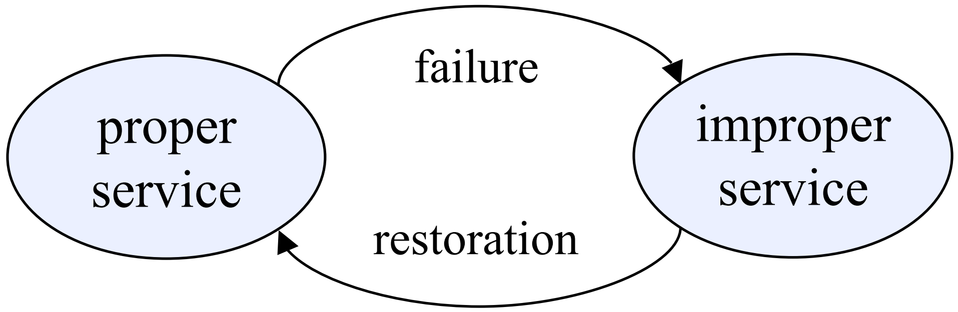
Dependability

- *Dependability* is the ability of a system to deliver a specified service.
- System service is classified as *proper* if it is delivered as specified; otherwise it is *improper*.
- System *failure* is a transition from proper to improper service.
- System *restoration* is a transition from improper to proper service.



⇒ The "properness" of service depends on the user's viewpoint!

Reference: J.C. Laprie (ed.), *Dependability: Basic Concepts and Terminology*, Springer-Verlag, 1992.

Examples of Specifications of Proper Service

- k out of N components are functioning.
- every working processor can communicate with every other working processor.
- every message is delivered within t milliseconds from the time it is sent.
- all messages are delivered in the same order to all working processors.
- the system does not reach an unsafe state.
- 90% of all remote procedure calls return within x seconds with a correct result.
- 99.999% of all telephone calls are correctly routed.

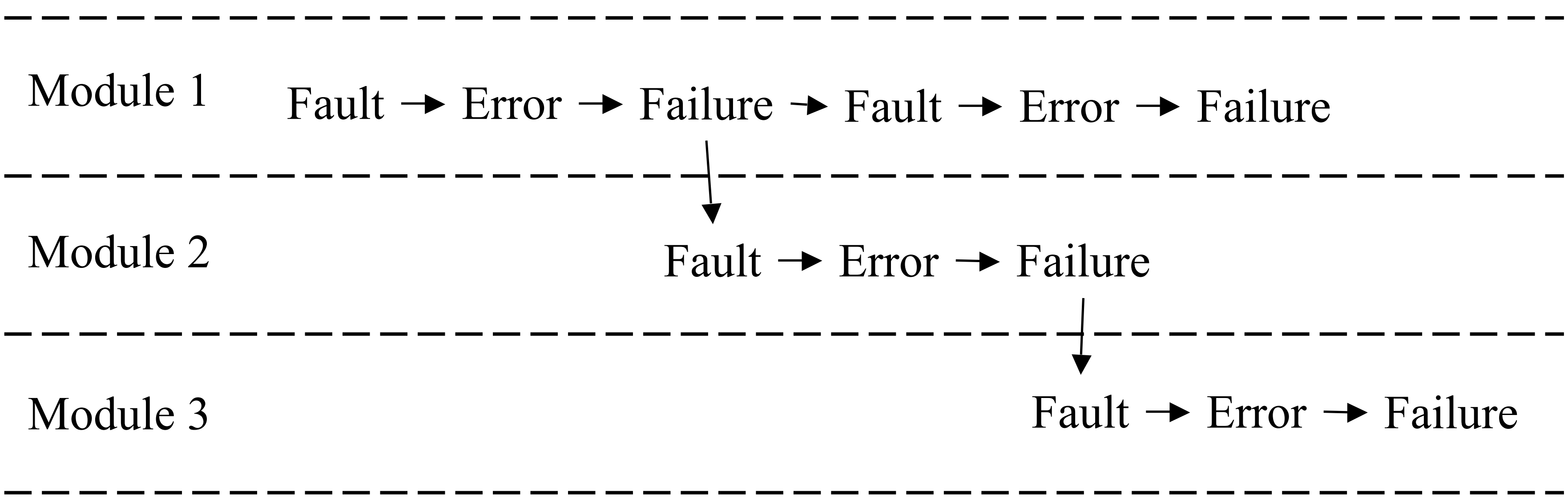
⇒ Notion of "proper service" provides a specification by which to evaluate a system's dependability.

