Basic Concepts and Taxonomy of Dependable and Secure Computing

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Introduction

- All the authors of this paper are well-known people in the area of dependable computing.
- A minimal consensus on dependability and security concepts.
- Develop an standard for standardization organizations to accept this taxonomy.

Basic Concepts

- Definition of system function, behavior, structure, and service
- The threats to dependability and security
- Dependability, security, and their Attributes
- The means to attain dependability and security

System and Function

- System is an entity that interacts with its environment (other systems, hardware, software, humans)
- The system boundary is the common frontier between the system and the environment.
- The function of a system is what the system is intended to do and is described by the functional specification

Behavior

- The behavior of a system is what the system does to implement its function and is described by a sequence of states.

- The total state of a given system is the set of the following states: computation, communication, stored information, interconnection, and physical condition.

Structure

- The structure of a system is what enables it to generate the behavior.

- From this viewpoint, a system is composed of a set of components bound together in order to interact.

Service

- The service delivered by a system is its behavior as it is seen by its users.
- A user is another system that receives service from the provider.
- States can be:
  - Internal: cannot be accessed through interfaces.
  - External: can be accessed through interfaces.

The Threats to Dependability and Security

- Correct service is delivered when the service implements the system function.
- Service failure, is an event that occurs when the delivered service deviates from correct service
- A service failure is a transition from correct service to incorrect service to not implementing the system function
- Service outage: the period of delivery of incorrect service
- Service restoration: transition from incorrect service to correct service

Threats

- A service failure means that at least one more external state of the system deviate from the correct service state.
- Error is the part of the total state of the system that may lead to service failure.
- The cause of a error is called a fault.
- A fault is active when it cause an error, otherwise is dormant.

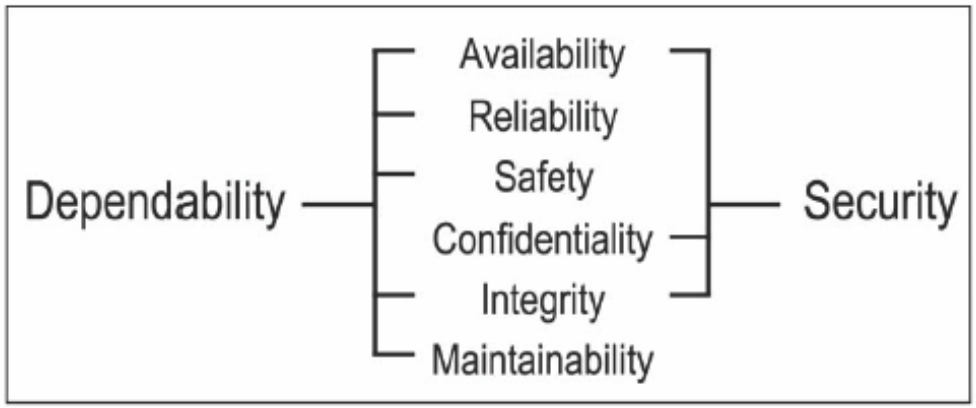
Dependability and Security Attributes

- **Dependability of a system is the ability to avoid service failures that are more frequent and more severe than is acceptable.**

- **Dependability attributes:**
  - availability: readiness for correct service.
  - reliability: continuity of correct service.
  - safety: absence of catastrophic consequences on the users and the environment.
  - integrity: absence of improper system alterations.
  - maintainability: ability to undergo modifications and repairs.

Dependability and Security Attributes (cont'd)

