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POLITECNICO DI TORINO

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Models and techniques to evaluate

Software and System reliability

Outline

- Dependability Concepts
- Means to achieve dependable software
- Reliability Measures
- Reliability Models
- Case Study
- Possible Tool usage
- Suggestions

Dependability Concepts

General Definition

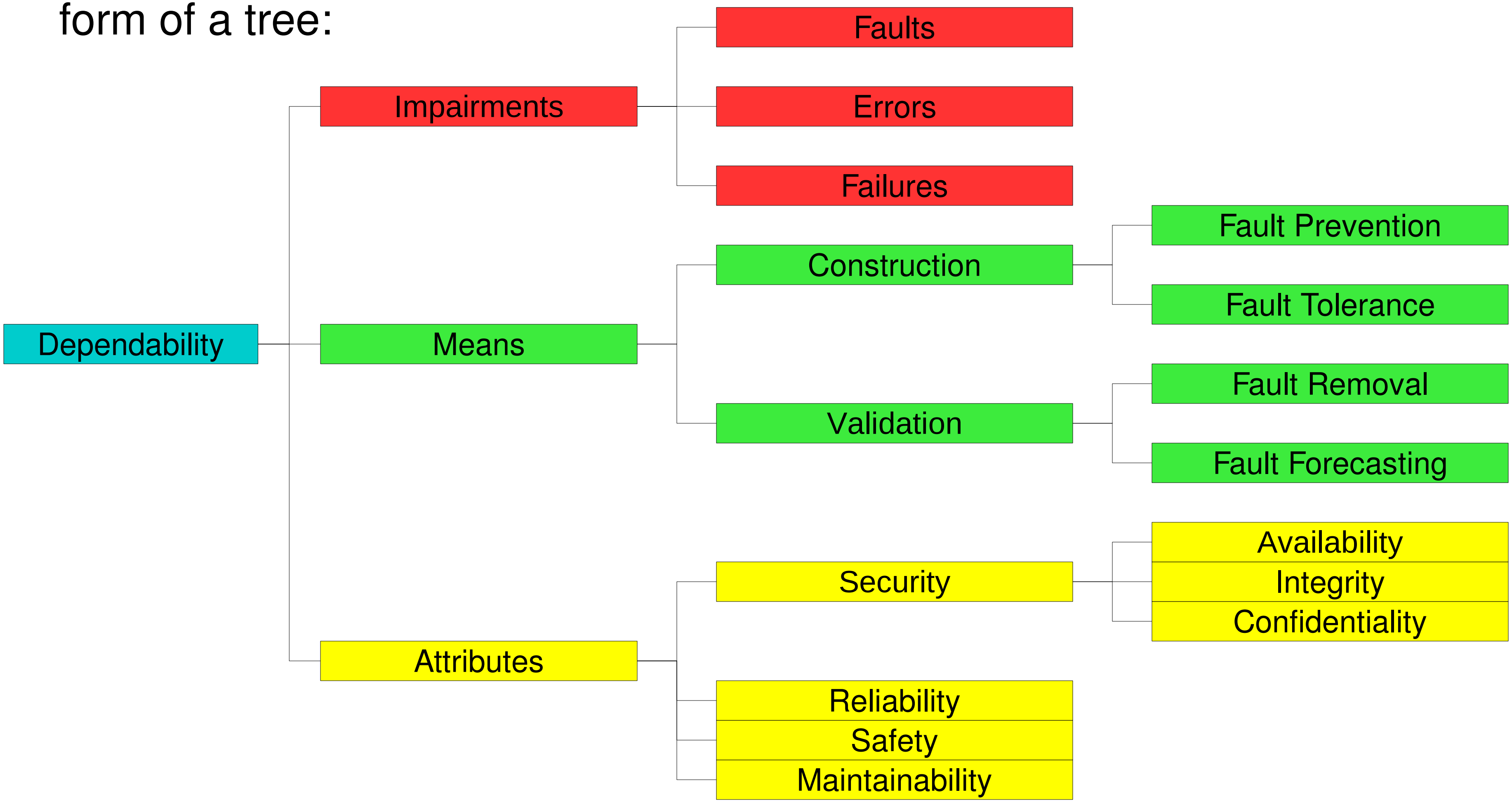
- Dependability is a value showing the reliability of a person to others because of his/her integrity, truthfulness, and trustfulness, traits that can encourage someone to depend on him/her.

