Distributed Systems
Master of Science in Engineering in Computer Science

AA 2020/2021

LECTURE 4: FAILURE DETECTION

Recap on Timing Assumptions

Synchronous

- timing assumptions are <u>explicit</u> either on
  - Bounds on process executions and communication channels, or
  - Existence of a common global clock, or
  - Both

achieve perfect clock synchronization.

Asynchronous

- there are no timing assumptions explicitly.

Recap on Timing Assumptions

Partial synchrony requires abstract timing assumptions (after an unknown time t the system becomes synchronous)

Two choices: from design pov → Synch/Async . —

1. Put assumption on the system model (including links and processes)
2. Create a separate abstractions that encapsulates those timing assumptions

into an oracle that may info depending on time ass.

Note: manipulating time inside a protocol/algorithm is complex and the correctness proof may become very involved and sometimes prone to errors

Failure Detector Abstraction

Software module to be used together with process and link abstractions

It encapsulates timing assumptions of either partially synchronous or fully synchronous system

The stronger are the timing assumption, the more accurate the information provided by a failure detector will be.

Described by two properties:

- Accuracy (informally is the ability to avoid mistakes in the detection)
- Completeness (informally is ability to detect all failures)

Perfect Failure detectors (P)

System model

- synchronous system
- crash failures

Using its own clock and the bounds of the synchrony model, a process can infer if another process has crashed

Perfect failure detectors (P) Specification

Module 2.6: Interface and properties of the perfect failure detector

Module:

Name: PerfectFailureDetector, **instance** $\mathcal{P}$.

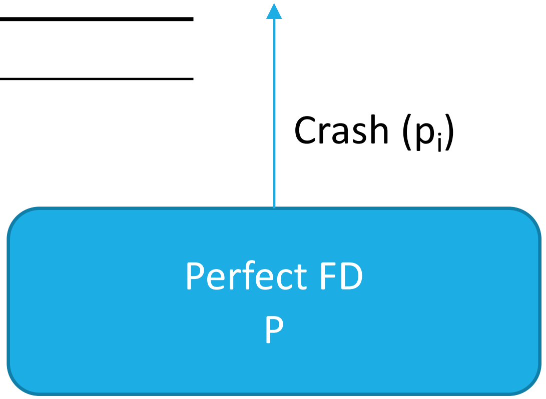
Events:

Indication: $\langle\, \mathcal{P}, \mathit{Crash} \mid p \,\rangle$: Detects that process p has crashed.

Properties:

PFD1: *Strong completeness:* Eventually, every process that crashes is permanently detected by every correct process.

PFD2: *Strong accuracy:* If a process p is detected by any process, then p has crashed.



Perfect failure detectors (P) Implementation

Algorithm 2.5: Exclude on Timeout

Implements:
PerfectFailureDetector, **instance** $\mathcal{P}$.

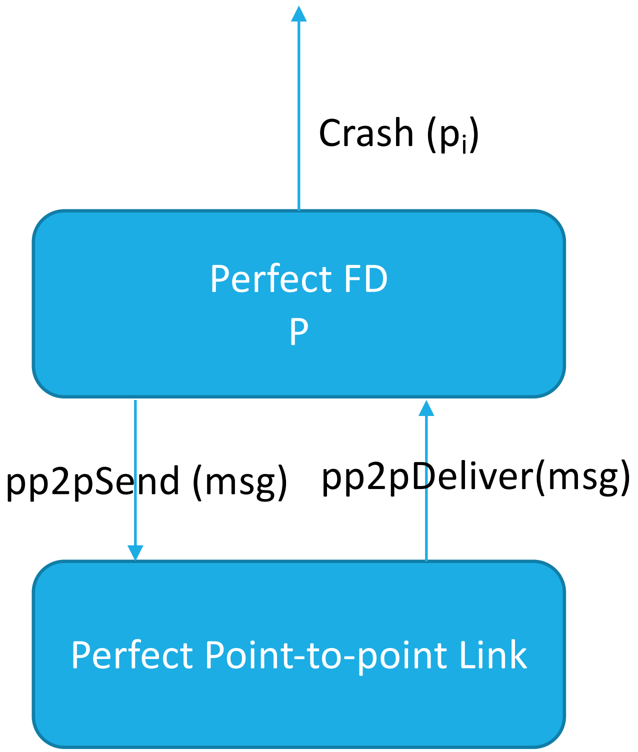
Uses:
PerfectPointToPointLinks, **instance** *pl*.

