POLITECNICO
MILANO 1863

# Computing Infrastructures
# -
# System Dependability

## Reliabiltity and Availability

# The topics of the course: what are we going to see today?

## HW Infrastructures:

**System-level**: Computing Infrastructures and Data Center Architectures, Rack/Structure;

**Node-level**: Server (computation, HW accelerators), Storage (Type, technology), Networking (architecture and technology);

**Building-level**: Cooling systems, power supply, failure recovery

## SW Infrastructures:

**Virtualization**: Process/System VM, Virtualization Mechanisms (Hypervisor, Para/Full virtualization)

**Computing Architectures**: Cloud Computing (types, characteristics), Edge/Fog Computing, X-as-a service

## Methods:

**Reliability and availability of datacenters** (**definition**, **fundamental laws**, RBDs)

**Disk performance** (Type, Performance, RAID)

**Scalability and performance of datacenters** (definitions, fundamental laws, queuing network theory)

# What dependability is? (SLIDE Form the OVERVIEW SET)

- A measure of how much we trust a system…

  …from a microwave oven up to an airplane and a large datacenter!

- The ability of a system to perform its functionality while exposing:
  - **Reliability** — Continuity of correct service
  - **Availability** — Readiness for correct service
  - Maintainability — Ability for easy maintainance
  - Safety — Absence of catastrophic consequences
  - Security — Confidentiality and integrity of data

# Reliability

The ability of a system or component to perform its required functions under stated conditions for a specified period of time
[IEEE610]

[IEEE610]: IEEE Standard Glossary of Software Engineering Terminology, IEEE Std 610.12-1990 (R2002).

# definition



R(t): probability that the system will operate correctly in a specified operating environment until time *t*

$$R(t) = P(\text{not failed during } [0, t])$$

**assuming it was operating at time t = 0**

- *t* is important!
- If a system needs to work for slots of ten hours at a time, then ten hours is the reliability target
- Often used to characterize systems in which even small periods of incorrect behavior are unacceptable (e.g. Impossibility to repair)

# Characteristics



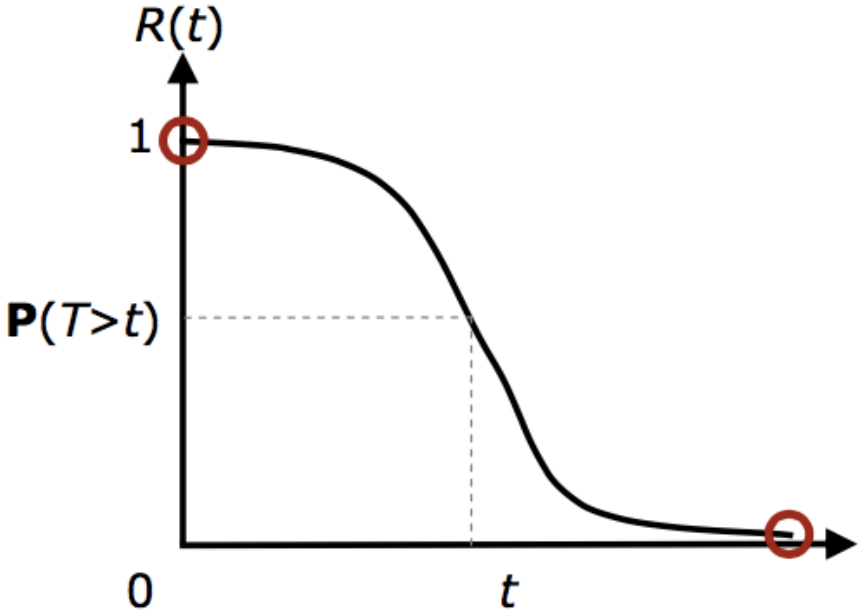
1 – R(*t*): unreliability, also denoted Q(*t*)

R(*t*) is a non-increasing function varying from 1 to 0 over [0,+∞)

$$R(0) = 1$$

$$\lim_{t \to +\infty} R(t) = 0$$

$$f(x) = -\frac{\mathrm{d}R(t)}{\mathrm{d}t}$$




probability density function of the failure

# Availability

The degree to which a system or component is operational and accessible when required for use [IEEE610]

– [IEEE610]: IEEE Standard Glossary of Software Engineering Terminology, IEEE Std 610.12-1990 (R2002).

Availability = Uptime / (Uptime + Downtime)

- Fundamentally different from reliability
  - "reliability: does not break down …"
  - "availability: even if it breaks down, it is working when needed…

- Any examples of designs requiring high reliability/availability?

# definition

Availability

$A(t)$: probability that the system will be operational at time $t$

$$A(t) = P(\text{not failed at time } t)$$

- Literally, readiness for service
- Admits the possibility of brief outages

- When the system is not repairable: $A(t) = R(t)$
- In general (repairable systems): $A(t) \geq R(t)$

- $1 - A(t)$: unavailability

# Some numbers



Availability as a function of the "number of 9's"

| Number of 9's | Availability | Downtime (mins/year) | Practical meaning |
|---|---|---|---|
| 1 | 90% | 52596.00 | ~5 weeks per year |
| 2 | 99% | 5259.60 | ~4 days per year |
| 3 | 99.9% | 525.96 | ~9 hours per year |
| 4 | 99.99% | 52.60 | ~1 hour per year |
| 5 | 99.999% | 5.26 | ~5 minutes per year |
| 6 | 99.9999% | 0.53 | ~30 secs per year |
| 7 | 99.99999% | 0.05 | ~3 secs per year |