Computer System Dependability

- Dependability as applied to computer systems is defined as the trustworthiness of a computer system such that reliance can justifiably be placed on the service it delivers.
- Dependability can be thought of as being composed of three elements:
  - Impairments
  - Means
  - Attributes

Dependability Tree

- The main characteristics of dependability can be summarized in the form of a tree:

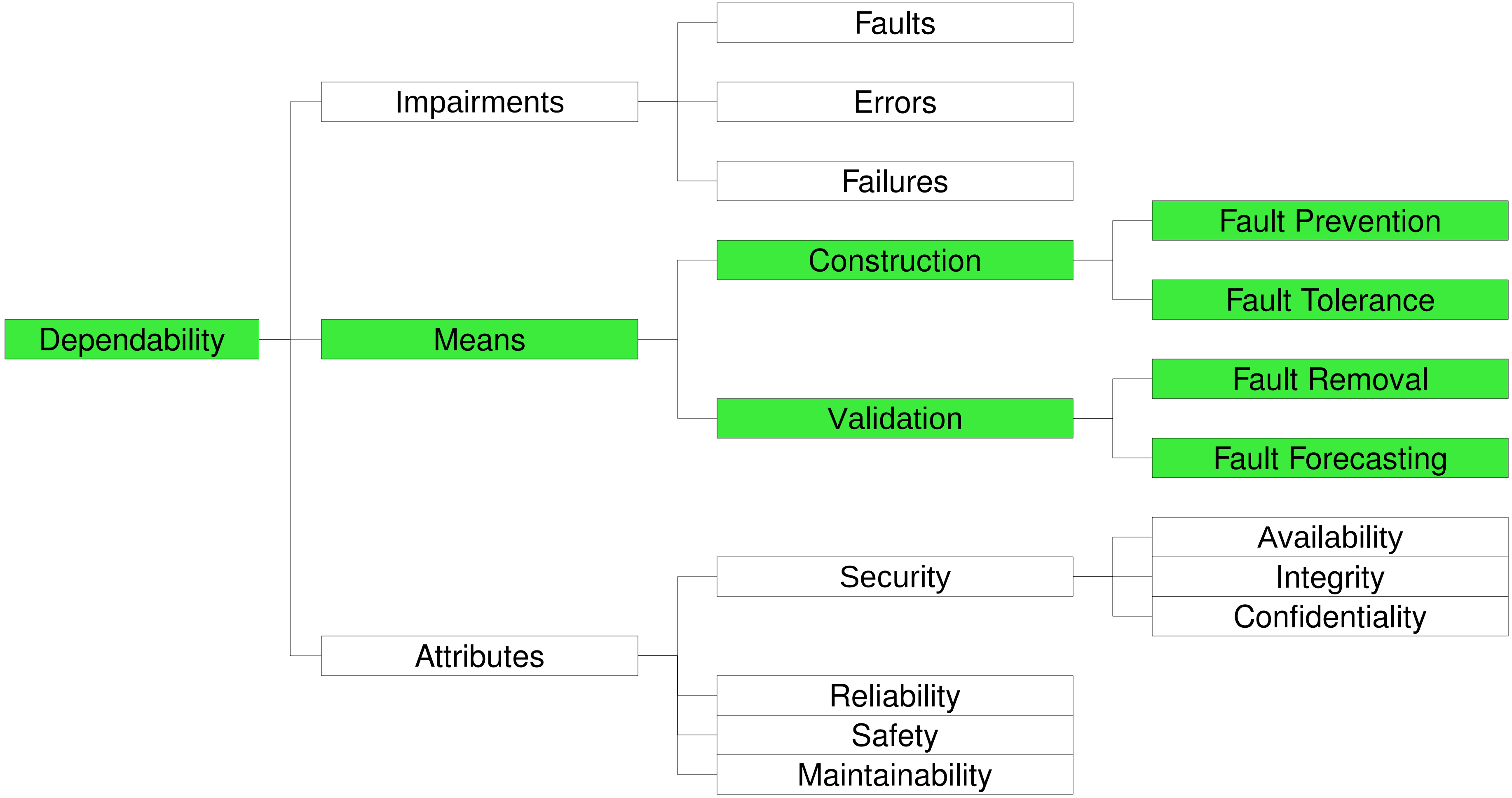


Impairments, Means and Attributes

- Impairments
  - Things that can affect Dependability
- Means
  - Ways to increase Dependability
- Attributes
  - Way to assess Dependability

