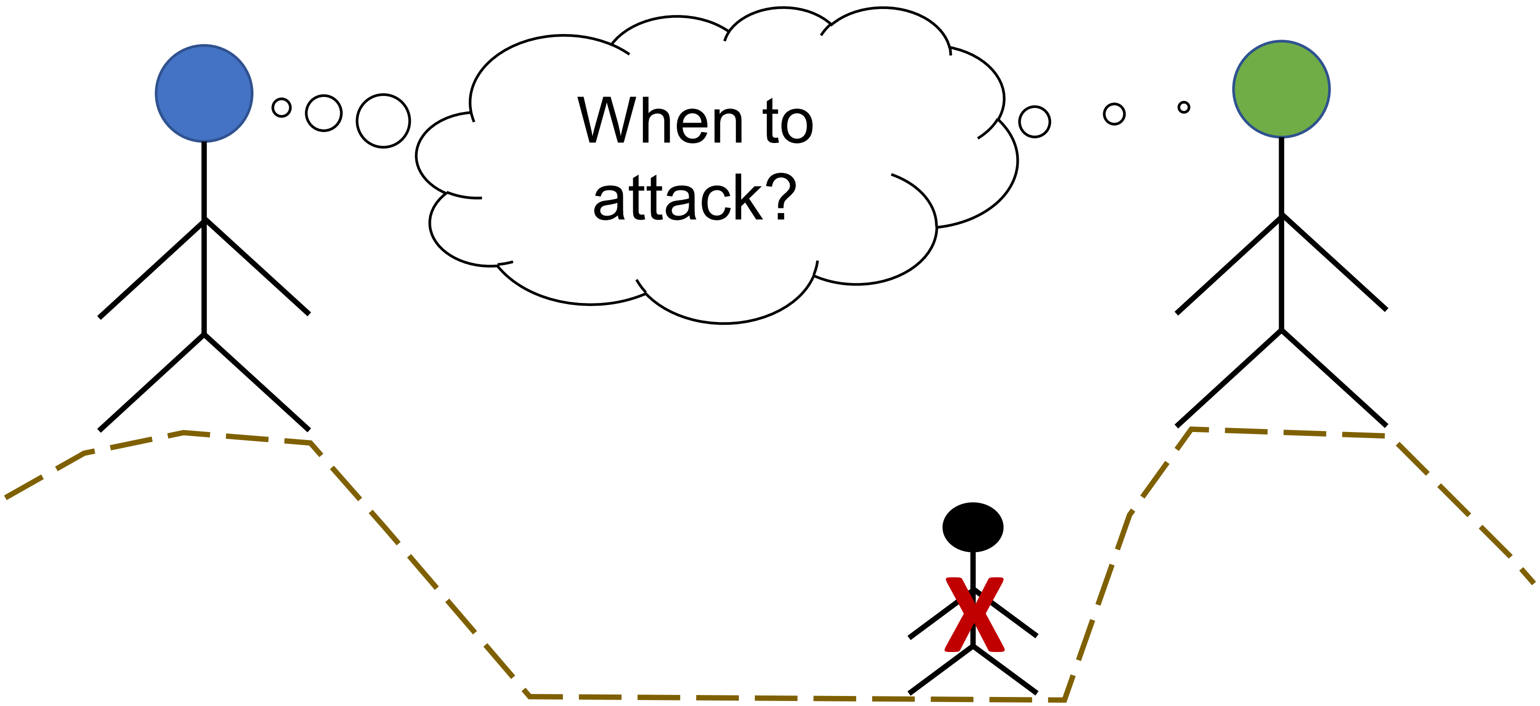
Distributed Systems

ECE428

Lecture 2

Adopted from Spring 2021

Something to think about while we wait…..