# Some example

| Number of 9's | Availability | Downtime/year | System |
|---|---|---|---|
| 2 | 99% | ~4 days | Generic web site |
| 3 | 99.9% | ~9 hours | Amazon.com |
| 4 | 99.99% | ~1 hour | Enterprise server |
| 5 | 99.999% | ~5 minutes | Telephone system |
| 6 | 99.9999% | ~30 seconds | Network switches |

# R(t) & A(t): Two points of view



Of course, they are related:

- if a system is unavailable it is not delivering the specified system services

It is possible to have systems with low reliability that must be available

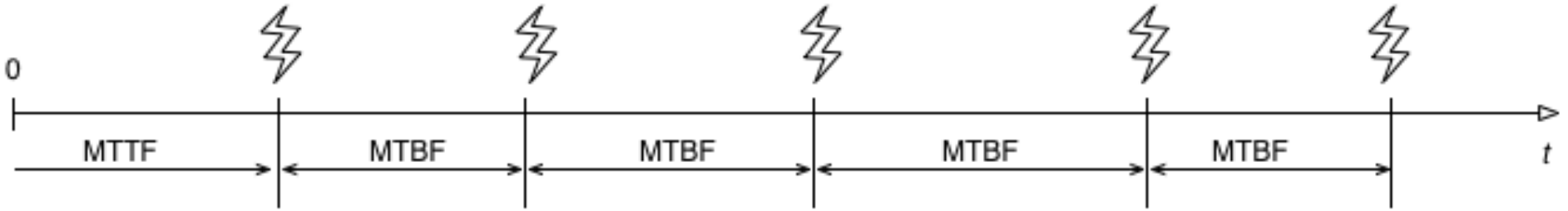
- system failures can be repaired quickly and do not damage data, low reliability may not be a problem (for example a database management system)