Means to achieve dependable software

Means


Dependability
Impairments
Means
Attributes
Faults
Errors
Failures
Construction
Validation
Security
Reliability
Safety
Maintainability
Fault Prevention
Fault Tolerance
Fault Removal
Fault Forecasting
Availability
Integrity
Confidentiality

Means

- Fault Prevention
  - Prevent fault occurrence or introduction
- Fault Removal
  - Reduce the presence of faults
- Fault Tolerance
  - Ensures a service capable of fulfilling system's functions in presence of faults
- Fault Forecasting
  - Predicts likely faults so that they can be removed or their effects can be circumvented

Fault Prevention

- Fault prevention techniques are dependability enhancing techniques employed during software development to reduce the number of faults introduced during construction.
- Fundamental techniques:
  - Refinement of system requirements
  - Engineering software specification process
  - Structured design methods (e.g. writing clear and structured code)
  - Reusability
  - Formal Methods

System Requirements Specification

- Imperfect process
- System failures may occur
  - due to logic errors incorporated in the requirements
  - Software matches requirements, but the derived system behavior is not the expected one
  - Due to lack of communication between software and system engineering disciplines
- Solution: Interactive refinement of requirements and engineering of the requirements specification process

Structured Design vs Formal Methods

- Structured Software Design and programming reduces component's complexity and interdependency => reduces the introduction of faults
  - Decoupling and modularization
  - Information hiding
- Formal Methods are very thorough, using mathematically tractable languages and tools to verify correctness and appropriateness.
  - Drawback: overhead on the development process
  - Used for small components highly critical to the entire system

Reusablity

- Reusability of code components can be helpful when the code to be reused has been proven to be dependable
  - Drawback: reuse of software doesn't guarantee improvement in dependability (e.g. highly reliable software is not necessarily safer)

Fault Removal

- Fault removal techniques involve
  - Detecting existing faults (through verification and validation (V&V) methods)
  - Eliminating existing faults
- This techniques improve system dependability through:
  - Software Testing
  - Formal inspection
  - Formal design proofs

Fault Removal Techniques

- Software testing
  - Prohibitive cost
  - Complexity of exhaustive testing over large systems
  - Testing can show the presence but not the absence of faults
  - Adequate test coverage and appropriate test quality measures
  - Efficient testing only on small and critical components
- Formal Inspection
  - Rigorous process, accompanied by documentation
  - Source code examination to find, correct faults and verify correction
  - Performed prior to the testing phase life cycle

Fault Removal Techniques

- Formal design proofs
  - Closely related to formal methods
  - Mathematical proof for correctness
  - Costly and complex to use
  - Not fully developed methods
  - Feasible on a small and critical portion of code

Fault Forecasting

- Fault Forecasting focuses on the reliability measure of dependability
- Fault Forecasting techniques are used during validation to:
  - Estimate the presence of faults
  - The occurrence and consequences of failures
- This techniques include two types of activities:
  - Reliability Estimation
  - Reliability Prediction

Reliability Estimation and Prediction

- Reliability Estimation
  - Determines current software reliability through statistical interference techniques to failure data obtained during testing or system operation
- Reliability Prediction
  - Determines future software reliability based upon available software metrics and measures
  - Techniques used depend on the software development stage

Fault Tolerance

- Fault Tolerance techniques enable a system to tolerate software faults remaining in the system after its development
- This techniques provide service complying with the relevant specification in spite of faults through:
  - Single Version Software Environment
  - Multiple Version Software Environment
  - Multiple Data Representation Environment