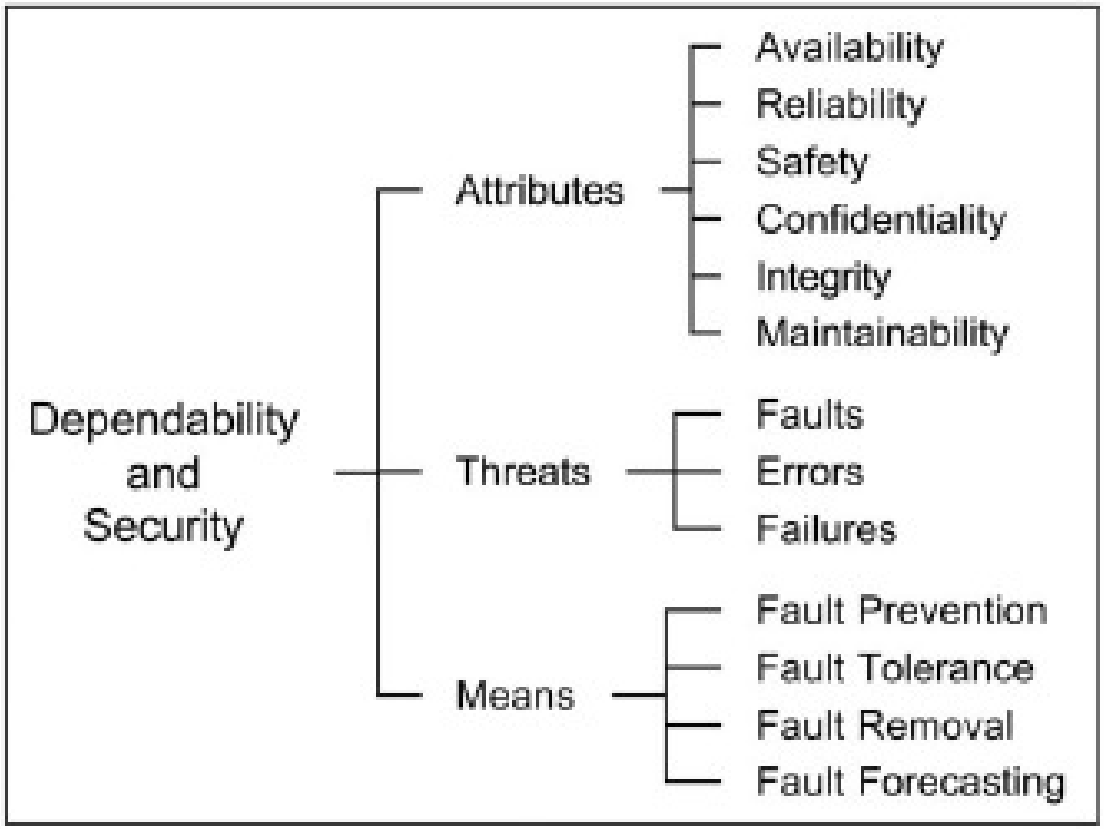
- Security attributes:
  - availability: for authorized action
  - confidentiality: absence of unauthorized disclosure of information
  - integrity: absence of unauthorized system alterations.



Means to Attain Dependability and Security

- Fault prevention
  - prevent the occurrence or introduction of faults.
- Fault tolerance
  - avoid service failures in the presence of faults.
- Fault removal
  - reduce the number and severity of faults.
- Fault forecasting
  - estimate the present number, the future incidence and the likely consequences of faults.

The Dependability and Security Tree



The dependability and security tree.

System Lifecycle

The lifecycle of a system includes two phases:

- Development

  All activities form requirement analysis to test phases

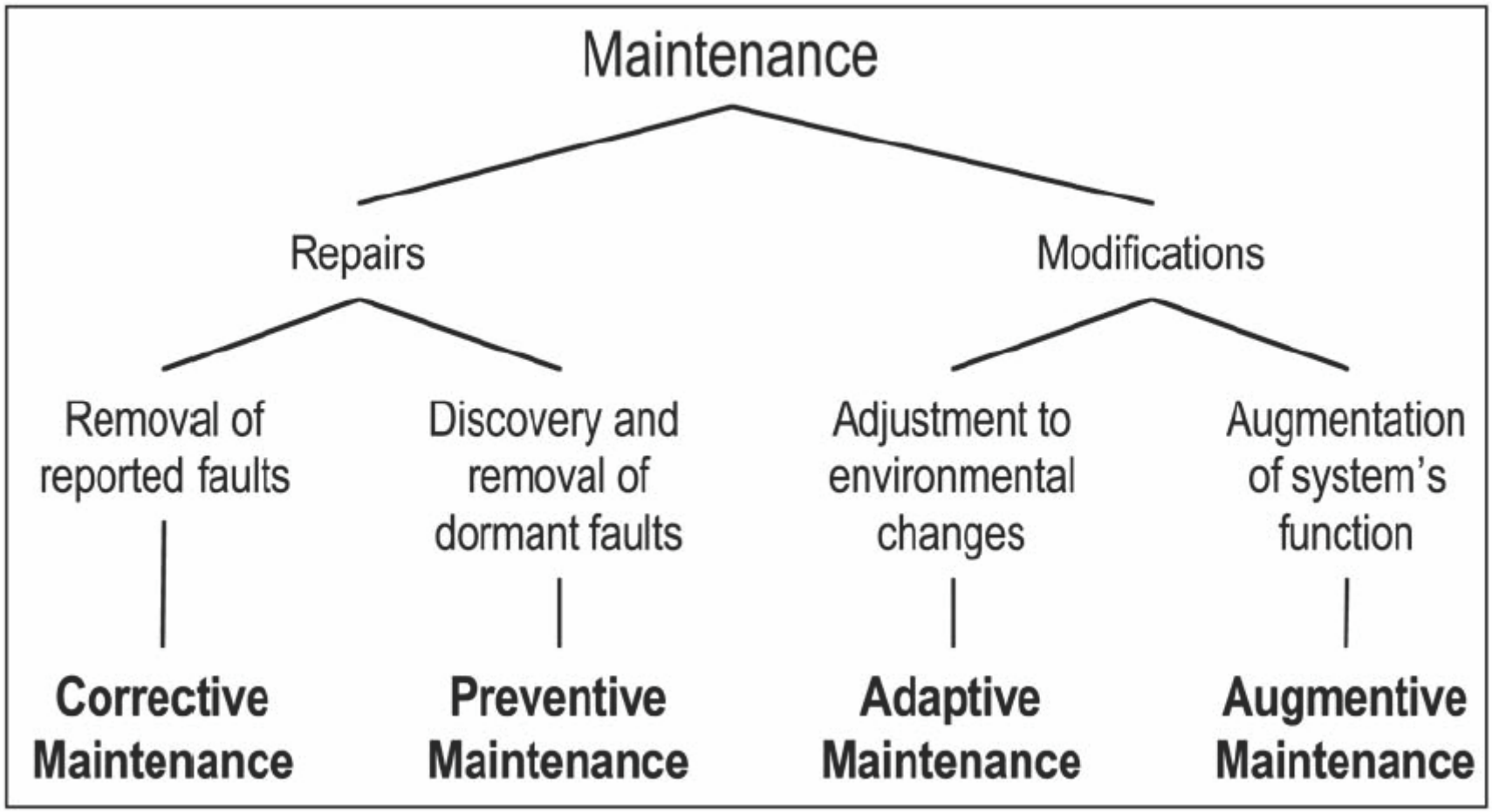
- Use

  begins when the system is accepted for use and starts delivering its services.

Maintenance

- Maintenance includes:
  - Repairs: Removing the fault by removing the cause of fault.
  - Modifications: Removing the fault by changing the system.

Maintenance



Maintenance vs. fault tolerance

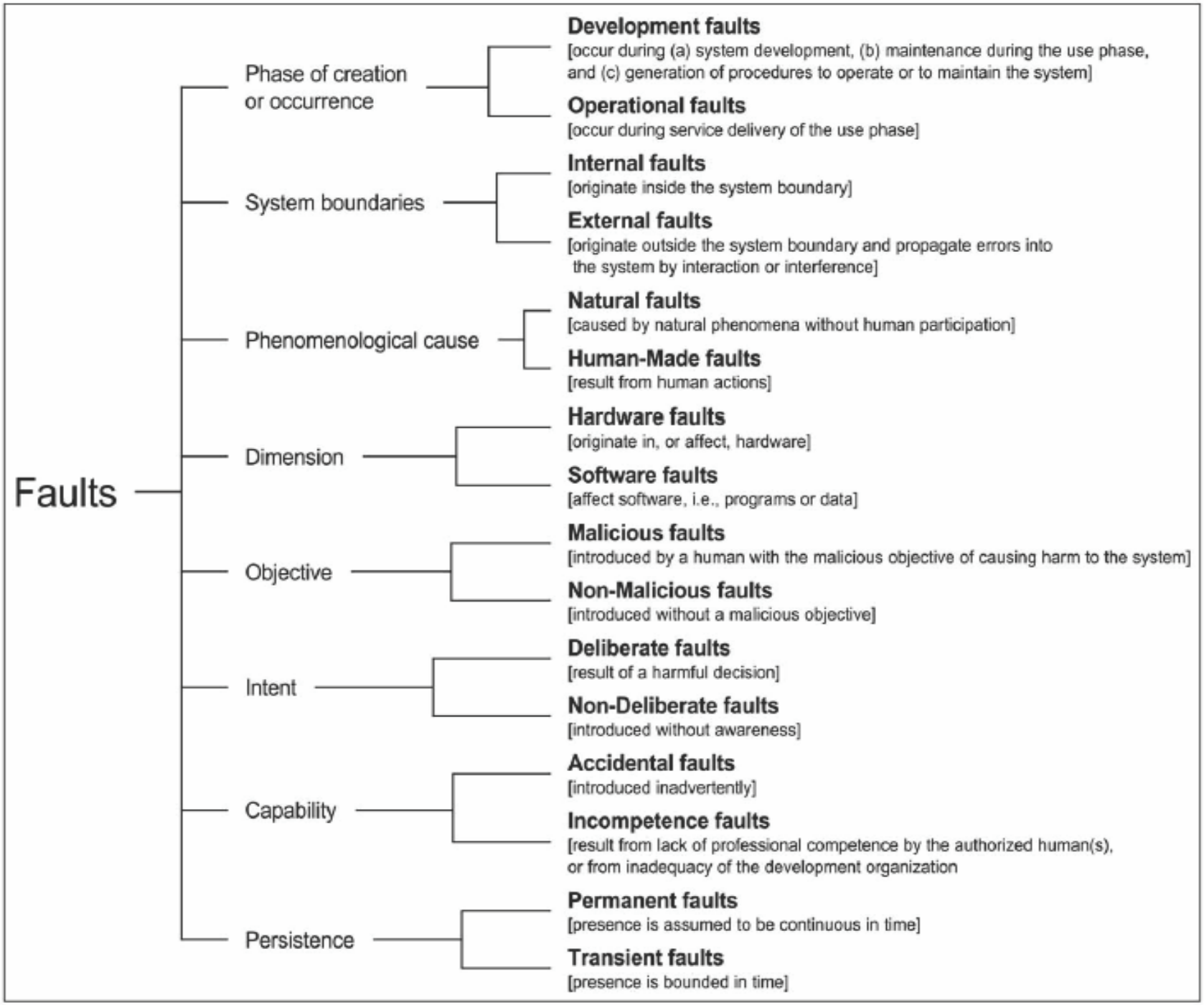
- Distinction between fault tolerance and maintenance:

maintenance involves the participation of an external agent, e.g., a repairman, test equipment, remote reloading of software

- Repair is part of fault removal (during the use phase)

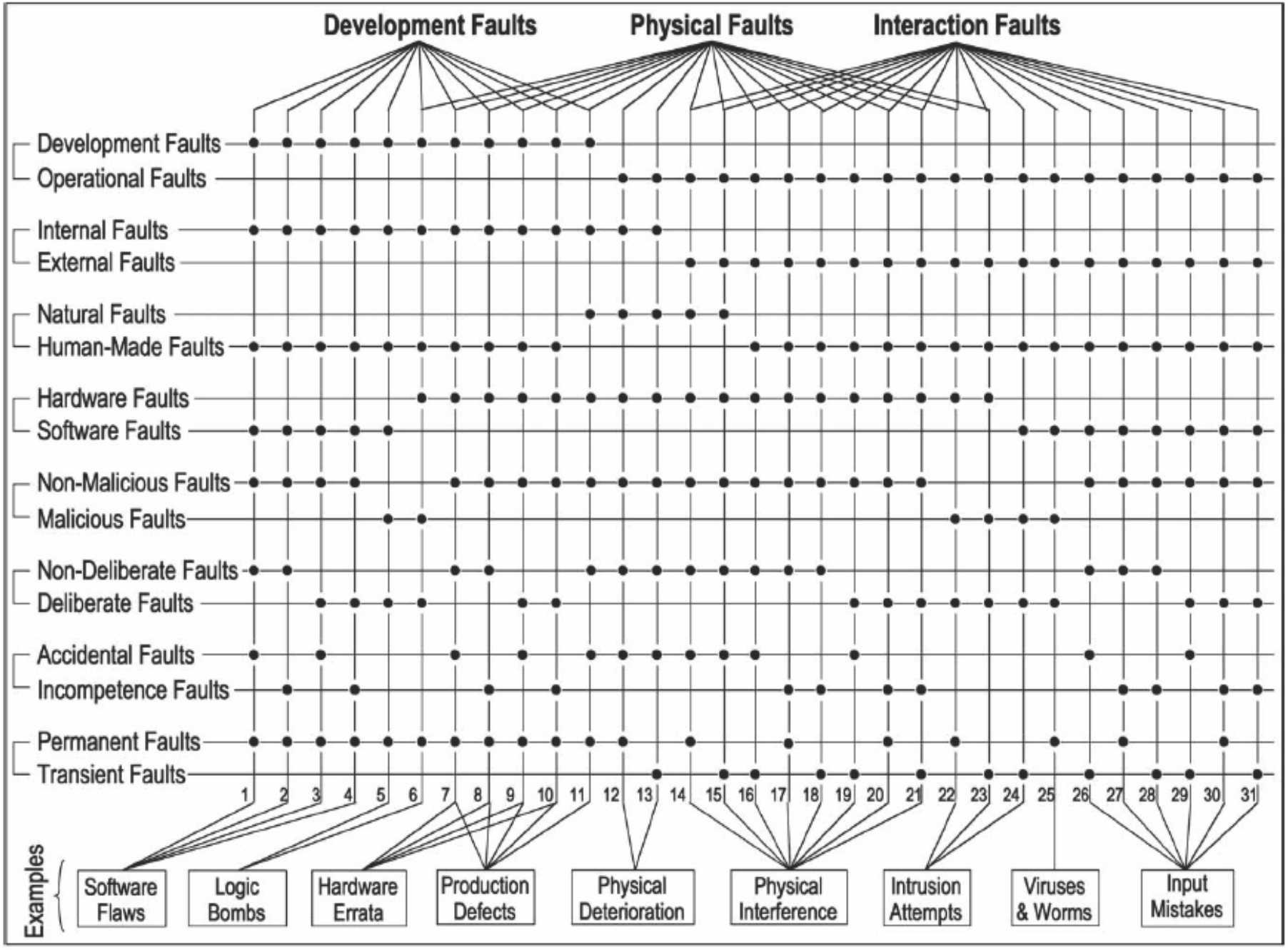
Taxonomy of Faults

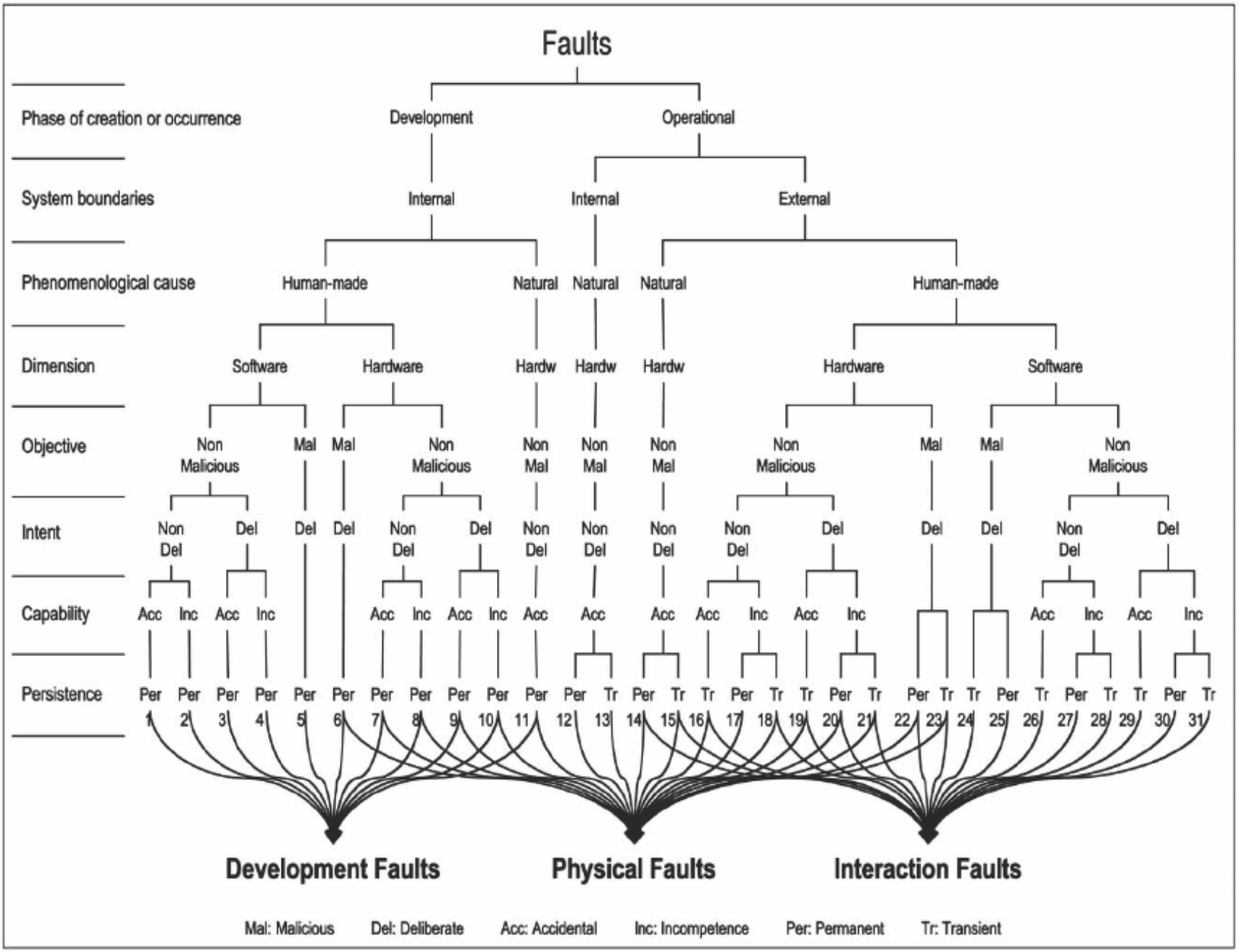
- All faults that may affect a system during its life are classified according to eight basic viewpoints
- If all combinations of the eight elementary fault classes were possible, there would be 256 different combined fault classes
- 31 faults have been identified


Faults
Phase of creation or occurrence
Development faults
[occur during (a) system development, (b) maintenance during the use phase, and (c) generation of procedures to operate or to maintain the system]
Operational faults
[occur during service delivery of the use phase]
System boundaries
Internal faults
[originate inside the system boundary]
External faults
[originate outside the system boundary and propagate errors into the system by interaction or interference]
Phenomenological cause
Natural faults
[caused by natural phenomena without human participation]
Human-Made faults
[result from human actions]
Dimension
Hardware faults
[originate in, or affect, hardware]
Software faults
[affect software, i.e., programs or data]
Objective
Malicious faults
[introduced by a human with the malicious objective of causing harm to the system]
Non-Malicious faults
[introduced without a malicious objective]
Intent
Deliberate faults
[result of a harmful decision]
Non-Deliberate faults
[introduced without awareness]
Capability
Accidental faults
[introduced inadvertently]
Incompetence faults
[result from lack of professional competence by the authorized human(s), or from inadequacy of the development organization
Persistence
Permanent faults
[presence is assumed to be continuous in time]
Transient faults
[presence is bounded in time]