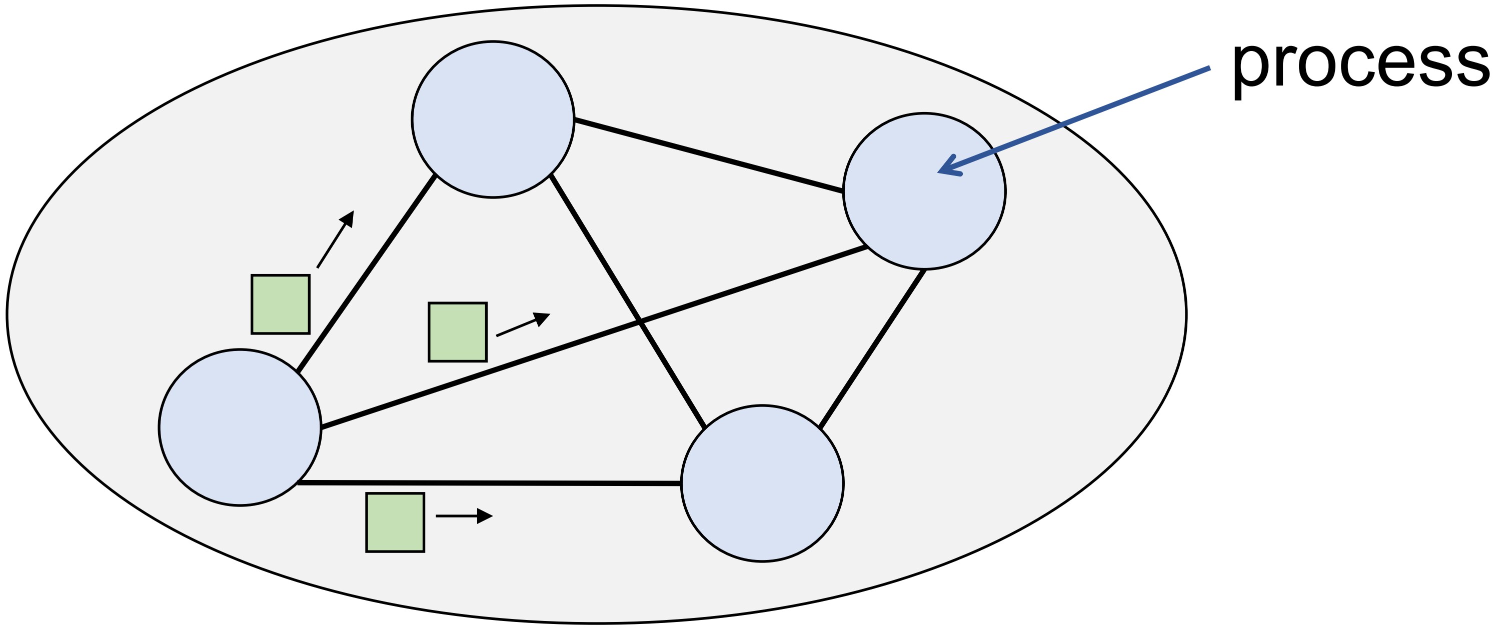


Two generals must agree on a time to attack the enemy base.
They can communicate with each-other by sending messengers.
But, a messenger may get killed by the enemy along the way.
Thankfully, they have unlimited no. of messengers at their disposals.
How can the two generals agree on a time to attack?

Today's agenda

- System Model
  - Chapter 2.4 (except 2.4.3), parts of Chapter 2.3
- Failure Detection
  - Chapter 15.1

What is a distributed system?



Independent components that are connected by a network and communicate by passing messages to achieve a common goal, appearing as a single coherent system.

Relationship between processes

- Two main categories:
  - Client-server
  - Peer-to-peer

Key aspects of a *distributed* system

- Processes must communicate with one another to coordinate actions. Communication time is variable.

- Different processes (on different computers) have different clocks!

- Processes and communication channels may fail.