The opposite is generally more difficult…

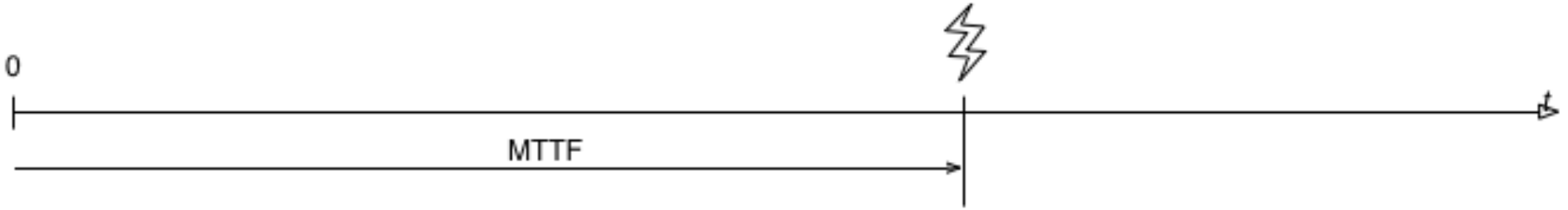
# R(t) & A(t) related indices

**MTTF (Mean Time To Failure)**: mean time before *any* failure will occur

**MTBF (Mean Time Between Failures)**: mean time between two failures



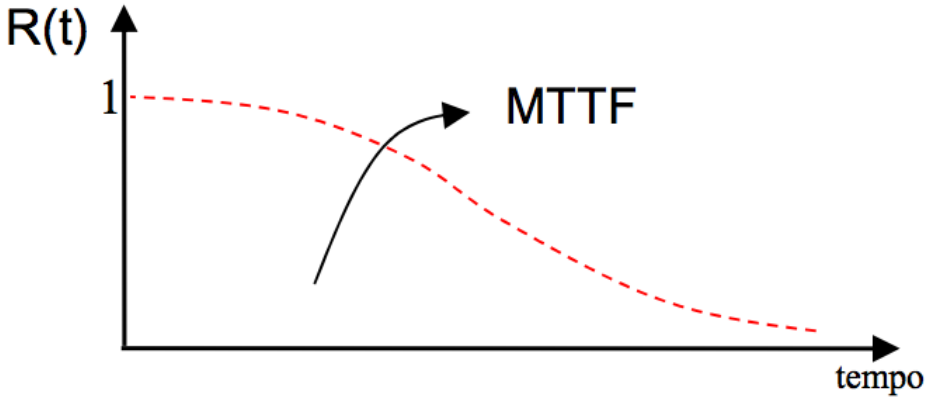

hypothesis: negligible repair time



# R(t) & A(t) related indices

**MTTF (Mean Time To Failure)**: mean time before *any* failure will occur

$$MTTF = \int_0^\infty R(t)dt$$



# R(t) & A(t) related indices

Other indices

**MTTF**: mean time to (first) failure, the up time before the first failure

**MTBF**: mean time between failures

$$\text{MTBF} = \frac{\text{total operating time}}{\text{number of failures}}$$

**FIT**: failures in time

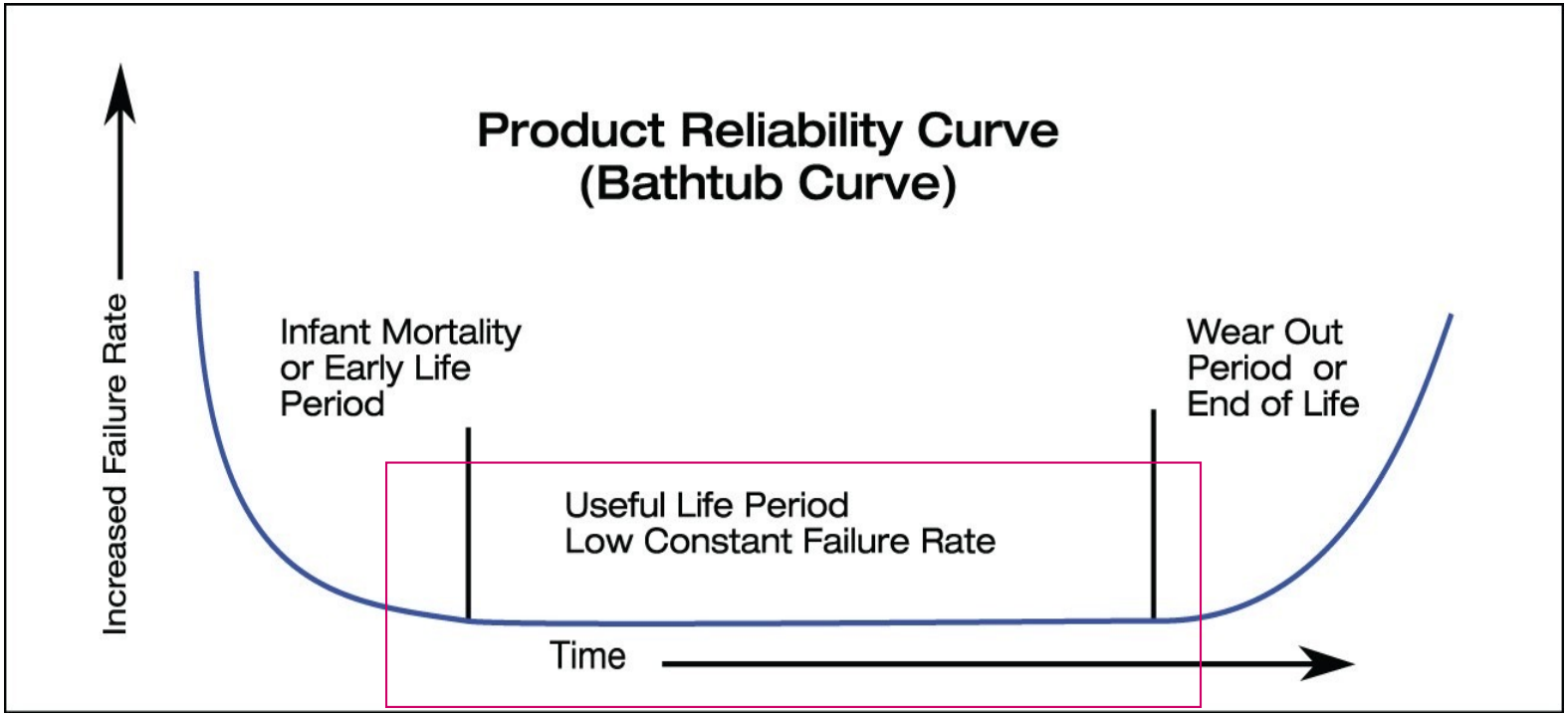
$$\text{Failure Rate } \lambda = \frac{\text{number of failures}}{\text{total operating time}}$$

- another way of reporting MTBF
- the number of expected failures per one billion hours ($10^9$) of operation for a device
- MTBF (in h) $=10^9/\text{FIT}$