Taxonomy of Faults (cont'd)

- All 31 combined faults are categorized to three major overlapping groups:
  - Development faults : occurring during development
  - Physical faults: affect hardware
  - Interaction faults: external faults


Development Faults
Physical Faults
Interaction Faults
Development Faults
Operational Faults
Internal Faults
External Faults
Natural Faults
Human-Made Faults
Hardware Faults
Software Faults
Non-Malicious Faults
Malicious Faults
Non-Deliberate Faults
Deliberate Faults
Accidental Faults
Incompetence Faults
Permanent Faults
Transient Faults
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Examples
Software Flaws
Logic Bombs
Hardware Errata
Production Defects
Physical Deterioration
Physical Interference
Intrusion Attempts
Viruses & Worms
Input Mistakes


Faults
Phase of creation or occurrence
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Development Faults
Physical Faults
Interaction Faults
Mal: Malicious
Del: Deliberate
Acc: Accidental
Inc: Incompetence
Per: Permanent
Tr: Transient

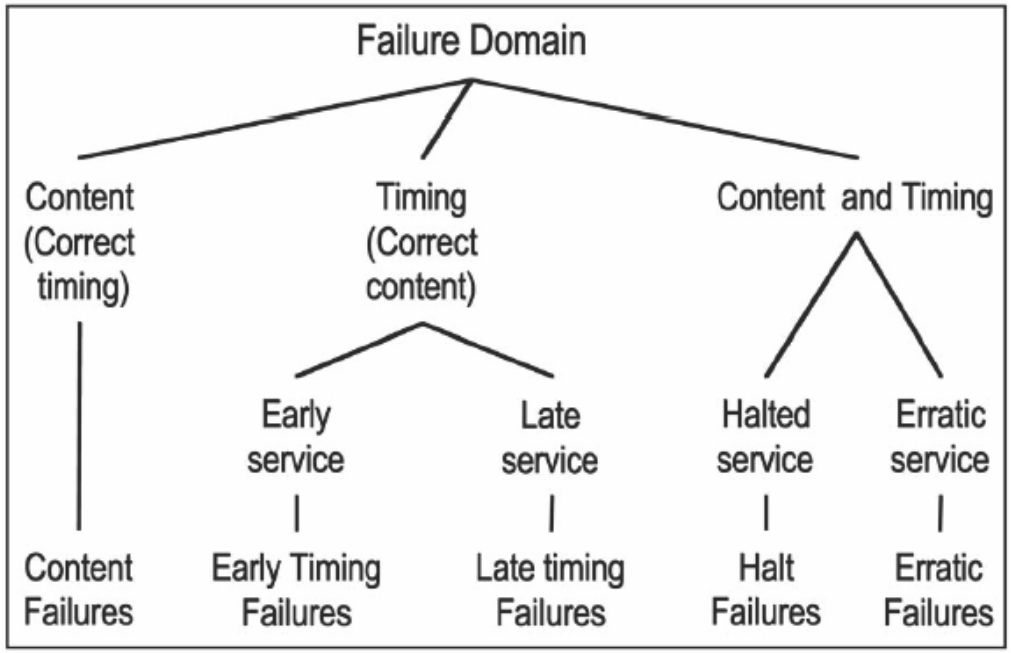
Failures

- Service failure: An event that occurs when the delivered service deviates from correct service.
- Development failure: Be introduced into the system being developed by its environment, especially by human developers, development tools and production facilities.
- Dependability and security failures: occurs when the given system suffers service failures more frequently or more severely than acceptable

Service Failures

- The service failures modes characterize according to four viewpoints:
  - Failure domain
  - Detectability of failures
  - Consistency of failures
  - Consequence of failures on the environment

Failure domain viewpoint



- content failures: service content deviates from implementing the system function
- timing failures: timing of service delivery deviates from implementing the system function
- halt failures: when the service is halted (silent failure)
- erratic failures: a service delivered but is erratic

Detectability viewpoint

- The detectability viewpoint addresses the signaling of service failures to the users

- Signaling at the service interface originates from detecting mechanisms in the system that check the correctness of the delivered service.
  - signaled failures: when the losses are detected and signaled by a warning signal
  - unsignaled failures: otherwise

- The detecting mechanisms themselves have two failure modes:
  - signaled failures :signaling a loss of function when no failure has actually occurred (false alarm)
  - unsignaled failures: not signaling a function loss