upon event $\langle\, \mathcal{P}, \mathit{Init}\, \rangle$ **do**
    $\mathit{alive} := \Pi$;
    $\mathit{detected} := \emptyset$;
    $\mathit{starttimer}(\Delta)$;

upon event $\langle\, \mathit{Timeout}\, \rangle$ **do**
    forall $p \in \Pi$ **do**
        if $(p \notin \mathit{alive}) \wedge (p \notin \mathit{detected})$ **then**
            $\mathit{detected} := \mathit{detected} \cup \{p\}$;
            trigger $\langle\, \mathcal{P}, \mathit{Crash} \mid p\, \rangle$;
        trigger $\langle\, \mathit{pl}, \mathit{Send} \mid p, [\text{HEARTBEATREQUEST}]\, \rangle$;
    $\mathit{alive} := \emptyset$;
    $\mathit{starttimer}(\Delta)$;

upon event $\langle\, \mathit{pl}, \mathit{Deliver} \mid q, [\text{HEARTBEATREQUEST}]\, \rangle$ **do**
    trigger $\langle\, \mathit{pl}, \mathit{Send} \mid q, [\text{HEARTBEATREPLY}]\, \rangle$;

upon event $\langle\, \mathit{pl}, \mathit{Deliver} \mid p, [\text{HEARTBEATREPLY}]\, \rangle$ **do**
    $\mathit{alive} := \mathit{alive} \cup \{p\}$;



Correctness

- To prove the correctness we must prove that both Strong Completeness and Strong Accuracy are satisfied

- What if links are fair loss?

- What if we select a timeout too long?

- What if we select a timeout too short?

Eventually perfect failure detectors (◊P)

System model

- partial synchrony
- Crash failures
- Perfect point-to-point links

Crashes can be accurately detected only after a (unknown) time *t*

- Before time *t* the systems behaves as an asynchronous one
- The failure detector may make mistake before time *t* considering correct processes as crashed.
- The notion of detection becomes suspicious

Eventually perfect failure detectors (◊P) Specification

Module 2.8: Interface and properties of the eventually perfect failure detector

Module:

Name: EventuallyPerfectFailureDetector, **instance** $\diamond\mathcal{P}$.

Events:

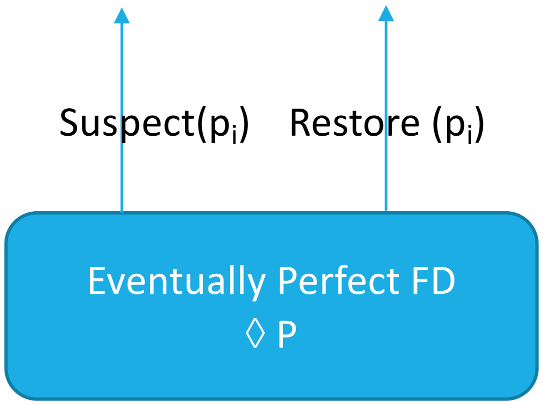
Indication: $\langle\ \diamond\mathcal{P}, \textit{Suspect} \mid p\ \rangle$: Notifies that process p is suspected to have crashed.

Indication: $\langle\ \diamond\mathcal{P}, \textit{Restore} \mid p\ \rangle$: Notifies that process p is not suspected anymore.

Properties:

EPFD1: *Strong completeness:* Eventually, every process that crashes is permanently suspected by every correct process.

EPFD2: *Eventual strong accuracy:* Eventually, no correct process is suspected by any correct process.



Basic constructions rules of an eventually perfect FD

- Use timeouts to suspect processes that did not sent expected messages
- A suspect may be wrong
  - A process p_i may suspect another one p_j as the current timeout is too short
- ◊ P is ready to reverse its judgment as soon as it receives a message from p_j
  - In this case, the timeout value is updated
- If p_j has actually crashed, p_i does not change its judgment anymore.

Eventually perfect failure detectors (◊P) Implementation

Algorithm 2.7: Increasing Timeout

Implements:
EventuallyPerfectFailureDetector, **instance** $\Diamond\mathcal{P}$.