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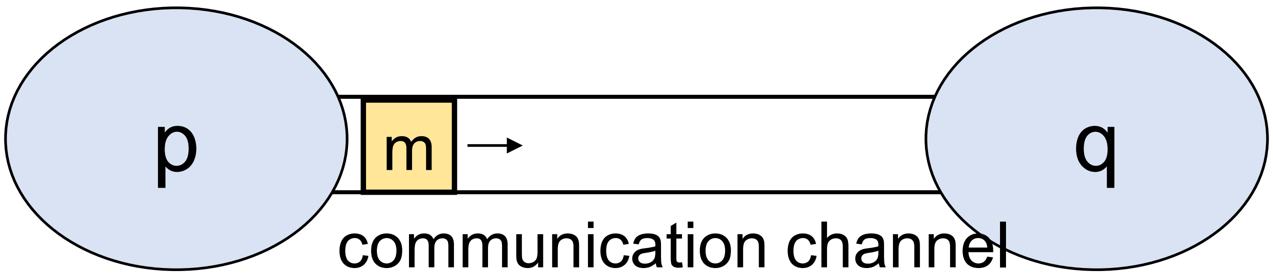
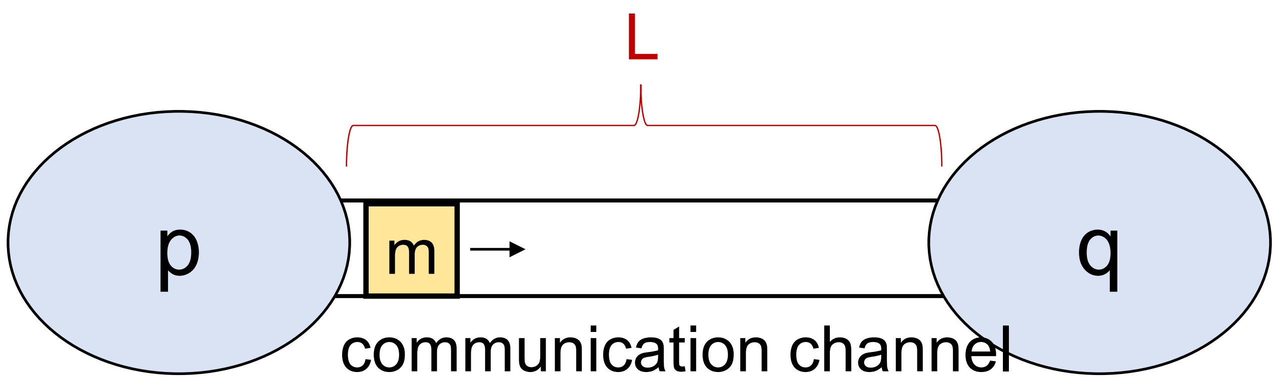
How processes communicate

- Directly using network sockets.
- Abstractions such as remote procedure calls, publish-subscribe systems, or distributed share memory.
- Differ with respect to how the message, the sender or the receiver is specified.

How processes communicate

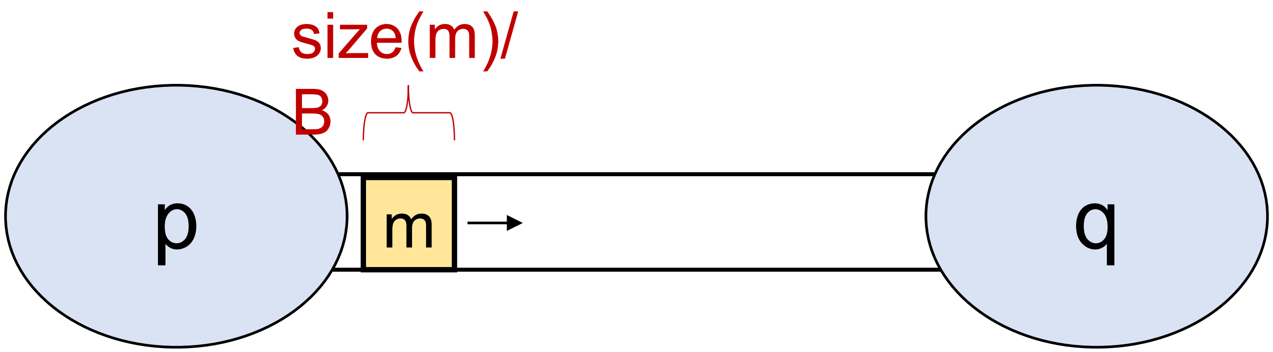


Communication channel properties



- Latency (L): Delay between the start of m's transmission at p and the beginning of its receipt at q.
  - Time taken for a bit to propagate through network links.
  - Queuing that happens at intermediate hops.
  - Overheads in the operating systems in sending and receiving messages.
  - …..