$$\text{MTBF} = \frac{1}{\lambda}$$

# R(t) & A(t) related indices

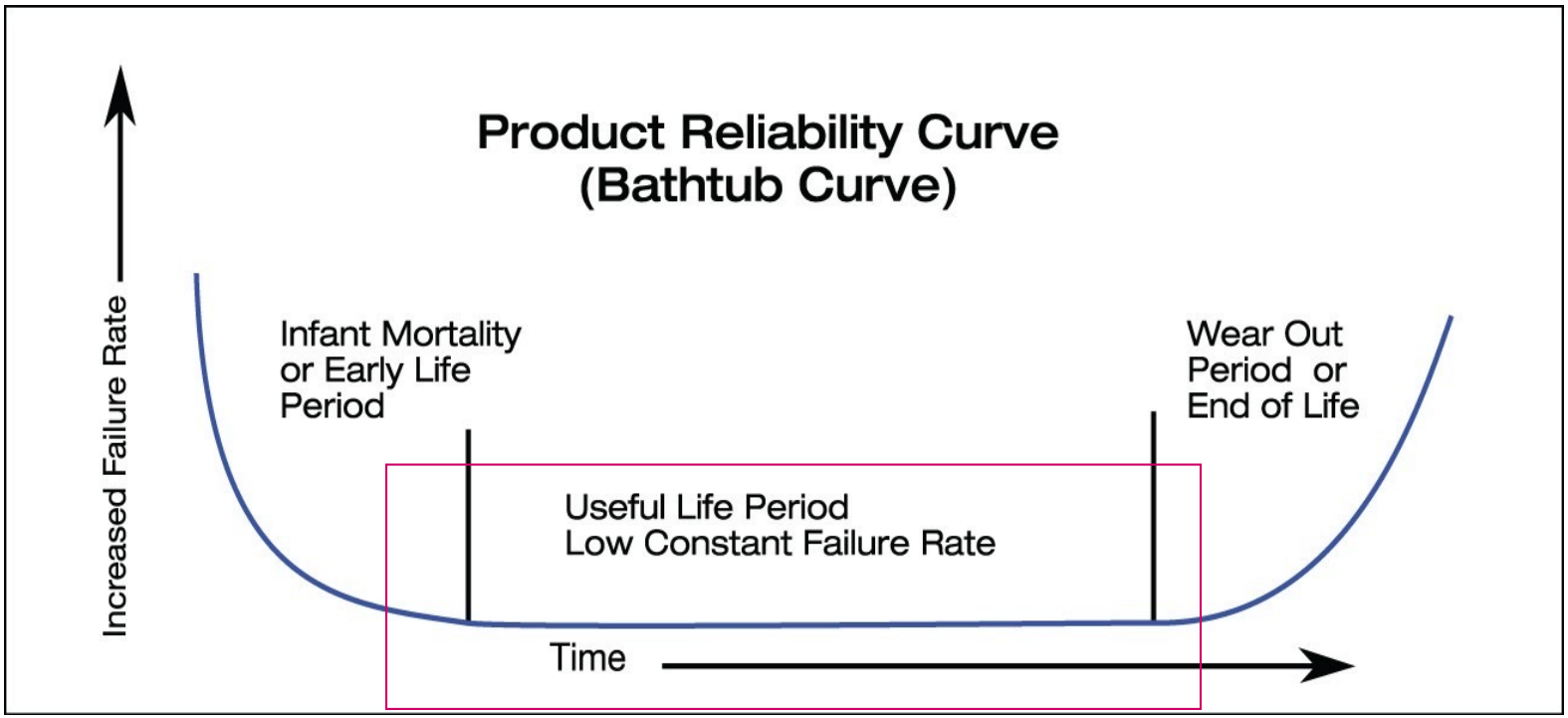
Other indices




- *Infant Mortality*: failures showing up in new systems. Usually this category is present during the testing phases, and not during production phases.
- *Random Failures*: showing up randomly during the entire life of a system.
  - **Our main focus**
- *Wear Out*: at the end of its life, some components can cause the failure of a system. **Predictive mainteinance** can reduce the number of this type of failures.

# R(t) & A(t) related indices



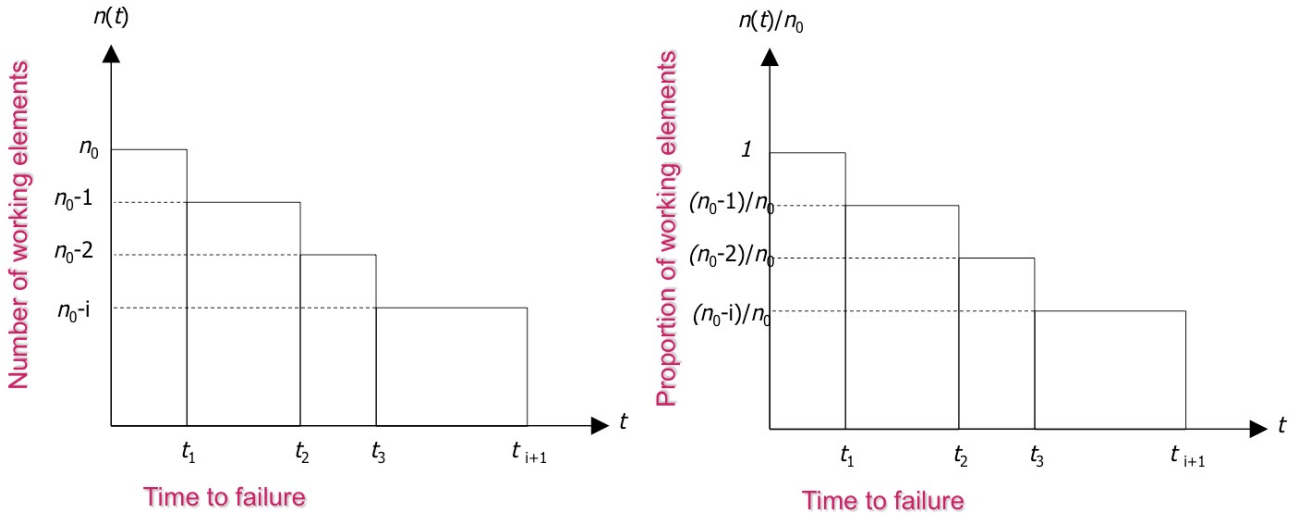



How to identify defective products and calculate MTTF?

Burn-in test: *stress* the system with excessive temperature, voltage, current, humidity so to accelerate wear out.

# How to compute reliability?
# Empirical Evaluation

- Let's consider $n_0$ independent and statistically identical elements deployed at time t = 0 in identical conditions $n(0) = n_0$
- At time t, n(t) elements are not failed
- $t_1, t_2, \ldots t_{n0}$ are the times to failure of the $n_0$ elements
  - times to failure are independent occurrences of the random quantity **T**



