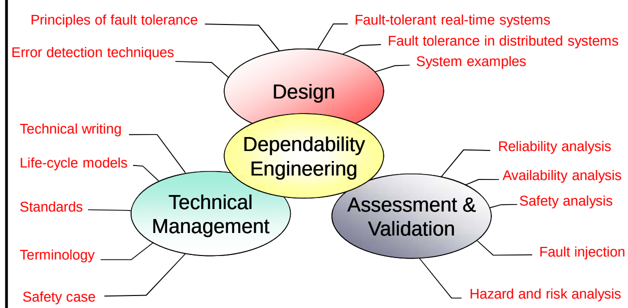
Overview of topics



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Learning goals

After completion of the course the student should be able to:

- Formulate dependability requirements for computer systems used in business-, safety- and mission-critical applications.
- Describe the structure and principles of commonly used system architectures of fault tolerant computers.
- Perform probabilistic dependability analysis of computer system using fault-trees, reliability block diagrams, Markov chains and stochastic Petri nets.
- Master the terminology of dependable computing and describe major elements of relevant standards.
- Describe basic concepts in life-cycle models and standards employed in the development of safety-critical systems.

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Outline for the rest of this lecture

- Overview of faults types
- Basic terminology
- Voting redundancy

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Fault Types

- Random faults (physical faults)
  - Aging faults
  - External disturbances
    - Ionizing particle radiation
    - Electromagnetic interference
- Systematic faults (development faults in HW or SW)
  - Specification faults
  - Design faults
  - Implementation faults

Terminology

Fault - Cause of an error, e.g., an open circuit, a software bug, or an external disturbance.

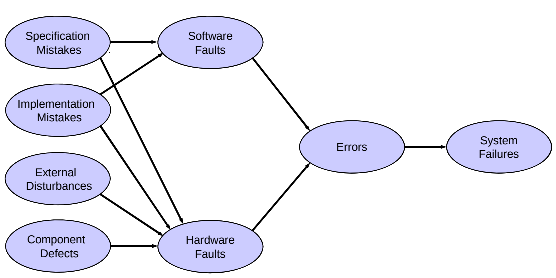
↓

Error - Part of the system state which is liable to lead to failure, e.g., a wrong value in a program variable.

↓

Failure - Delivered service does not comply with the specification, e.g., a cruise control in a car locks at full speed.

Cause-and-Effect Relationship

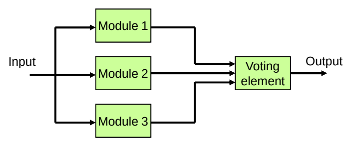


Hardware Redundancy

- Voting redundancy (this lecture)
- Stand-by redundancy (lecture 3)
- Active redundancy (lecture 3)

Voting redundancy

Triple Modular Redundancy (TMR)

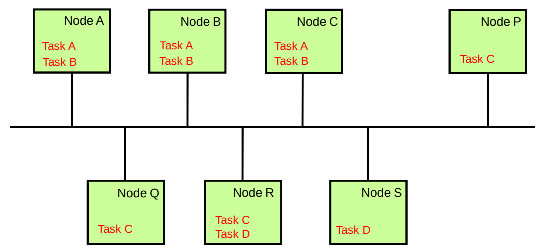


The three modules receive the same inputs and perform the same calculations.

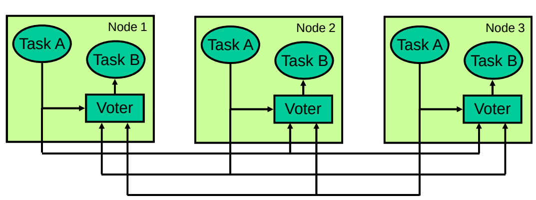
The modules are assumed to fail independently, one at a time.

The voting element uses majority voting to mask errors.

Replicated tasks in a distributed system



Voting in a distributed system



The tasks and voters are implemented in software.

The figure shows the exchange of data messages between the replicas of Task A and Task B in the previous slide.