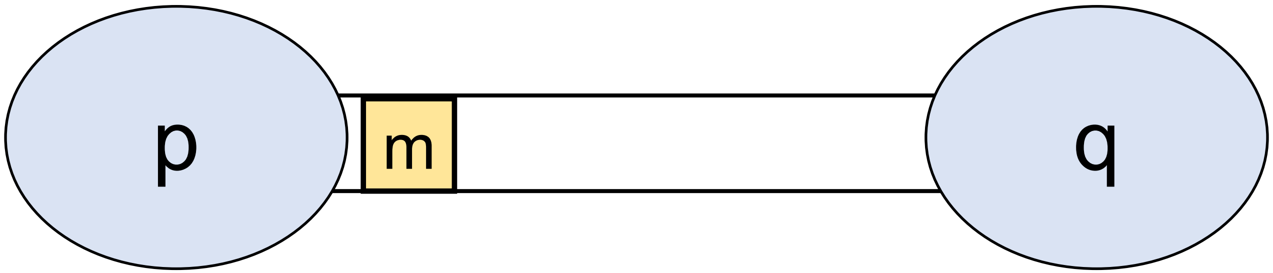
Communication channel properties



- Latency (L): Delay between the start of m's transmission at p and the beginning of its receipt at q.

- Bandwidth (B): Total amount of information that can be transmitted over the channel per unit time.
    - Per-channel bandwidth reduces as multiple channels share common network links.

Communication channel properties



- Total time taken to pass a message is governed by latency and bandwidth of the channel.
  - Both latency and available bandwidth may vary over time.

- *Sometimes useful to measure "bandwidth usage" of a system as amount of data being sent between processes per unit time.*

Key aspects of a *distributed* system

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Differing clocks

- Each computer in a distributed system has its own internal clock.
- Local clock of different processes show different time values.
- Clocks *drift* from perfect times at different rates.

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Two ways to model

- Synchronous distributed systems:
  - Known upper and lower bounds on time taken by each step in a process.
  - Known bounds on message passing delays.
  - Known bounds on clock drift rates.
- Asynchronous distributed systems:
  - No bounds on process execution speeds.
  - No bounds on message passing delays.
  - No bounds on clock drift rates.

Synchronous and Asynchronous

- Most real-world systems are asynchronous.
  - Bounds can be estimated, but hard to guarantee.
  - Assuming system is synchronous can still be useful.

- Possible to build a synchronous system.

Key aspects of a *distributed* system

- Processes must communicate with one another to coordinate actions. Communication time is variable.

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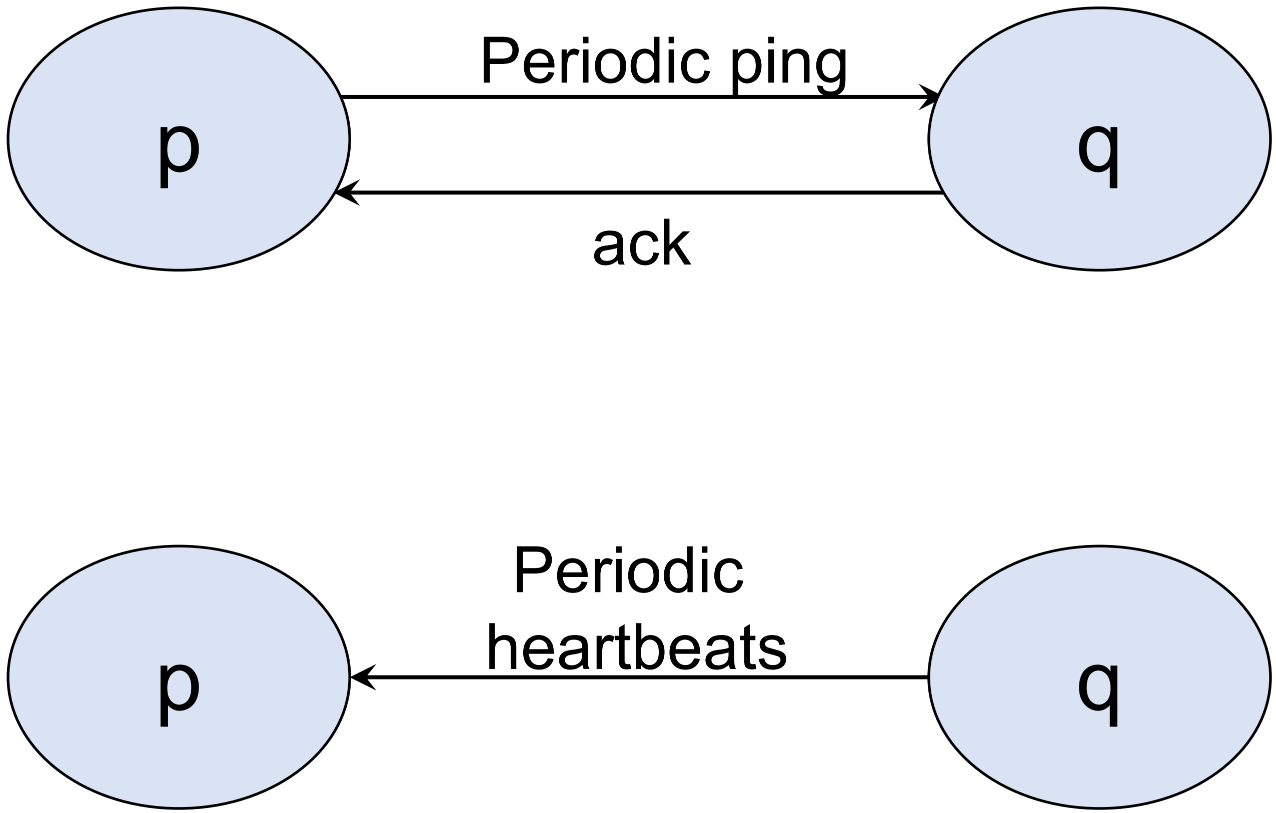
Types of failure