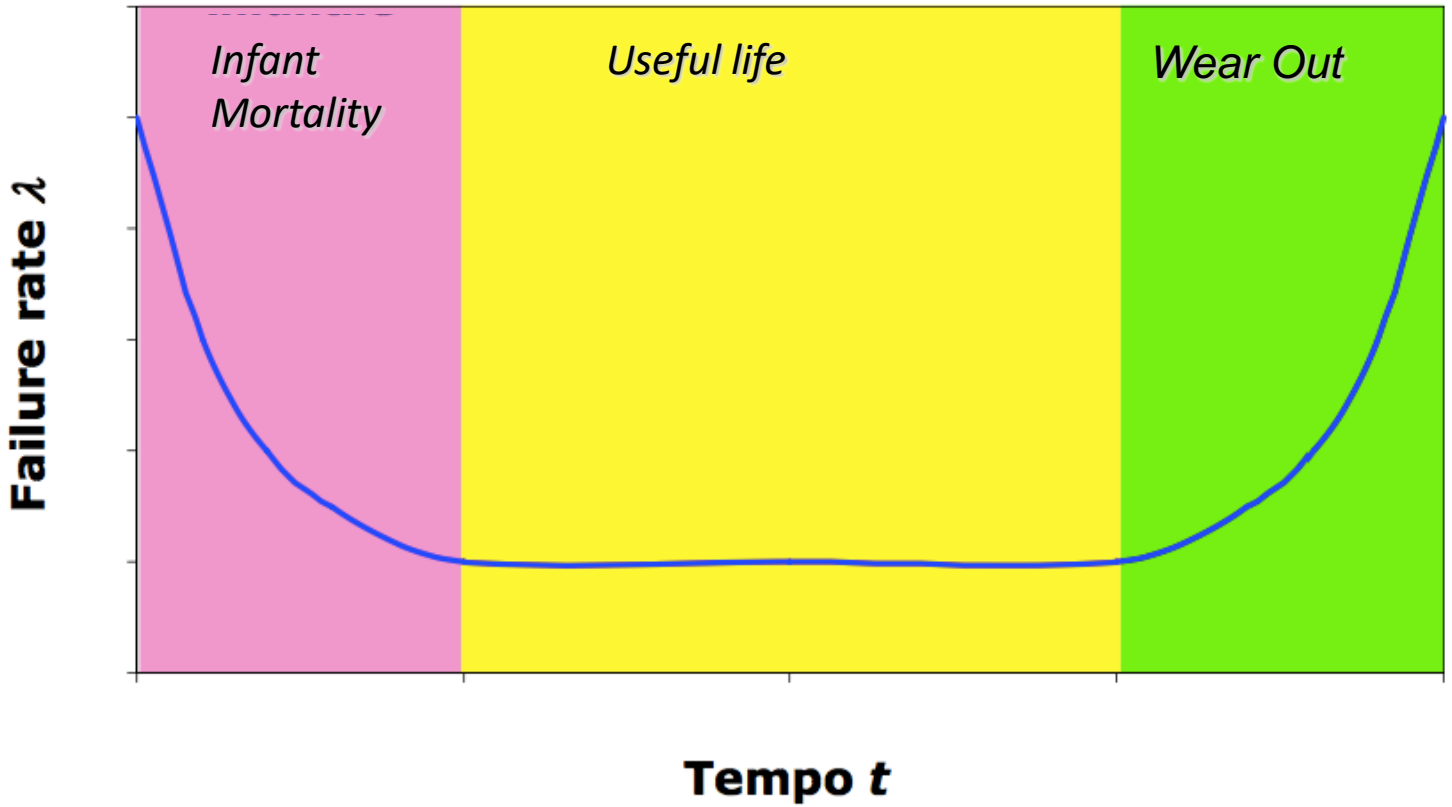

- Function $n(t) / n_0$ is the empirical function of reliability that as $n_0 \to \infty$ converges to the value: $n(t) / n_0 \to R(t)$