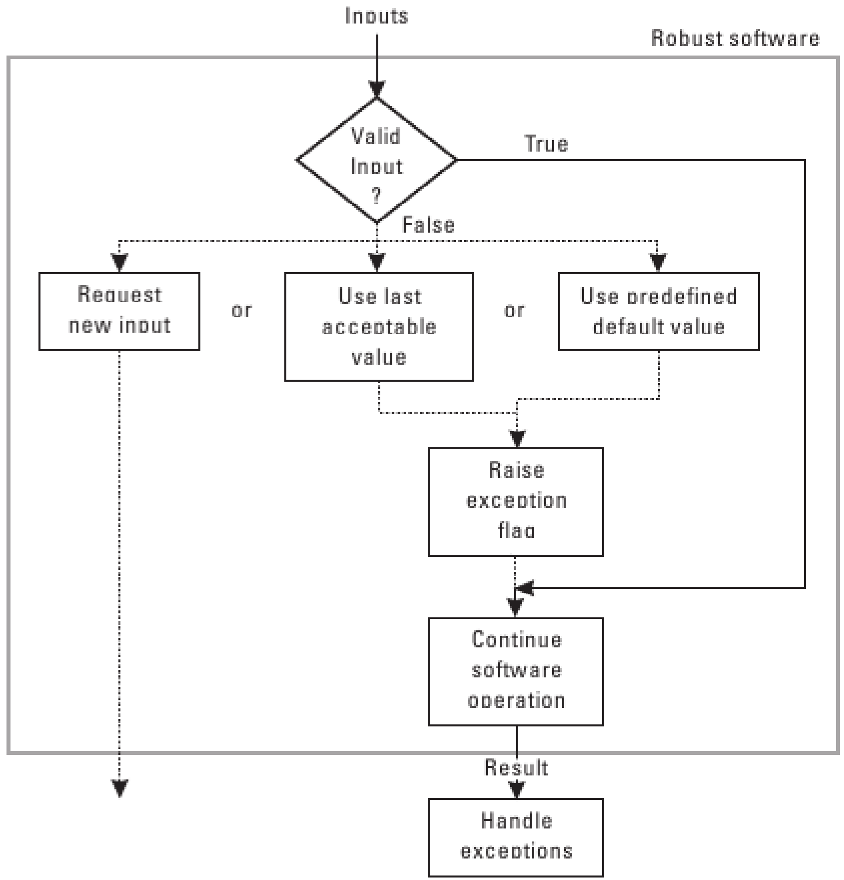
Single vs Multiple Version SE

- Single Version SE
  - Monitoring
  - Atomicity of actions
  - Decision Verification
  - Exception Handling
- Multiple Version SE (design diversity)
  - Functionally equivalent and independent software versions
  - Examples: Recovery Blocks (RcB), N-version programming (NVP), N-self checking programming

Redundancy for software fault tolerance

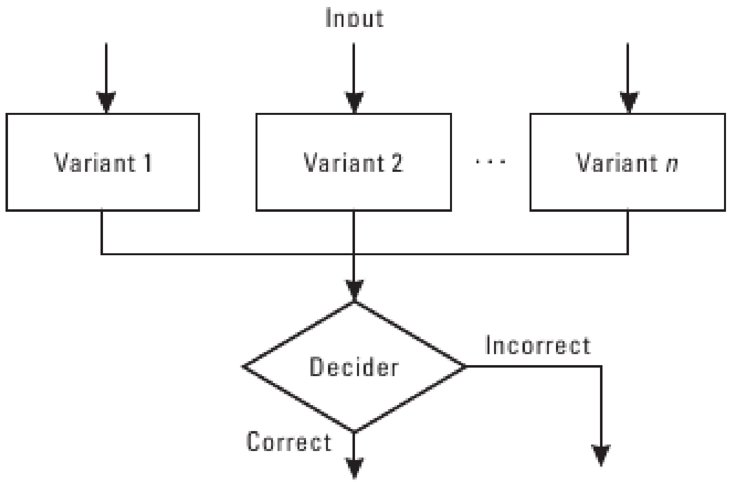
- Robust Software
  - Out of range inputs
  - Inputs of the wrong type
  - Inputs in the wrong format

Redundancy Implementation



Design Diversity

- Provision of identical services through separate design and implementations



Design diverse techniques

- Well-known design diverse techniques are:
  - Recovery Blocks (RcB)
  - N-Version Programming (NVP)
  - Distributed Recovery Blocks
  - N Self-Checking Programming
  - Consensus Recovery Block
  - Acceptance Voting

Data diversity

- Three well-known data diverse techniques are:
  - Retry blocks (Amman and Knight)
  - N-Copy Programming (Ammann and Knight)
  - Two pass adjudicator (Phullum)

