Dependable systems (3CFU)

Master of Science in Embedded Computing Systems

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Course outline

- Dependability foundations:
  - Reliability, Availability, Safety
  - Fault, failures, and errors
- Quantitative/qualitative analysis:
  - Block diagrams, Fault trees, FMEA, Markov models
- Fault-tolerant systems design
- Case studies of dependable systems
- International Standards for safety-related systems
- Resilient Computing and Resilience Engineering

Dependable Systems

Our society depends on a broad variety of computer controlled systems, in particular, computers are increasingly used in safety critical systems (transport, medicine, process control, ….) .

A safety critical system is a system whose failure or malfunction may result in death or serious injury to people, loss or serious damage of equipment, or environmental harm.

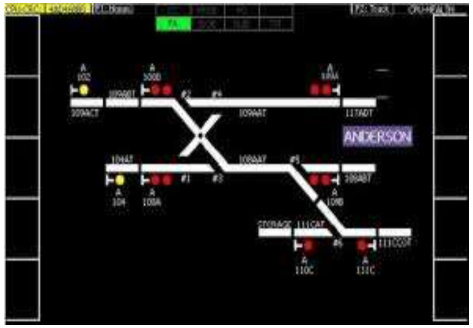
For a computer based safety critical system, the safety of the system depends strongly on its compuerts.

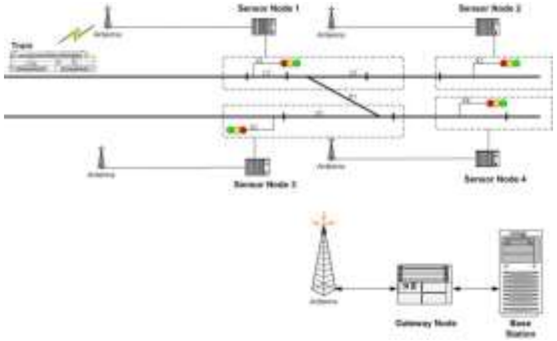
System dependability is the ability of the system to deliver the expected functionality during its operational life.

General question: how to deal with unexpected events?

Transport systems

Railway: Interlocking systems





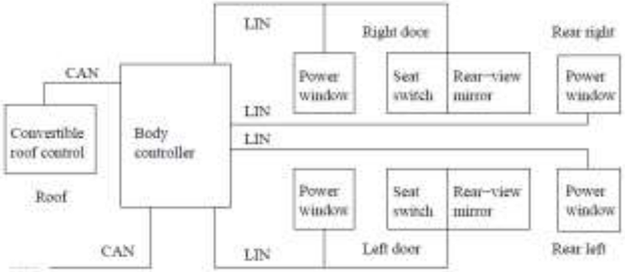
Railway Signalling using WSNs

Automotive: Electronic Control Unit (ECU - embedded system that controls one or more of the electrical system or subsystems in a motor vehicle). Some modern motor vehicles have up to 80 ECUs

Automatic Emergency Braking (AEB)
A safety system to react to a critical situation.

Collision mitigation braking

Body Controller Unit: in charge of controlling a car's electrically operated windows, rear-view mirrors, and other components.

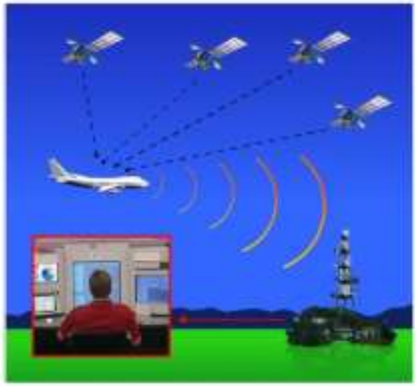


BCU designed as a centralized FPGA controller

Air traffic control

Air Traffic Control (ATC) is a service provided by ground-based controllers who are responsible for maintaining a safe and efficient air traffic flow.

Future generation of ATC: Airborne Self-Separation, an operating environment where pilots are allowed to select their flight paths in real-time.