# Different types of faults

- **Hardware faults**:
  - Electronic
  - Mechanical

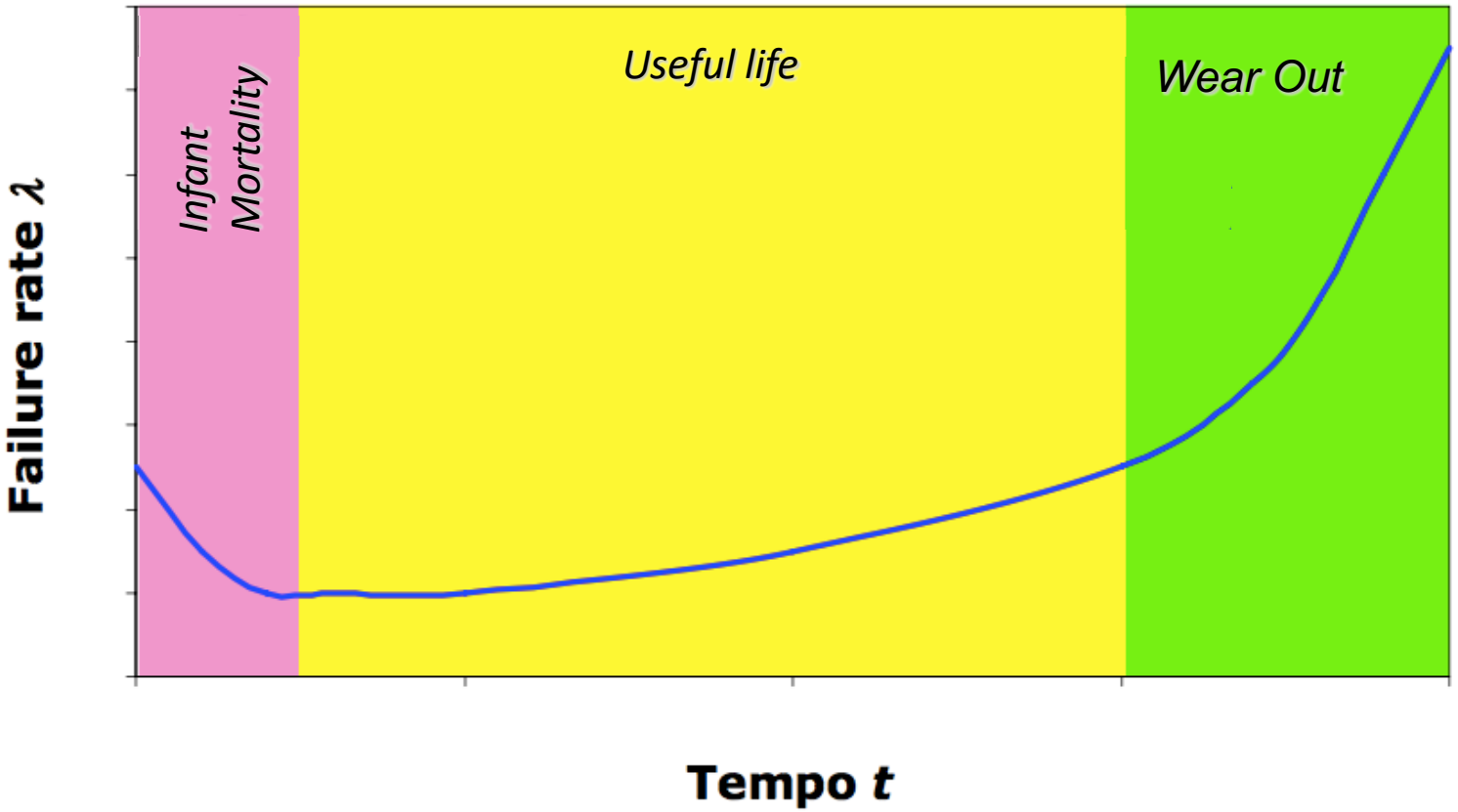

- **Software faults**:

# Hardware: electronic components



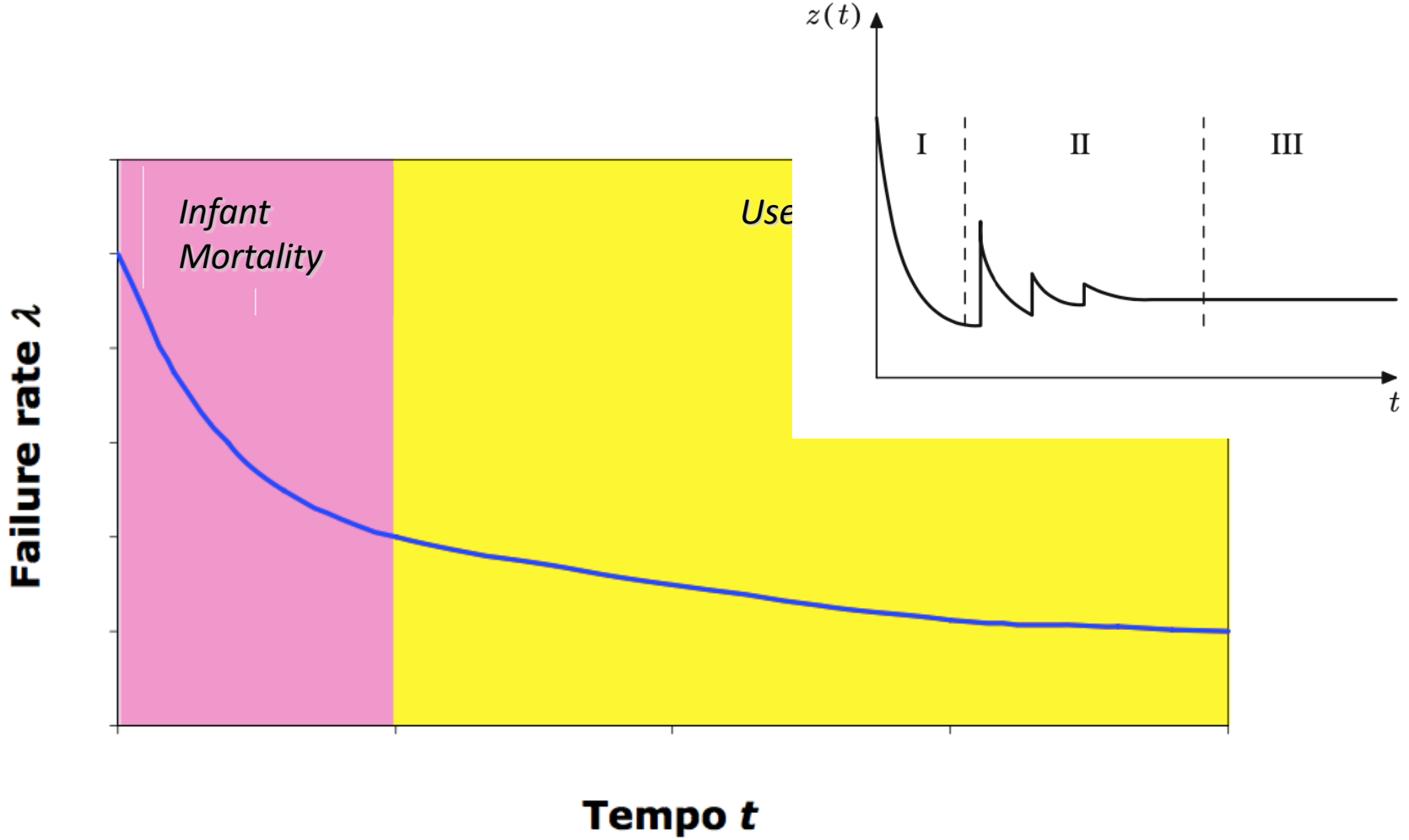
# Hardware: Mechanical components





# Software





# R(t) … what to do?

Exploitation of R(t) information is used to compute, for a complex system, its reliability in time, that is the expected lifetime