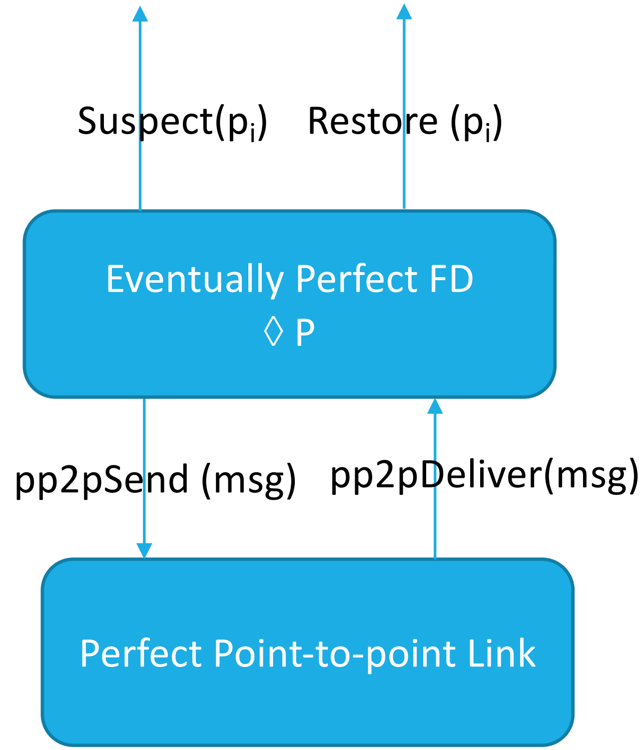
Uses:
PerfectPointToPointLinks, **instance** *pl*.

upon event $\langle\, \Diamond\mathcal{P}, \mathit{Init} \,\rangle$ **do**
  $\mathit{alive} := \Pi$;
  $\mathit{suspected} := \emptyset$;
  $\mathit{delay} := \Delta$;
  $\mathit{starttimer}(\mathit{delay})$;

upon event $\langle\, \mathit{Timeout} \,\rangle$ **do**
  if $\mathit{alive} \cap \mathit{suspected} \neq \emptyset$ **then**
    $\mathit{delay} := \mathit{delay} + \Delta$;
  forall $p \in \Pi$ **do**
    if $(p \notin \mathit{alive}) \wedge (p \notin \mathit{suspected})$ **then**
      $\mathit{suspected} := \mathit{suspected} \cup \{p\}$;
      trigger $\langle\, \Diamond\mathcal{P}, \mathit{Suspect} \mid p \,\rangle$;
    else if $(p \in \mathit{alive}) \wedge (p \in \mathit{suspected})$ **then**
      $\mathit{suspected} := \mathit{suspected} \setminus \{p\}$;
      trigger $\langle\, \Diamond\mathcal{P}, \mathit{Restore} \mid p \,\rangle$;
    trigger $\langle\, pl, \mathit{Send} \mid p, [\textsc{HeartbeatRequest}] \,\rangle$;
  $\mathit{alive} := \emptyset$;
  $\mathit{starttimer}(\mathit{delay})$;

upon event $\langle\, pl, \mathit{Deliver} \mid q, [\textsc{HeartbeatRequest}] \,\rangle$ **do**
  trigger $\langle\, pl, \mathit{Send} \mid q, [\textsc{HeartbeatReply}] \,\rangle$;

upon event $\langle\, pl, \mathit{Deliver} \mid p, [\textsc{HeartbeatReply}] \,\rangle$ **do**
  $\mathit{alive} := \mathit{alive} \cup \{p\}$;



Correctness

Strong completeness. If a process crashes, it will stop to send messages. Therefore the process will be suspected by any correct process and no process will revise the judgement.

Eventual strong accuracy. After time T the system becomes synchronous. i.e., after that time a message sent by a correct process p to another one q will be delivered within a bounded time. If p was wrongly suspected by q, then q will revise its suspicious.

References

C. Cachin, R. Guerraoui and L. Rodrigues. Introduction to Reliable and Secure Distributed Programming, Springer, 2011

- Chapter 2 – from Section 2.6.1 to Section 2.6.5