CSE 515 — Winter 2004

Dependable Distributed Systems

Class 9

Two Top-level Topics:

1. Taxonomy
   – Terminology
   – Mapping the space of dependability
2. Paradigms for distributed fault tolerance
   – A high-level view of the ways that we can build fault-tolerance into a distributed system.

What's the connection between...

... fault tolerance and distribution?

- Distribution needs fault tolerance
- Fault tolerance needs distribution

Taxonomy

Why bother?

1.
2.

Faults, Errors and Failures

- Fault
  - An *event* (presumably, undesired)
- Error
  - A *state* (presumably bad) internal to the (sub-) system
- Failure
  - externally observable behavior of (sub-)system no longer meets its specification
  - requires the existence of a specification!

Fault Models

Why do we need a fault model?

- There is always some catastrophe too serious too be tolerated
- Dependability is not free

When building a distributed system:

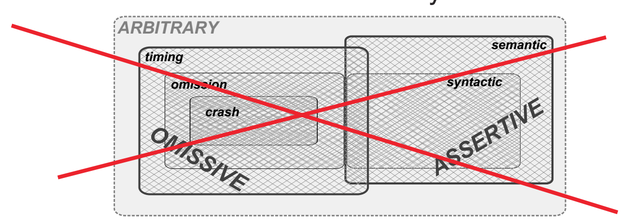
- we need a way of describing the faults despite which we must be dependable
- We focus on *interaction* faults

Omissive Faults

- Omission: some component does not engage in a particular interaction (ever)
- Crash: some component does not engage in an interaction, nor in any of the subsequent interactions. Also known as “fail stop”
- Timing: some component does not engage in a particular interaction at the right time
  - All omissive faults are in the time dimension

Assertive faults

- The data communicated in an interaction are wrong
  - *Syntactically* wrong, *e.g.*, packet format is out of conformance to protocol
  - *Semantically* wrong, e.g., packet format is OK, but data does not conform to reality



Consistency Faults

- If a component is specified as interacting with other components in multiple ways, we can also get consistency faults, *e.g.*,
  - a multicast message might be sent to some peers but not to others — *inconsistent omission*
  - it might not be sent at all — *consistent omission*
  - the "copies" of the messages might have different contents — *inconsistent assertive*

Coverage

We might be asked: how likely is it that this system will be dependable?

- To answer such a question, we must first ask: in the face of what eventualities?
  - Environmental assumption: probability that the environment will behave as we have assumed
    - temperature in given range, not more than assumed number of faults of the assumed kind
  - Operational assumptions: probability that the programs will do what we have assumed

How do computers fail?

- Gray (1986) study:
  - 42%: incorrect system administration
  - 25%: buggy software
  - 18%: hardware
  - 14%: environmental
    - (9% power failures > 4 hours)
  - 3%: other
- Some categories more under-reported than others.

Strategies for Dependability

1. Avoid or mask all of the faults that you can
2. Tolerate the rest
   - prevent the fault causing an error, or
   - prevent the error from causing a failure
3. Provide for recovery if a failure does occur
   - Not always possible, *e.g.*, with aeroplane flight control

Fault Tolerance

Fault tolerance comes through *redundancy* in space, time and value

- *space* redundancy: several copies of the same component, *e.g.*, disks, servers
- *time* redundancy: repeat the action, *e.g.*, send multiple copies of message, restart failed computation (after a Heisenbug)
- *value* redundancy: add extra data, e.g., error correcting codes, signatures

Error processing

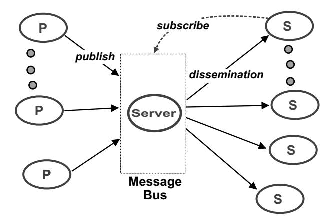
1. Detect the error
   - time-outs
   - value redundancy
2. Recover from it
   - backward error recovery, e.g., retransmit lost message, restore from checkpoint
   - forward error recovery, i.e., continue on, correcting effects of the error
3. Mask the error
   - in a lower level component, e.g. process-pair.

Modularity

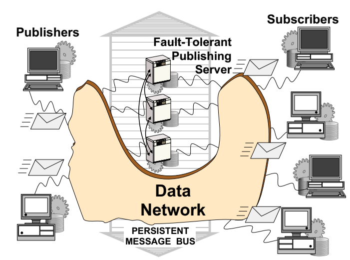
- Modularity is the key to fault tolerance
  - allows for independence of hardware and software components
  - allows for replication of components
  - allows a component to be replaced by a sub-system of higher dependability
  - allows graceful degradation to a lower level of service

Modularity and Publish-Subscribe

–Conceptual (V&R Fig 3.21)



Fault-tolerant (V&R Fig 6.9(b)



Distributed Fault-tolerance: How to get it

1. Failure Detection
2. Membership
3. Communication
4. Replication management
5. Resiliance
6. Recovery

Failure Detection

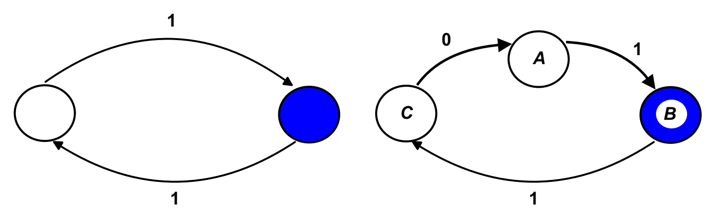
- To recover from a failure, you have to detect it first
- Even if you can mask the failure, you still need to detect it
  - Why?
- Failure detectors can fail!
- A detcetor is
  - *accurate*, if correct processes are not labeled "failed"
  - *complete*: failed processes are eventually reported

Local Failure Detectors

- Assume perfect channel between detector and target
  - Watch-dog components
  - self checking routines or boards
- Timeliness may still be a problem

$n \geq 2f + 1$

- In (a), it is impossible to tell which node is faulty
- In (b) if we know that $f = 1$ (at most 1 node is faulty), it must be node B



(a) (b)

Distributed Failure Detection

- Perfect failure detectors: (*strong accuracy* & *strong completeness*) possible if
  - failures are crashes
  - system is synchronous
  - channel is perfect, or omissions are bounded
- Normally, failure detectors are imperfect:
  - no bounds on channel failure
  - no bounds on delay

FLP Incompleteness

Fischer, Lynch & Paterson 1985

- In an asynchronous system with one faulty processor, it's impossible to guarantee consensus.
- An *eventually weak* failure detector (p199) would enable one to reach consesus.
- So:
  - deduce that it's impossible to build even an eventually weak failure detector in an asynchronous system