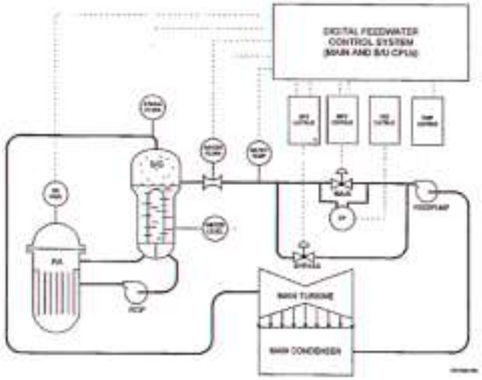


Digital Instrumentation and Control

Nuclear Power Plants

A Digital Control System samples feedback from the system under control and issues commands to the system in an attempt to achieve some desired behaviour

Digital I&C: analog and mechanical parts are replaced by CPUs and software



One of the reactor coolant loops with its associated Digital FeedWater Control System

Medical devices

PCA devices

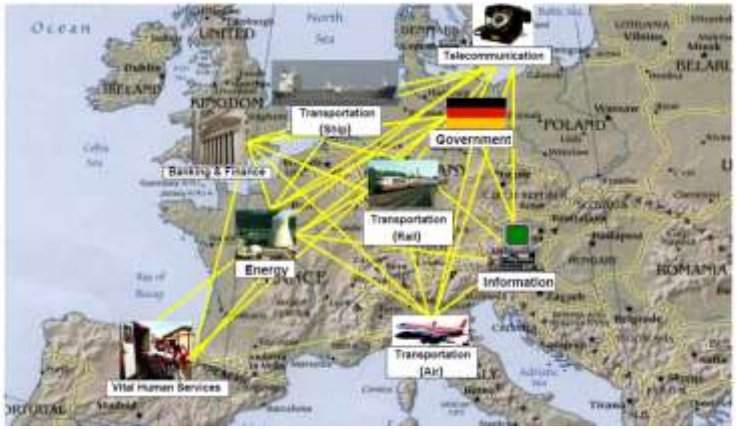
A patient-controlled analgesia (PCA) infusion pump, configured for intravenous administration of morphine for postoperative analgesia

Implantable Cardiac Pacemakers

The bulk of the device contains its battery and electronic control systems. The leads detect the heart's electrical activity, transmit that information to the artificial pacemaker's electronics for analysis and, if the natural activity is deemed irregular, deliver an electrical charge from the artificial pacemaker's batteries that causes the cardiac muscle to contract, pacing the pumping of the heart.

Complex socio-technical systems

Present market trends push forward the deployment and operation of **complex software-based socio-technical systems of systems** that have to be dependable



Computer controlled systems

Can we justifiably trust the dependability of such systems?

Hw and sw systems relaying on hidden components

- A system is as strong as its weakest component
- Design failures: unintended system function due to incomplete problem description
- Human failure: the system includes the operator.
- Hursh environment (wide temperature range , …)

Computer failures differ from failures of other equipment

- Subtler failures than "breaking down" or "stopping working", ..
- The computer is used to store information: there are many ways information can be wrong, many different effects both within and outside the computer
- Small hidden faults may have large effects (digital machine)

Computer designers and programmers would be students of reliability and so do computer system users

D. P. Siewiorek R.S. Swarz, Reliable Computer Systems, Prentice Hall, 1992

Dependability foundations

Supporting reading

A. Avizienis, J.C. Laprie, B. Randell, C. Landwehr
Basic Concepts and Taxonomy of Dependable and Secure Computing
IEEE Transactions on Dependable and Secure Computing, Vol. 1, N. 1, 2004

Dependability: a definition

Dependability is “that property of a computer system such that reliance can justifiably be placed on the service it delivers”

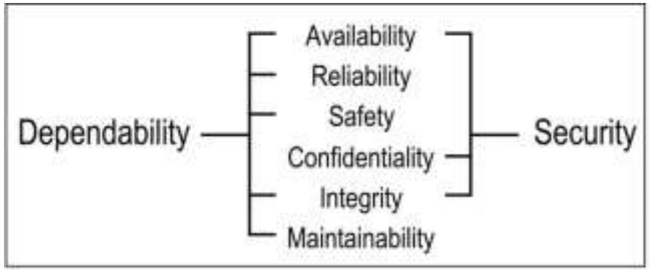
If the system stops delivering the intended service, we call this a failure.