Dependability Concepts

- *Measures* - properties expected from a dependable system
  - Availability
  - Reliability
  - Safety
  - Confidentiality
  - Integrity
  - Maintainability
  - Coverage
- *Means* - methods to achieve dependability
  - Fault Avoidance
  - Fault Tolerance
  - Fault Removal
  - Dependability Assessment
- *Impairments* - causes of undependable operation
  - Faults
  - Errors
  - Failures

Faults, Errors, and Failures can Cause Improper Service

- *Failure* - transition from proper to improper service
- *Error* - that part of system state that is liable to lead to subsequent failure
- *Fault* - the hypothesized cause of error(s)



Dependability Measures: Availability

Availability - quantifies the alternation between deliveries of proper and improper service.

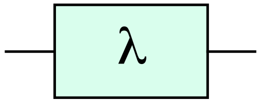
- $A(t)$ is 1 if service is proper at time t, 0 otherwise.
- $E[A(t)]$ (Expected value of $A(t)$) is the probability that service is proper at time t.
- $A(0,t)$ is the fraction of time the system delivers proper service during $[0,t]$.
- $E[A(0,t)]$ is the expected fraction of time service is proper during $[0,t]$.
- $P[A(0,t) > t^*]$ $(0 \le t^* \le 1)$ is the probability that service is proper more than $100t^*$% of the time during $[0,t]$.
- $A(0,t)_{t\rightarrow\infty}$ is the fraction of time that service is proper in steady state.
- $E[A(0,t)_{t\rightarrow\infty}]$, $P[A(0,t)_{t\rightarrow\infty} > t^*]$ as above.

Other Dependability Measures

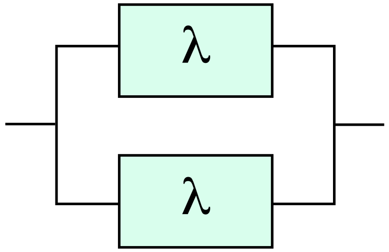
- *Reliability* - a measure of the continuous delivery of service
  - $R(t)$ is the probability that a system delivers proper service throughout $[0,t]$.
- *Safety* - a measure of the time to catastrophic failure
  - $S(t)$ is the probability that no catastrophic failures occur during $[0,t]$.
  - Analogous to reliability, but concerned with catastrophic failures.
- *Time to Failure* - measure of the time to failure from last restoration. (Expected value of this measure is referred to as *MTTF - Mean time to failure*.)
- *Maintainability* - measure of the time to restoration from last experienced failure. (Expected value of this measure is referred to as *MTTR - Mean time to repair*.)
- *Coverage* - the probability that, given a fault, the system can tolerate the fault and continue to deliver proper service.

Illustration of the Impact of Coverage on Dependability

- Consider two well-known architectures: simplex and duplex.