- computation of the MTTF

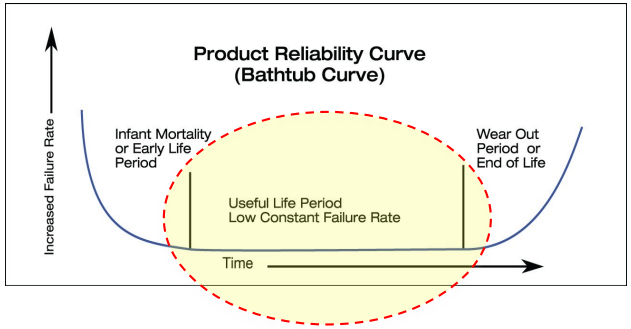
Computation of the overall reliability starting from the components' one

Within the course we consider only a reliability with an exponential distribution:

- Constant Failure rate

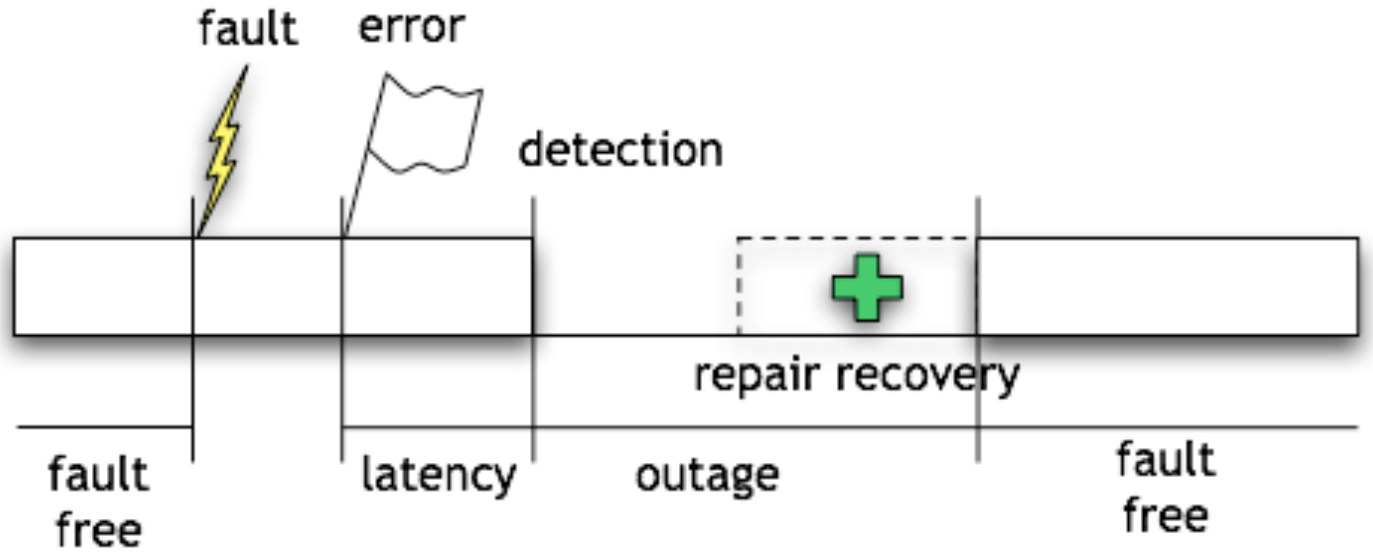
$$R(t) = e^{-\lambda t}$$

$$MTTF = \int_0^\infty R(t)\,dt = \frac{1}{\lambda}$$



# Reliability terminology

| Term | Description |
|---|---|
| Fault | A defect within the system |
| Error | A deviation from the required operation of the system or subsystem |
| Failure | The system fails to perform its required function |



# Reliability terminology

An example: a flying drone with an automatic radar-guided landing system

**Fault**: electromagnetic disturbances interfere with a radar measurement

**Error**: the radar-guided landing system calculates a wrong trajectory

**Failure**: the drone crashes to the ground

# Reliability terminology

Another example: a tele-surgery system

**Fault**: radioactive ions make some memory cells change value (bitflip)

**Error**: some frames of the video stream are corrupted

**Failure**: the surgeon kills the patient

# Reliability terminology

**Not always the *fault – error – failure chain* closes**

example: a tele-surgery system

**Fault**: radioactive ions make some memory cells change value (bitflip) but the corrupted memory does not involve the video stream