Trust in a computer controlled system could be justified through numbers that show the quality level of the system.
Such numbers are obtained using probabilities and statistical methods

In the field of safety critical systems, for example in the avionic field, a rate of occurrence of failures of 10^{-9} was set as a design target

Dependability attributes

Dependability is a concept that encompasses multiple properties



- **Availability**
  readiness for correct service
- **Reliability**
  continuity of correct service
- **Safety**
  absence of catastrophic consequences on the user(s) and the environment
- **Confidentiality**
  the absence of unauthorized disclosure of information
- **Integrity**
  absence of improper system alterations
- **Maintainability**
  ability to undergo modifications and repairs

What is a system?

System: entity that interacts with other entities, i.e., other systems, including

- hardware,
- networks,
- operating systems software,
- application software,
- humans, and
- the physical world with its natural phenomena.

These other systems are the environment of the given system.

The **system boundary** is the common frontier between the system and its environment.

Fundamental properties of a system:
functionality, performance, dependability and security, and cost.

System

Function of a system:
what the system is intended to do and is described by the functional specification in terms of functionality and performance.

Behavior of a system:
what the system does to implement its function and is described by a sequence of states.

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

Structure of a system:
what enables it to generate the behavior.

A system is composed of a set of components bound together in order to interact, where each component is another system, etc. The recursion stops when a component is considered to be atomic

The total state of a system is the set of the (external) states of its atomic components.

System

Service delivered by a system (in its role as a provider):
its behavior as it is perceived by its user(s)

A user is another system that receives service from the provider. The part of the provider’s system boundary where service delivery takes place is the **provider’s service interface**.

The part of the provider’s total state that is perceivable at the service interface is its external state; the remaining part is its internal state.

The delivered service is a sequence of the provider’s external states.

A system may sequentially or simultaneously be a provider and a user with respect to another system, i.e., deliver service to and receive service from that other system.

Use interface: the interface of the user at which the user receives service

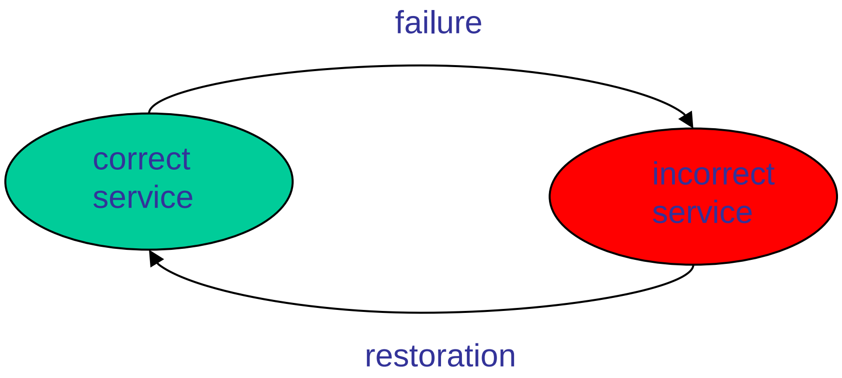
Threats to Dependability: Failures, Errors and Faults

Correct service is delivered when the service implements the system function.

A service failure, often abbreviated failure, is an event that occurs when the delivered service deviates from correct service. A service fails either because it does not comply with the functional specification, or because this specification did not adequately describe the system function.

Failure is a transition from correct service to incorrect service,

Restoration is the transition from incorrect service to correct service.



Threats to Dependability: Failures, Errors and Faults

A service failure means that at least one (or more) external state of the system deviates from the correct service state. The deviation of a state from the correct state is called an error.