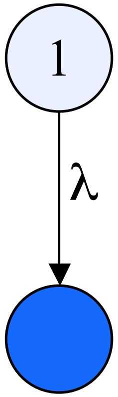


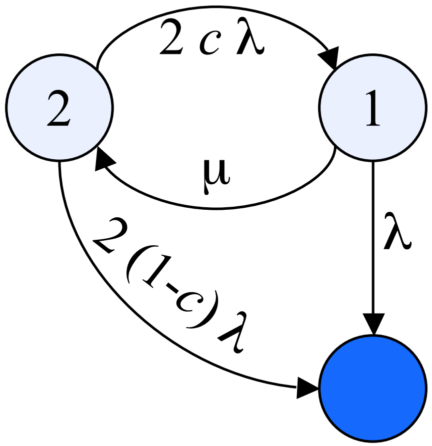
Simplex System



Duplex System

- The Markov model for both architectures is:

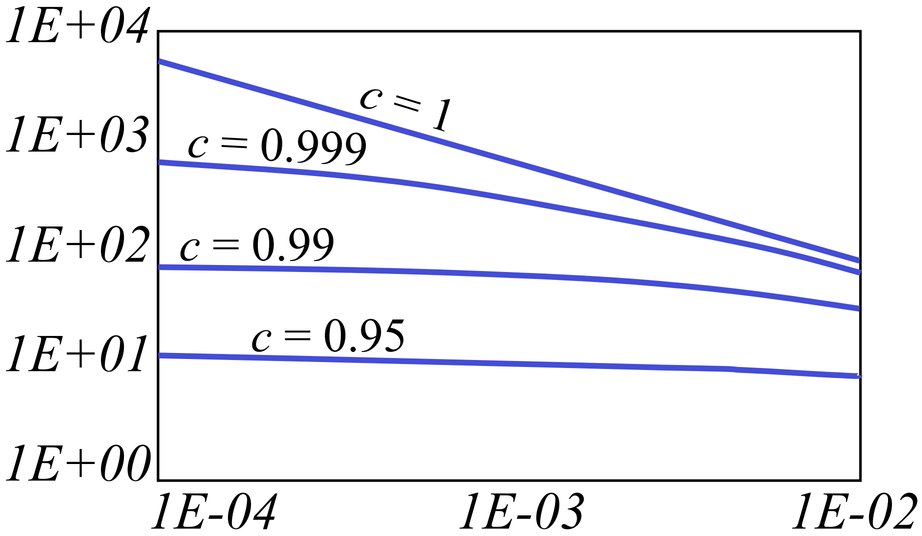




- The analytical expression of the MTTF can be calculated for each architecture using these Markov models.

Illustration of the Impact of Coverage, cont.

- The following plot shows the ratio of MTTF (duplex)/MTTF (simplex) for different values of coverage (all other parameter values being the same).
- The ratio shows the dependability gain by the duplex architecture.



Ratio of failure rate to repair rate $\left(\frac{\lambda}{\mu}\right)$

- We observe that the coverage of the detection mechanism has a significant impact on the gain: a change of coverage of only 10^{-3} reduces the gain in dependability by the duplex system by a full order of magnitude.

Failure Sources and Frequencies

<u>Non-Fault-Tolerant Systems</u>

– Japan, 1383 organizations (Watanabe 1986, Siewiorek & Swarz 1992)

– USA, 450 companies (FIND/SVP 1993)

Mean time to failure: 6 to 12 weeks

Average outage duration after failure:

1 to 4 hours

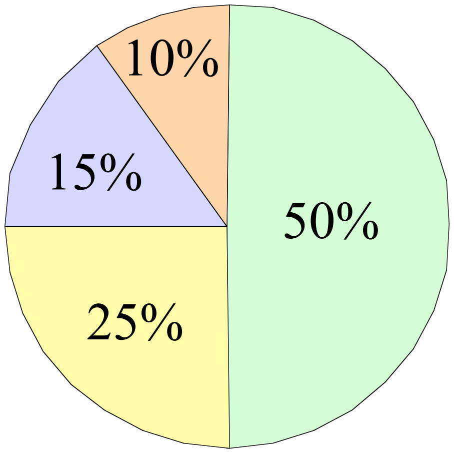
<u>Fault-Tolerant Systems</u>

– Tandem Computers (Gray 1990)

– Bell Northern Research (Cramp et al. 1992)

Mean time to failure:

21 years (Tandem)



<u>Failure Sources:</u>

- Hardware
- Software
- Communications Environment
- Operations-Procedures