Reliability Measures

Software Reliability Definition and Measure

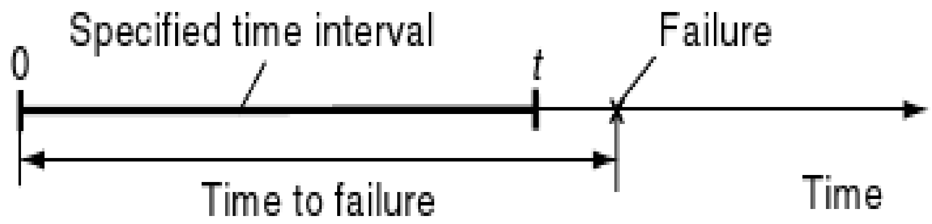
- Software Reliability is defined as the probability of failure-free software operation for a specified period of time in a specified environment
- => Reliability may be used as a measure of the system's success in providing it's function properly

Reliability Measure

- Reliability Function *R(t)* is the probability that a system will be successful in the interval from time 0 to time
  - Mathematically:

$$R(t) = P(T > t) \ \ s.t. \ \ t \geq 0$$

  - T is a random variable denoting the time-to-failure



Time to failure: probability density function

- The time to failure random variable T has a density function *f(t)*, such that:

$$f(t) = \lim_{\Delta t \to 0} P(t < T \le t + \Delta t)$$

- *f(t)* describes how the failure probability is spread over time
- *f(t)* properties:
  - Non-negative
  - Total area beneath *f(t)* is equal to one : $\int_0^{\infty} f(t)\,dt = 1$

Common pdf

- Common probability distribution functions (pdf) that have applications in reliability engineering (Pham 2000a) are:
  - Binomial Distribution
  - Poisson Distribution
  - Exponential Distribution
  - Normal Distribution
  - Weibull Distribution
- Given a particular pdf:
  - $R(t)$ can be derived directly

Availability Measure

- Availability *A(t)* is defined as the probability that the the system is successful at time *t*
  - Mathematically:

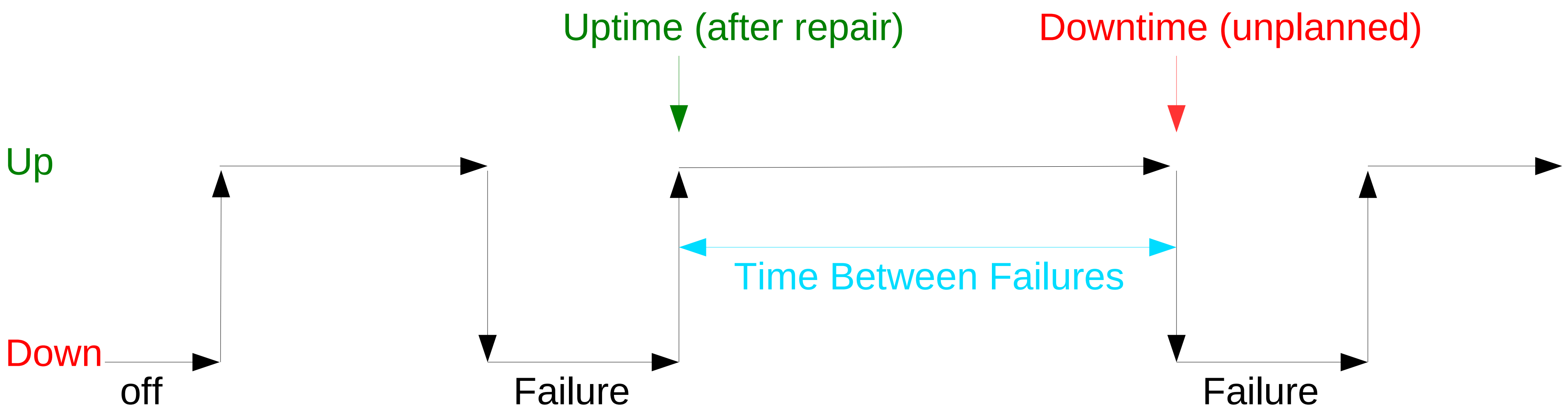
$$A(t) = \frac{System\,up\,time}{System\,up\,time + System\,down\,time} = \frac{MTTF}{MTTF + MTTR}$$

- Repairable systems: $A(t) \geq R(t)$
- Non-repairable systems: $A(t) = R(t)$

Availability: Mean Time Between Failures (MTBF)

- MTBF is the expected value of the random variable time between failures defined as:

$$MTBF = MTTF + MTTR$$



Reliability Models

Model Types

- It is highly desirable and difficult, without knowing what the initial errors are, to have an estimate of the remaining errors in a software system
- There exist two main types of software reliability models:
  - Deterministic
  - Probabilistic