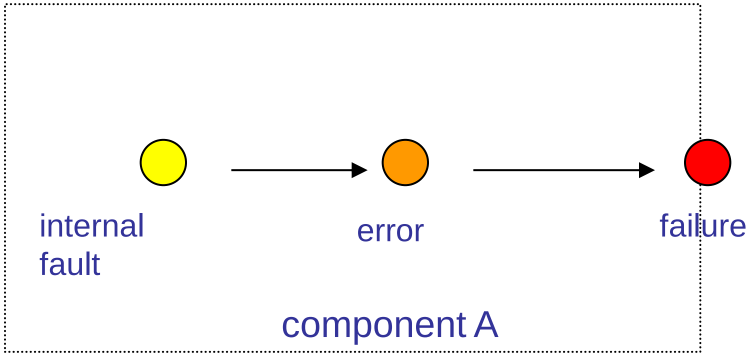
The deviation from correct service may assume different forms that are called service failure modes and are ranked according to failure severities.

Fault: the adjudged or hypothesized cause of an error.
Faults can be internal or external of a system. The prior presence of a vulnerability, i.e., an internal fault that enables an external fault to harm the system, is necessary for an external fault to cause an error and possibly subsequent failure(s).

A fault first causes an error in the service state of a component that is a part of the internal state of the system and the external state is not immediately affected.

For this reason, the definition of an error is the part of the total state of the system that may lead to its subsequent service failure. It is important to note that many errors do not reach the system’s external state and cause a failure.

Threats to Dependability: Failures, Errors and Faults



A fault causes an error in the internal state of the system. The error causes the system to fail

Partial failure: Services implementing the functions may leave the system in a degraded mode that still offers a subset of needed services to the user. The specification may identify several such modes, e.g., slow service, limited service, emergency service, etc. Here, we say that the system has suffered a partial failure of its functionality or performance.

Means for achieving dependability

- A combined use of methods can be applied as means for achieving dependability. These means can be classified into:

1. **Fault Prevention techniques**

   to prevent the occurrence and introduction of faults

   – design review, component screening, testing, quality control methods, ...

   – formal methods

2. **Fault Tolerance techniques**

   to provide a service complying with the specification in spite of faults

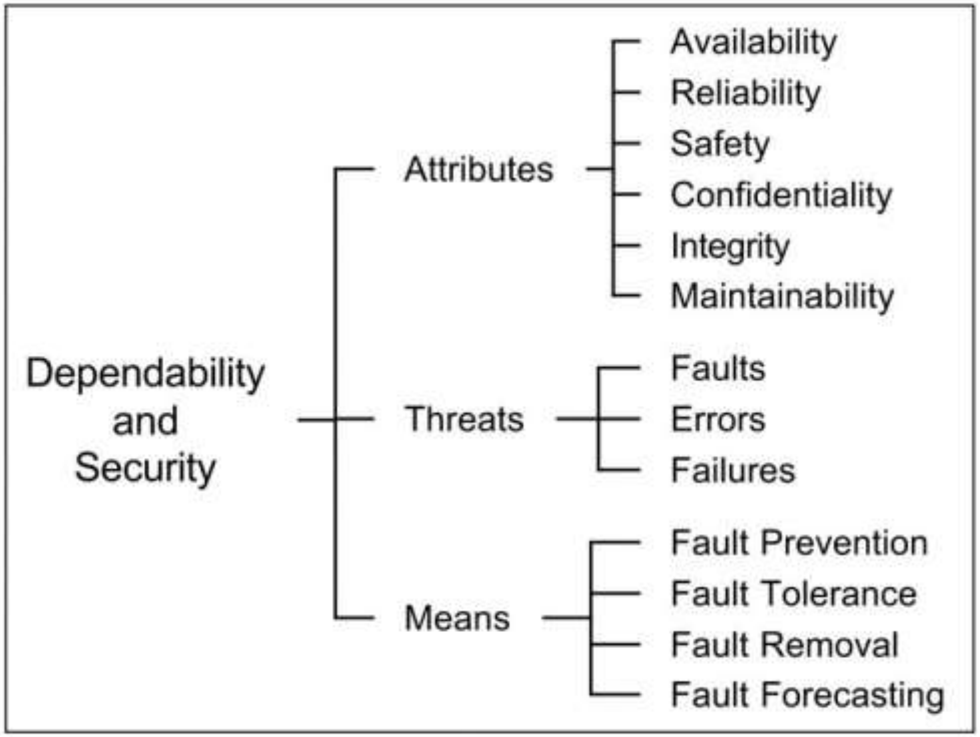
3. **Fault Removal techniques**

   to reduce the presence of faults (number,seriouness, ...)