- Omission: when a process or a channel fails to perform actions that it is supposed to do.
    - Process may crash.

How to detect a crashed process?



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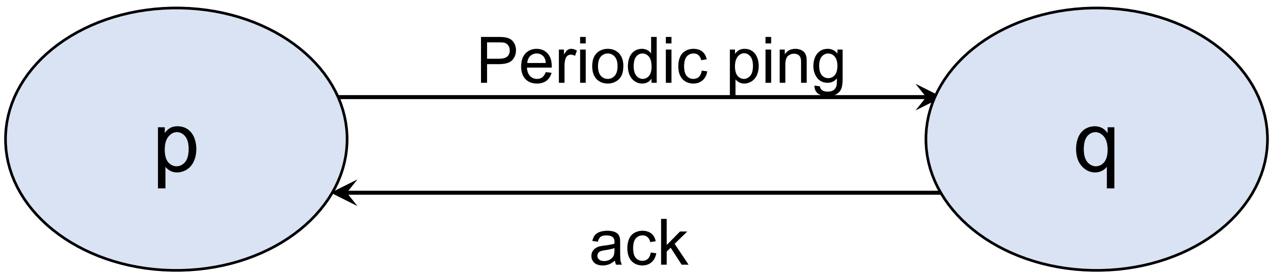


p sends pings to q every T seconds.

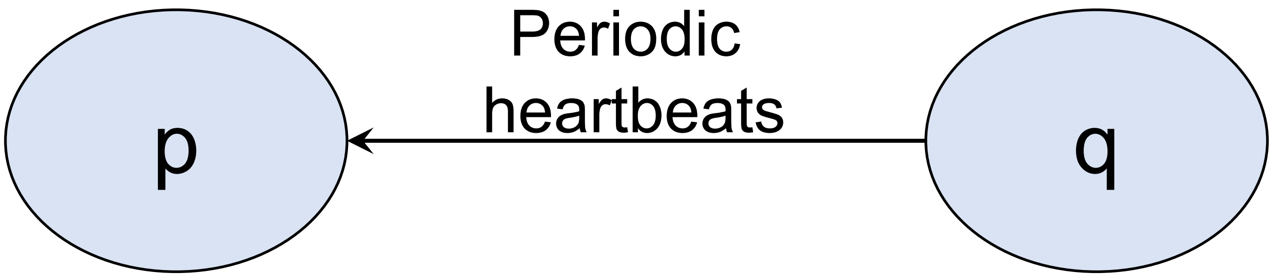
Δ_1 is the *timeout* value at p.

If Δ_1 time elapsed after sending ping, and no ack, report q crashed.

If synchronous, Δ_1 = 2(max network delay)

If asynchronous, $\Delta_1 = k$ (max observed round trip time)

How to detect a crashed process?



q sends heartbeats to p every T seconds.