Deterministic Reliability Models

Deterministic Model

- The Deterministic Model is used to study in the program:
  - The number of distinct operators and operands
  - The number of errors and machine instructions
- Performance measures of deterministic type are obtained:
  - By analyzing the program texture
  - Do not involve any random event

Well-known models

- There exist two deterministic well-known models:
  - Halstead's software metric
  - McCabe's cyclomatic complexity metric

Halstead vs McCabe

- Halstead's software metric is used to estimate the number of errors in a program
- McCabe's cyclomatic complexity metric is used to determine an upper bound model for estimating the number of remaining software defects
- Both models represent a growing quantitative approach to the measurement of computer software

Probabilistic Reliability Models

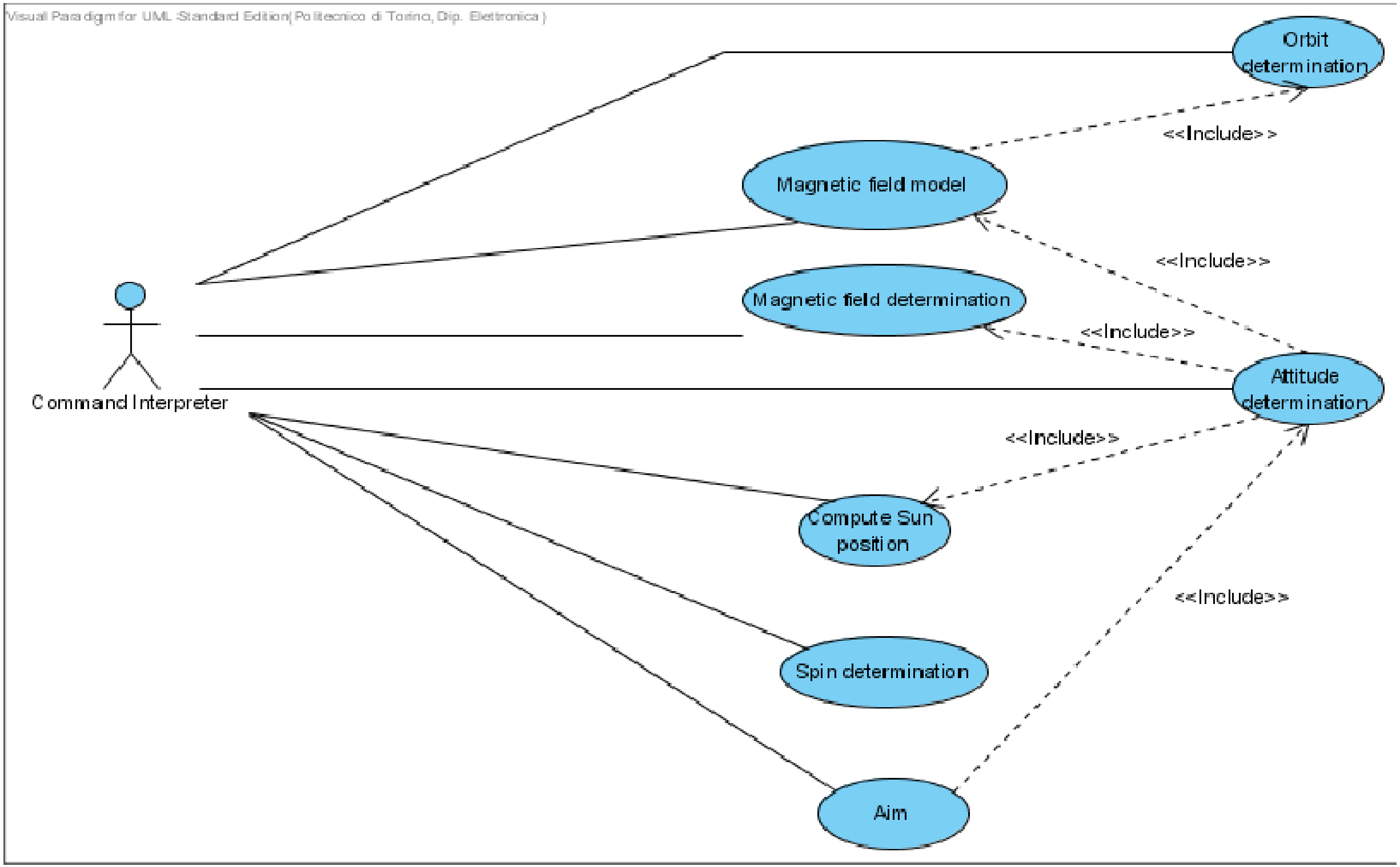
Classification

- According to (Pham2000a) probabilistic reliability models are classified in different groups:
  - Error seeding
  - Failure rate
  - Curve fitting
  - Reliability growth
  - Markov structure
  - Time-series
  - Nonhomogeneous Poisson process

