Fault Tolerance Measures
♦ It is important to have proper yardsticks - measures - by which to measure the effect of fault tolerance
♦ A measure is a mathematical abstraction, which expresses only some subset of the object's nature
♦ Measures?

Traditional Measures - Reliability
♦ Assumption: The system can be in one of two states: "up" or "down"
♦ Examples:
  - Lightbulb - good or burned out
  - Wire - connected or broken
♦ Reliability, R(t):
  Probability that the system is up during the whole interval [0,t], given it was up at time 0
♦ Related measure - Mean Time To Failure, MTTF:
  Average time the system remains up before it goes down and has to be repaired or replaced

Traditional Measures - Availability
♦ Availability, A(t):
  Fraction of time system is up during the interval [0,t]
♦ Point Availability, A_p(t):
  Probability that the system is up at time t
♦ Long-Term Availability, A:
  \( A = \lim_{t \to \infty} A(t) = \lim_{t \to \infty} A_p(t) \)
♦ Availability is used in systems with recovery/repair
♦ Related measures:
  - Mean Time To Repair, MTTR
  - Mean Time Between Failures, MTBF = MTTF + MTTR
  \( A = \frac{MTTF}{MTBF} \)

Need For More Measures
♦ The assumption of the system being in state "up" or "down" is very limiting
♦ Example: A processor with one of its several hundreds of millions of gates stuck at logic value 0 and the rest is functional - may affect the output of the processor once in every 25,000 hours of use
♦ The processor is not fault-free, but cannot be defined as being "down"
♦ More detailed measures than the general reliability and availability are needed

Computational Capacity Measures
Example: N processors in a gracefully degrading system
♦ System is useful as long as at least one processor remains operational
♦ Let \( p_i \) = Prob \( i \) processors are operational
  \( R(t) = \sum p_i \)
♦ Let \( c \) = computational capacity of a processor (e.g., number of fixed-size tasks it can execute)
♦ Computational capacity of \( i \) processors: \( C_i = i \times c \)
♦ Average computational capacity of system:
  \( \sum_{i=1}^{N} C_i \)
Another Measure - Performability

- Another approach - consider everything from the perspective of the application
- Application is used to define "accomplishment levels" L1, L2, ..., Ln
- Each represents a level of quality of service delivered by the application
  - Example: Li indicates i system crashes during the mission time period T
- Performability is a vector (P(L1), P(L2), ..., P(Ln)) where P(Li) is the probability that the computer functions well enough to permit the application to reach up to accomplishment level Li

Network Connectivity Measures

- Focus on the network that connects the processors
- Classical Node and Line Connectivity - the minimum number of nodes and lines, respectively, that have to fail before the network becomes disconnected
  - Measure indicates how vulnerable the network is to disconnection
  - A network disconnected by the failure of just one (critically-positioned) node is potentially more vulnerable than another which requires several nodes to fail before it becomes disconnected

Connectivity - Examples

Network N1

Network N2

Network Resilience Measures

- Classical connectivity distinguishes between only two network states: connected and disconnected
  - It says nothing about how the network degrades as nodes fail before becoming disconnected
  - Two possible resilience measures:
    - Average node-pair distance
    - Network diameter - maximum node-pair distance
  - Both calculated given probability of node and/or link failure