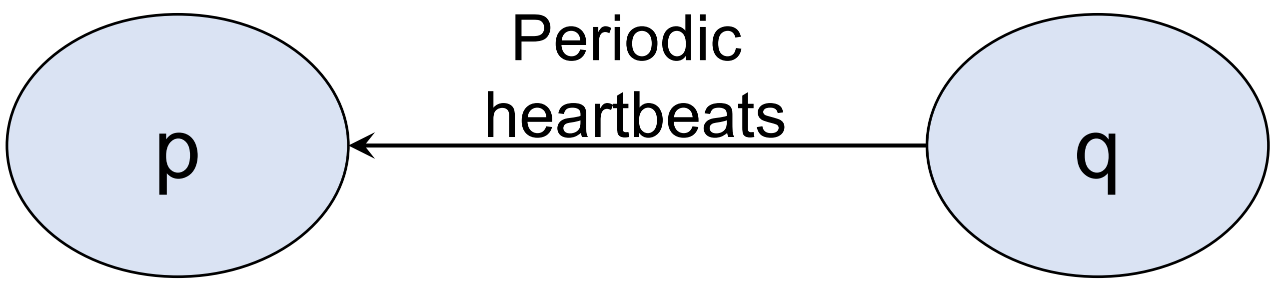
$(T + \Delta_2)$ is the *timeout* value at p.

If $(T + \Delta_2)$ time elapsed since last heartbeat, report q crashed.

If synchronous, Δ_2 = max network delay – min network delay

If asynchronous, Δ_2 = k(observed delay)

How to detect a crashed process?



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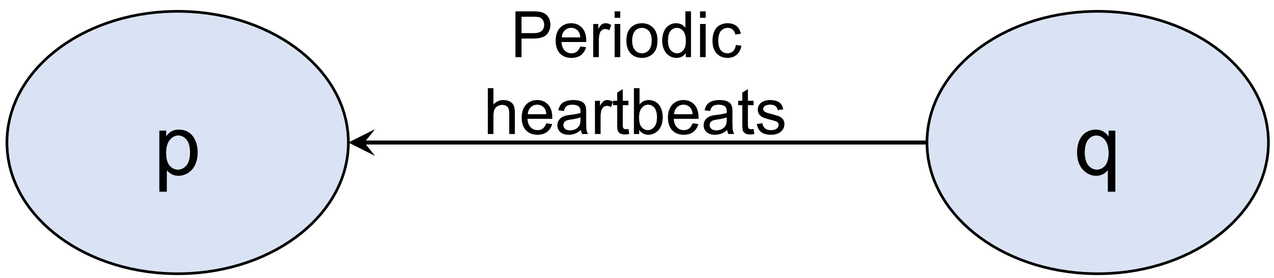

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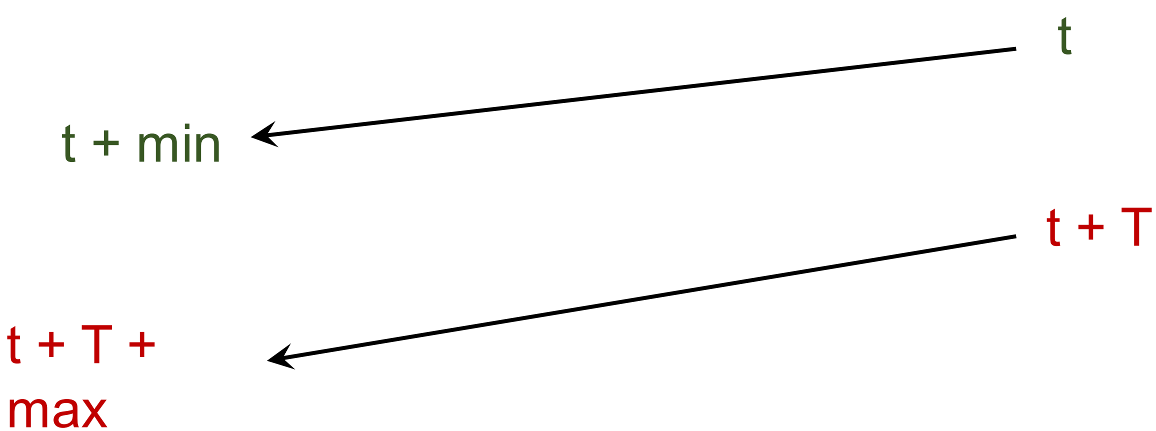