Failure = Service failure

- A failure occurs when a **service provider** (system, or subsystem) delivers an incorrect service.
- Example: A node is a subsystems in a distributed system
  - Node failure – a node delivers an incorrect service
- Example: A network is a subsystems in a distributed system
  - Network failure – a network delivers an incorrect service
- Example: A processor core is a subsystem in a multi-core processor
  - Core failure – a core delivers an incorrect service

Fundamental Concepts
Failure mode

A ***failure mode*** describes the nature of a failure

- Examples of failure modes:
  - Value failure – a service provider delivers an erroneous result
  - Content failure – same as value failure
  - Timing failure – a service provider delivers a result too late, or too early
  - Silent failure – a service provider delivers no result
  - Signaled failure – a service provider sends a failure signal
  - Interference failure – a service provider disturbs the service delivered by another service provider

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Failure model vs. Failure mode

- A ***failure model*** is a set of assumptions about likely failure modes for a service provider
- A ***failure mode*** describes the nature of a given class of failures

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Fundamental Concepts
Error processing

Error processing aims at removing errors from the computational state, if possible, before a failure occurs.

Error processing techniques:

- Error detection - to detect errors
- Error masking - to mask the effects of errors
- Recovery - to restore the system to an error-free state

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Recovery

- We distinguish between two types of recovery
  - Forward recovery
    - The state of the service provider is moved *forward* in time
    - Example: Error free state is copied from another (redundant) service provider
  - Backward recovery
    - The state of the service provider is moved *backward* in time
    - Example: Error free state is restored from a previously stored checkpoint
    - Checkpoint is stored in a crash proof memory, a.k.a. stable storage

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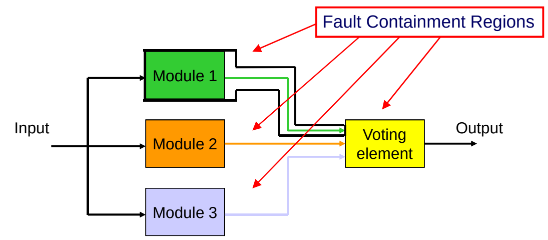
Fundamental Concepts
Fault/Error Containment

Fault/Error containment aims at preventing faults/errors from affecting other (redundant) units in the system.

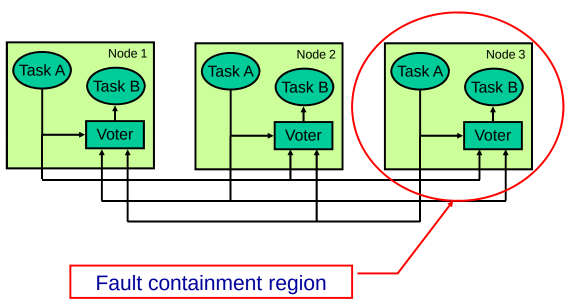
- A fault-tolerant system consist of several ***fault/error containment regions***

Fault Containment Regions in a TMR System

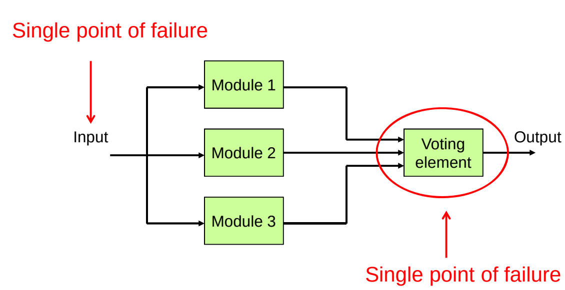


The designer must prevent that a fault in one module causes faults in the other module, or the voting element.

Fault Containment Region in a Distributed TMR system

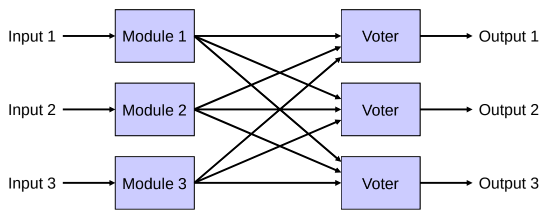


Single Points of Failure in a TMR System

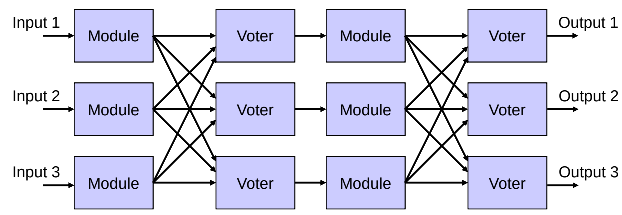


Masking Redundancy

TMR with triple voting and triple inputs



Masking Redundancy
Multi-stage TMR



Summary

- Fault tolerance
- Graceful degradation
- Safety
- Terminology: faults → errors → failures
- Voting redundancy
- Fault/error containment
- Single point of failure
- Multi-stage voting

Overview of Lecture 2

- **Reliability modeling**
  - Basic concepts in probability
  - Reliability block diagrams
  - Fault-trees

Preparations:

Storey: Section 7.1 and 7.2 (pages 167 – 177)