Consistency viewpoint

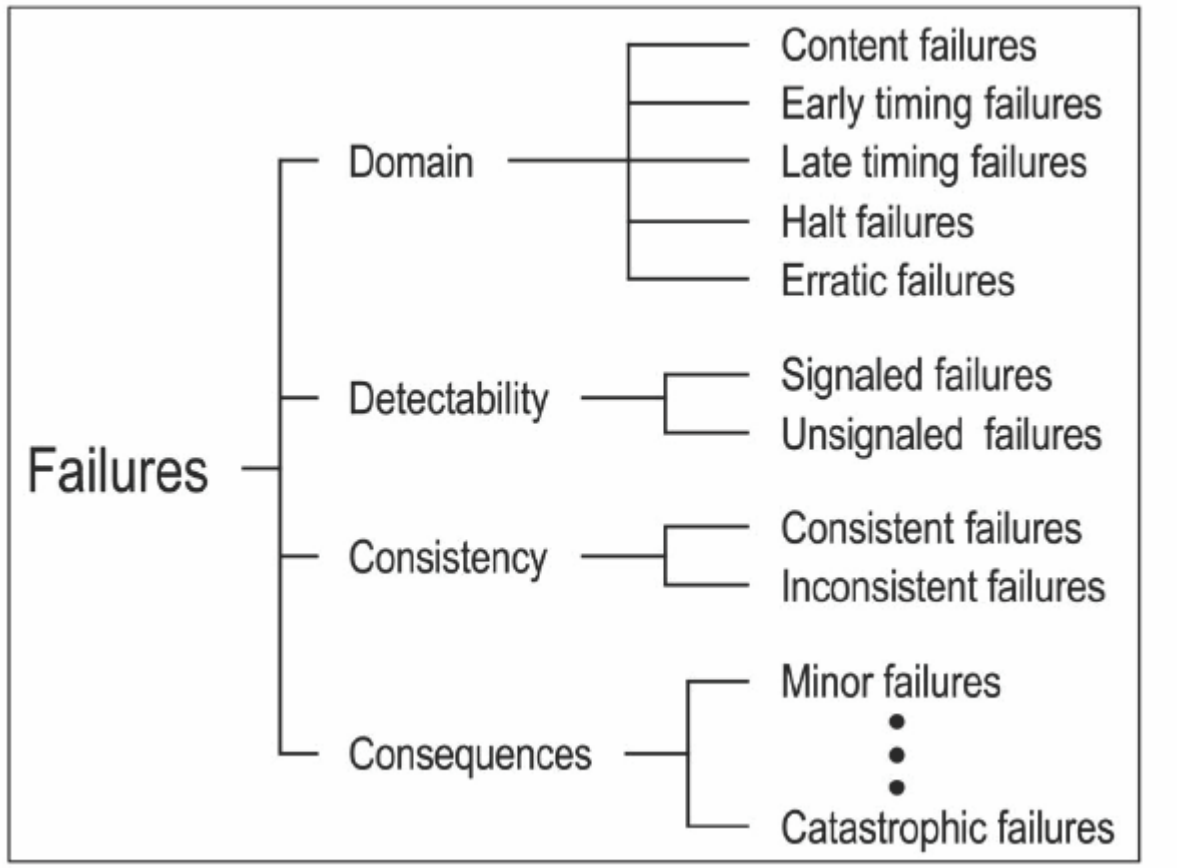
- The consistency of failures leads us to distinguish, when a system has *two or more users*

  - consistent failures: The incorrect service is perceived identically by all system users
  - inconsistent failures: Some or all system users perceive differently incorrect service and some users may actually perceive correct service (Byzantine failures)

Consequence viewpoint

- Grading the consequence of the failures upon the system environment enables failure *severities* to be defined
- Two levels can be defined:
  1. minor failures: the harmful consequences are of similar cost to the benefits provided by correct service delivery
  2. catastrophic failures: the cost of harmful consequences is higher than the benefit provided by correct service delivery

Service failure modes



Development Failures

principle causes: incomplete or faulty specifications, user initiated specification changes, faulty estimates of development costs…

- Complete development failures: the development process will be terminated before the use phase
  - budget failure
  - schedule failure
- Partial development failures: lesser severity than project termination
  - Downgrading
  - Overrun