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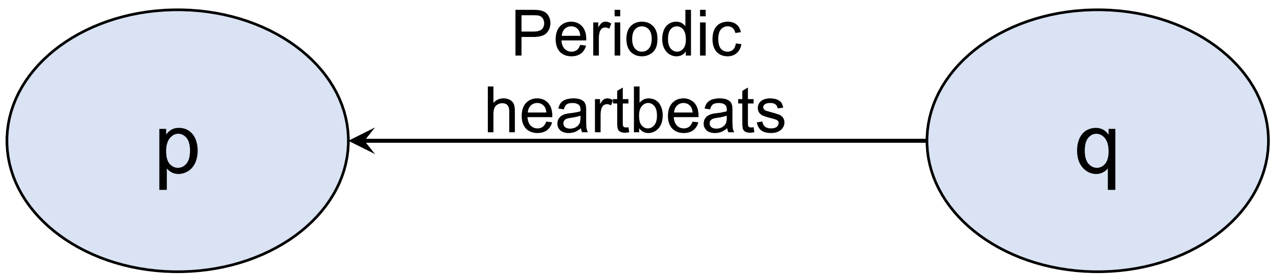

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If asynchronous, Δ_2 = k (observed delay)

Correctness of failure detection

- Completeness
  - Every failed process is *eventually* detected.
- Accuracy
  - Every detected failure corresponds to a crashed process (no mistakes).

Correctness of failure detection

- Characterized by completeness and accuracy.

- Synchronous system
  - Failure detection via ping-ack and heartbeat is both complete and accurate.

- Asynchronous system
  - *Our strategy for ping-ack and heartbeat is complete.*
  - Impossible to achieve both completeness and accuracy.
  - Can we have an accurate but incomplete algorithm?
    - *Never report failure.*

Metrics for failure detection

- Worst case failure detection time
  - After a process crashes, how long does it take for the other process to detect the crash in the worst case?

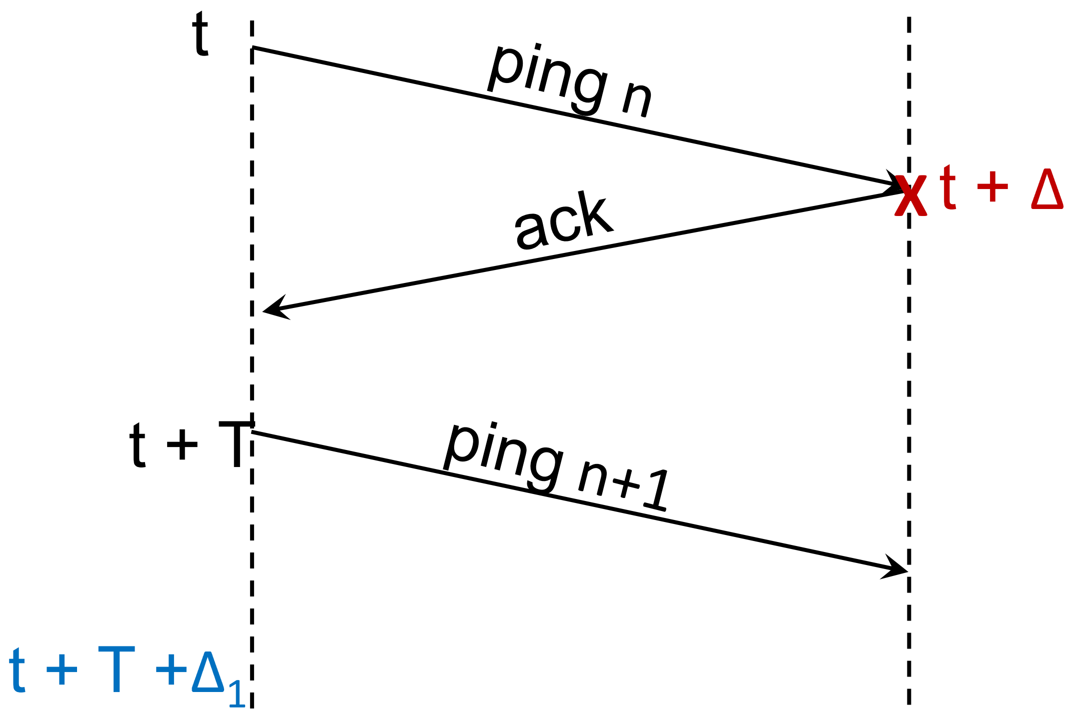
Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$ where Δ is time taken for last ping from p to reach q before q crashed. T is the time period for pings, and Δ_1 is timeout value.