4. **Fault Forecasting techniques**

   to estimate the present number, the future incidence, and the consequences of faults

Dependability tree



From A. Avizienis, J.C. Laprie, B. Randell, C. Landwehr. Basic Concepts and Taxonomy of Dependable and Secure Computing, IEEE Transactions on Dependable and Secure Computing, Vol. 1, N. 1, 2004

(*) Security: Availability, Confidentiality, Integrity

Threats to dependability

The life cycle of a system consists of two phases:

- development
- use

Development phase includes all activities from presentation of the user's initial concept to the decision that the system has passed all acceptance tests and is ready to deliver service in its user's environment. During the development phase, the system interacts with the development environment and development faults may be introduced into the system by the environment.

The development environment of a system consists of the following elements:

1. the physical world with its natural phenomena
2. human developers, some possibly lacking competence or having malicious objectives
3. development tools: software and hardware used by the developers to assist them in the developmen process
4. production and test facilities

The use phase of a system's life begins when the system is accepted for use and starts the delivery of its services to the users.

The system interacts with its use environment.

Threats to dependability

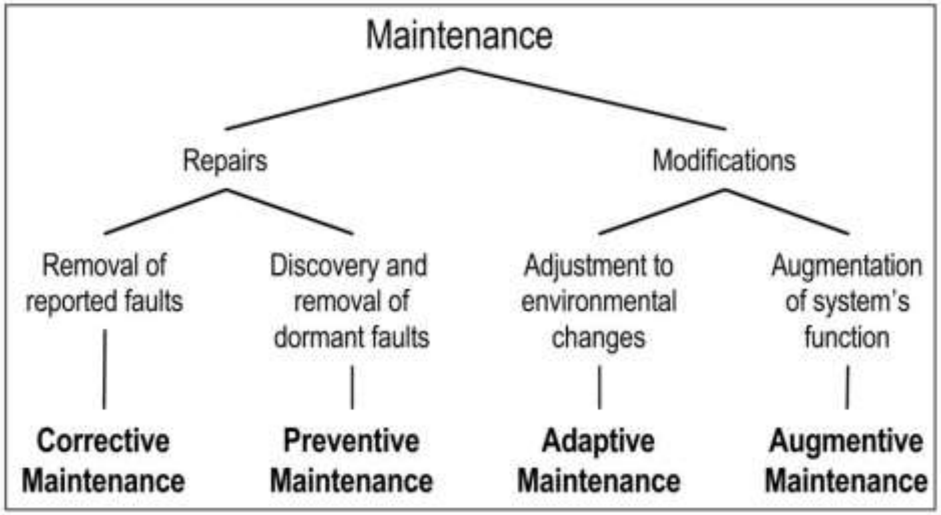
Use consists of alternating periods of correct service delivery (to be called service delivery), service outage, and service shutdown.

A service outage is caused by a service failure. It is the period when incorrect service (including no service at all) is delivered at the service interface.

A service shutdown is an intentional halt of service by an authorized entity.

Maintenance actions may take place during all three periods of the use phase. Maintenance, following common usage, includes not only repairs, but also all modifications of the system that take place during the use phase of system life.

Forms of Maintenance


Maintenance
Repairs
Modifications
Removal of reported faults
Discovery and removal of dormant faults
Adjustment to environmental changes
Augmentation of system's function
Corrective Maintenance
Preventive Maintenance
Adaptive Maintenance
Augmentive Maintenance

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

Furthermore, repair is part of fault removal (during the use phase), and fault forecasting usually considers repair situations. In fact, repair can be seen as a fault tolerance activity within a larger system that includes the system being repaired and the people and other systems that perform such repairs.