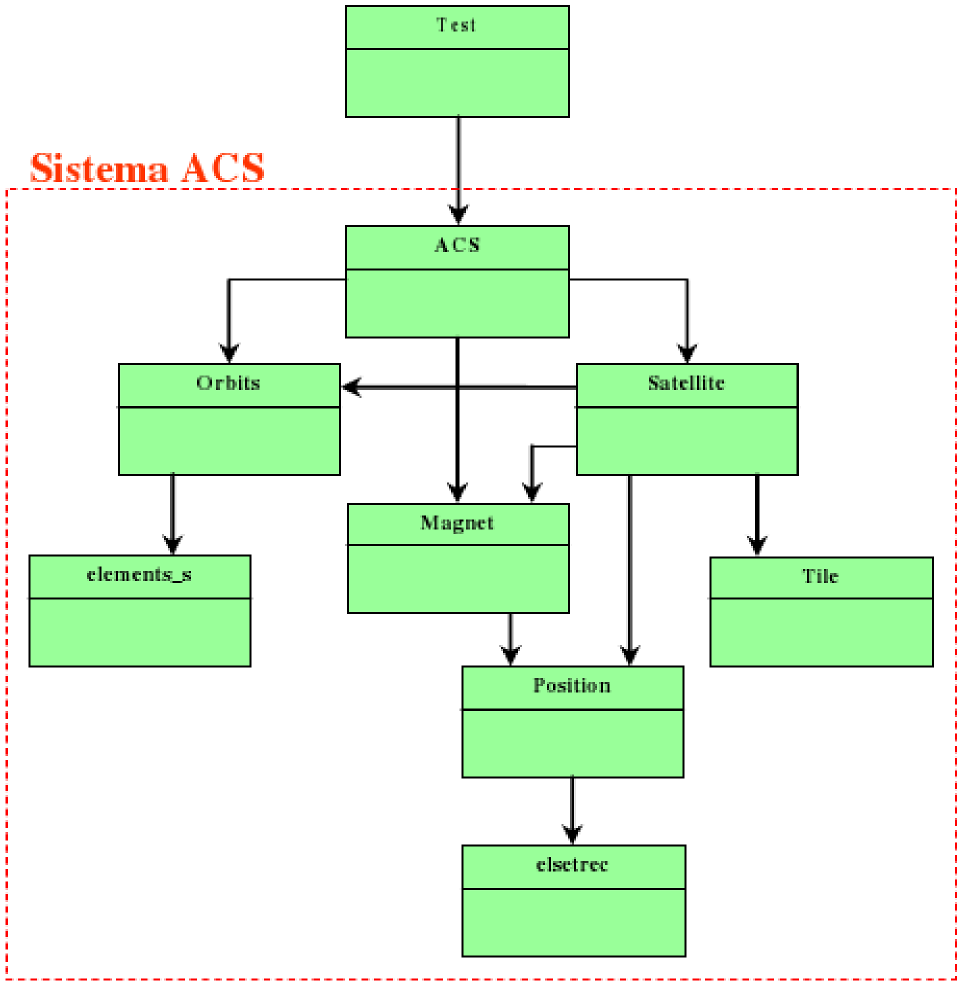
Case Study

ACS (Attitude Control System) for AraMiS satellite

Use Case Diagram of the ACS system



Class Case Diagram of the ACS system



Tools usage

Tools

- Commercial tools:

  Lambda Predict

  Weibull++

  ALTA

  DOE++

  Etc...
- Other tools:
  - CASRE (Computer Aided Software Reliability tool)
  - AutoTest

Conclusions

- All software tolerance techniques provide tolerance to software design faults, but do not provide protection against errors in requirement specifications
- This techniques are widely used in systems where faults can result in failures with catastrophic consequences:
  - Aerospace, Nuclear Power, Healthcare etc.

Thank you very much for the attention!

Suggestions are kindly appreciated