Try deriving this!

Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$ where Δ is time taken for last ping from p to reach q before q crashed. T is the time period for pings, and Δ_1 is timeout value.



Worst case failure detection time:
$t + T + \Delta_1 - (t + \Delta)$
$= T + \Delta_1 - \Delta$

Q: What is worst case value of Δ for a *synchronous system?*
A: min network delay

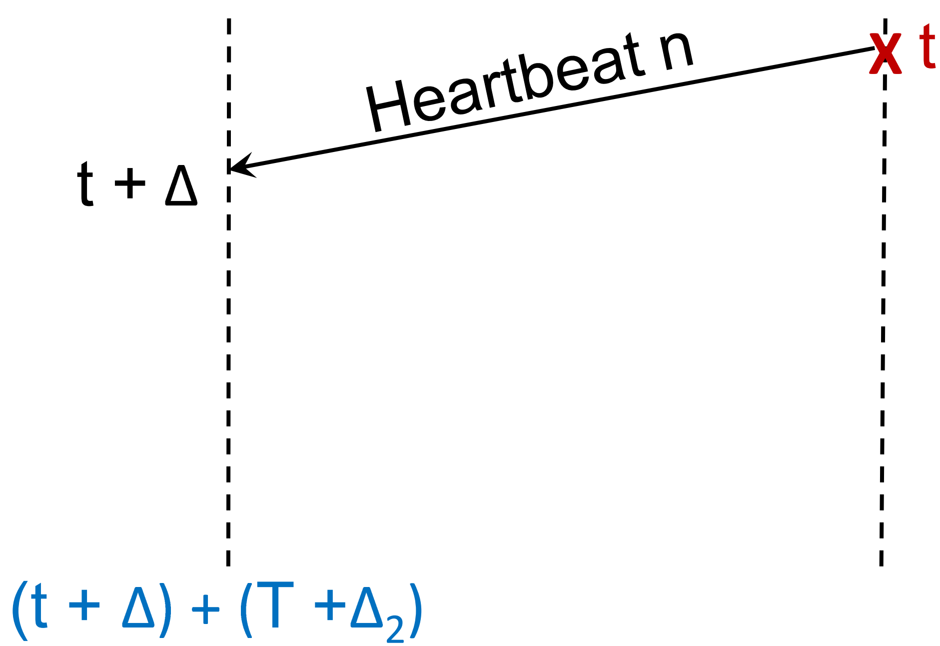
Metrics for failure detection

- Worst case failure detection time
  - Heartbeat: $T + \Delta_2 + \Delta$ where Δ is time for last heartbeat from q to reach p
    T is time period for heartbeats, $T + \Delta_2$ is the timeout.

Try deriving this!

Metrics for failure detection

- Worst case failure detection time
  - Heartbeat: $T + \Delta_2 + \Delta$ where Δ is time for last heartbeat from q to reach p
    T is time period for heartbeats, $T + \Delta_2$ is the timeout.



Worst case failure detection time:
$(t + \Delta) + (T + \Delta_2) - t$
$= T + \Delta_2 + \Delta$

Q: What is worst case value of Δ in a synchronous system?
A: max network delay

Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$
    (Δ is time taken for last ping from p to reach q before crash)
  - Heartbeat: $T + \Delta_2 + \Delta$
    (Δ is time taken for last heartbeat from q to reach p)

Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$
    (Δ is time taken for previous ping from p to reach q before crash)
  - Heartbeat: $T + \Delta_2 + \Delta$
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- Bandwidth usage:
  - Ping-ack: 2 messages every T units
  - Heartbeat: 1 message every T units

Metrics for failure detection

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Effect of decreasing T?

Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: T + Δ_1- Δ (where Δ is time taken for previous ping from p to reach q)
  - Heartbeat: T + Δ_2+ Δ (where Δ is time taken for last heartbeat from q to reach p)
- Bandwidth usage:
  - Ping-ack: 2 messages every T units
  - Heartbeat: 1 message every T units

Effect of increasing Δ_1 or Δ_2?

Summary

- Sources of uncertainty
  - Communication time, clock drift rates
- Synchronous vs asynchronous models.
- Types of failures: omission, arbitrary, timing
- Detecting failed a process.