Errors

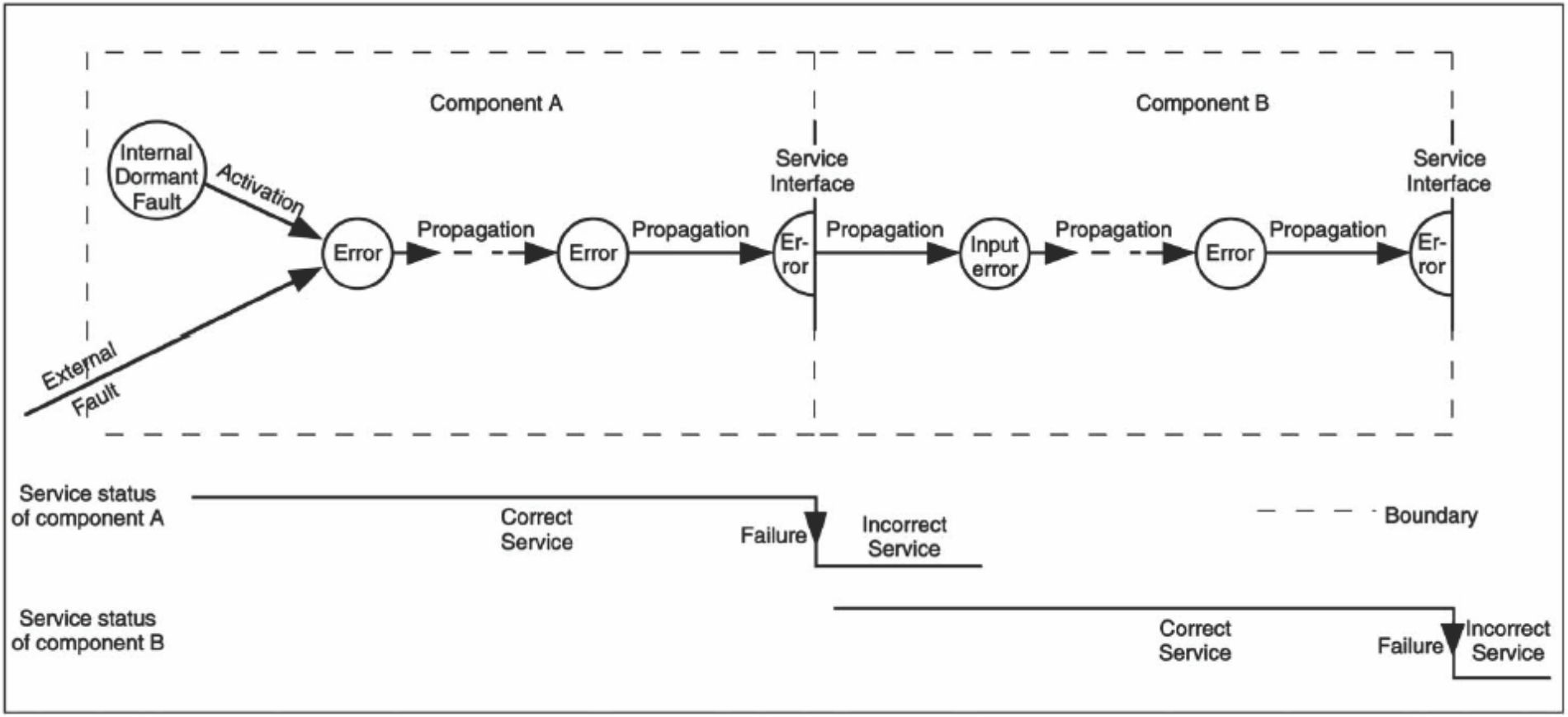
- A failure occurs when the error causes the delivered service to deviate from correct service
- An error is detected if its presence is indicated by an *error message* or *error signal*.
- Errors that are present but not detected are latent errors.

Errors (cont'd)

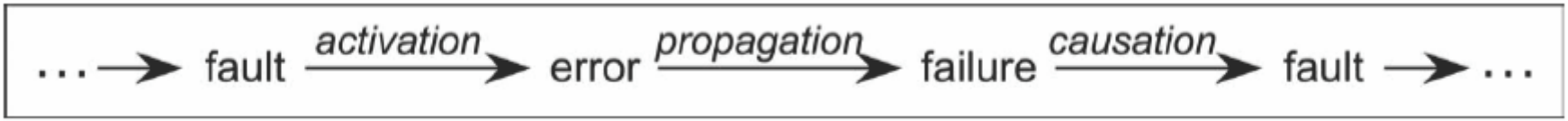
- An error will actually lead to a service failure or not depends on two factors:
  - The structure of the system
    - nature of any redundancy that exists in it
  - The behavior of the system
    - the part of the state that contains an error may never be needed for service

  - Single errors are errors that affect only one component.
  - multiple related errors are errors that affect more than one component simultaneously.

The Pathology of Failure



The Pathology of Failure



The arrows in this chain express a causality relationship between ***faults***, ***errors*** and ***failures***

Fault Activation Reproducibility

- The ability to identify the activation pattern of a fault that had caused one or more errors is the fault activation reproducibility

- Faults can be categorized according to their activation reproducibility:
  - Solid or Hard faults: faults whose activation is reproducible
  - Elusive or Soft faults: faults whose activation is not reproducible