**Error**: no frames are corrupted

**Failure**: the surgeon carries out the procedure

# Reliability terminology

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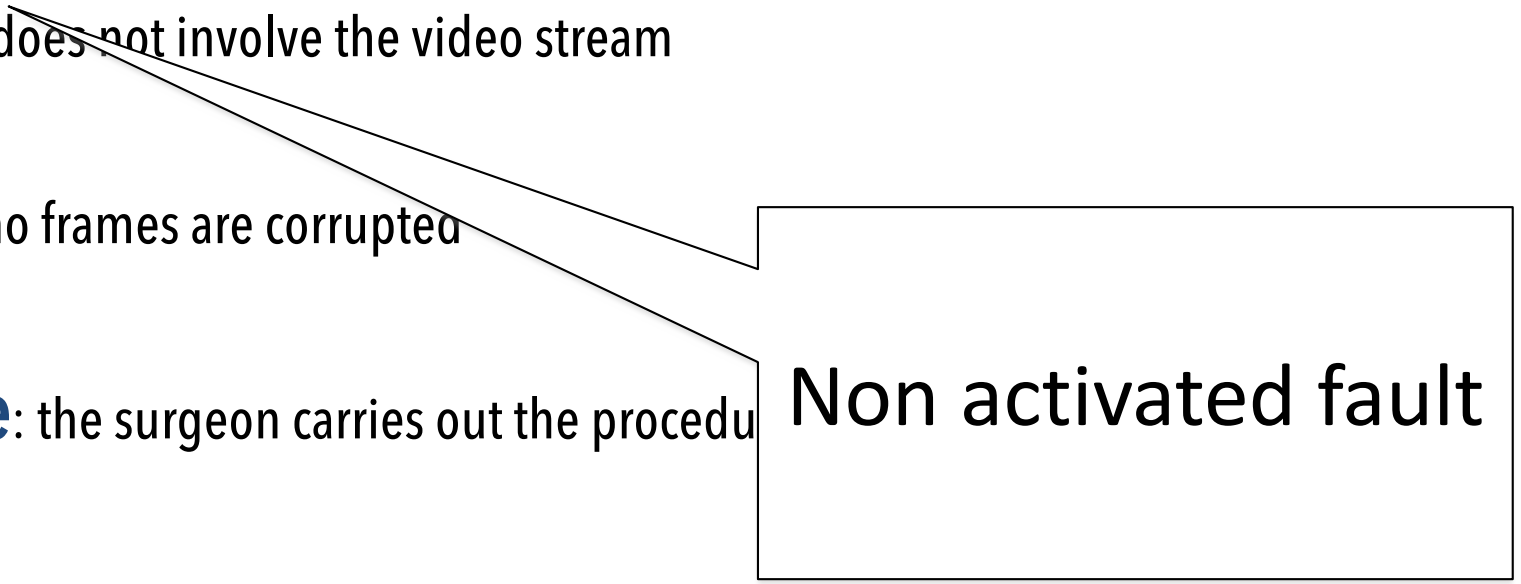

# Reliability terminology

**Not always the *fault – error – failure chain* closes**

example: a flying drone with automatic radar-guided landing

**Fault**: electromagnetic disturbances interfere with a radar measurement

**Error**: the radar-guided landing system calculates a wrong trajectory, but then, based on subsequent correct radar measurements it is able to recover the right trajectory

**Failure**: the drone safely lands

# Reliability terminology

**Not always the *fault – error – failure chain* closes**

example: a flying drone with automatic radar-guided landing

**Fault**: electromagnetic disturbances interfere with a radar measurement

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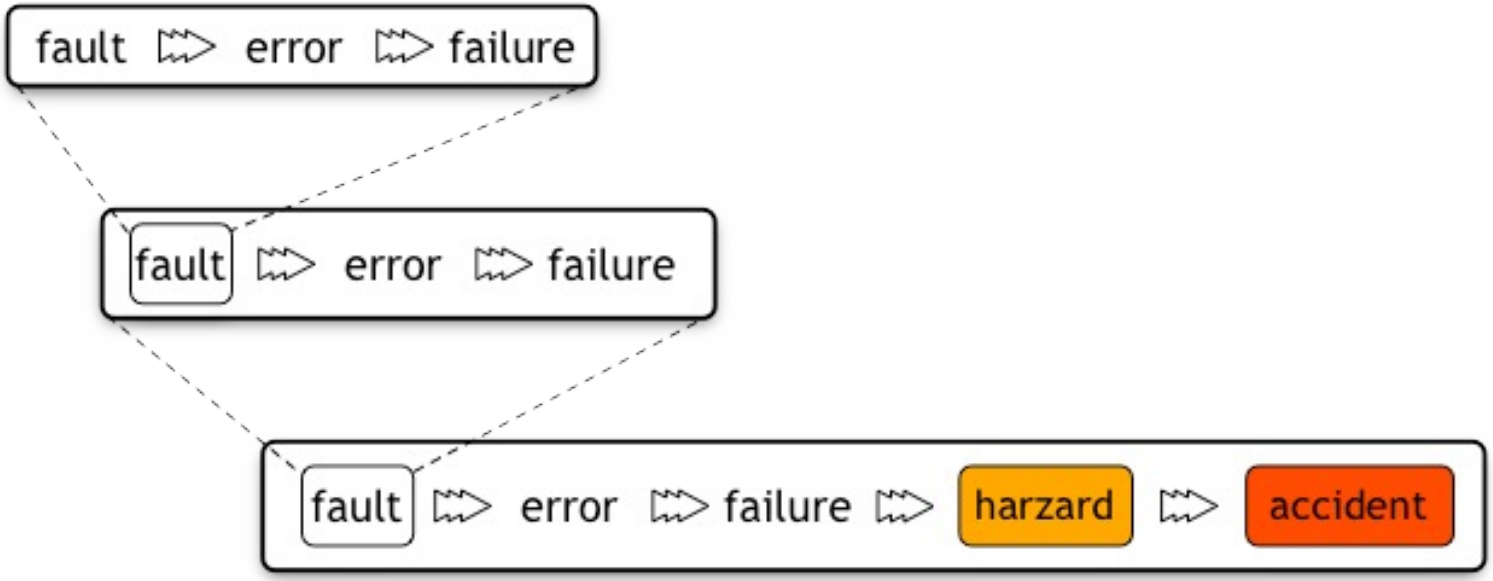
**Failure**: the drone safely lands

Non propagated (or absorbed) error

# Fault hierarchy




Fault-error-failure cascades can lead to life-threatening hazards