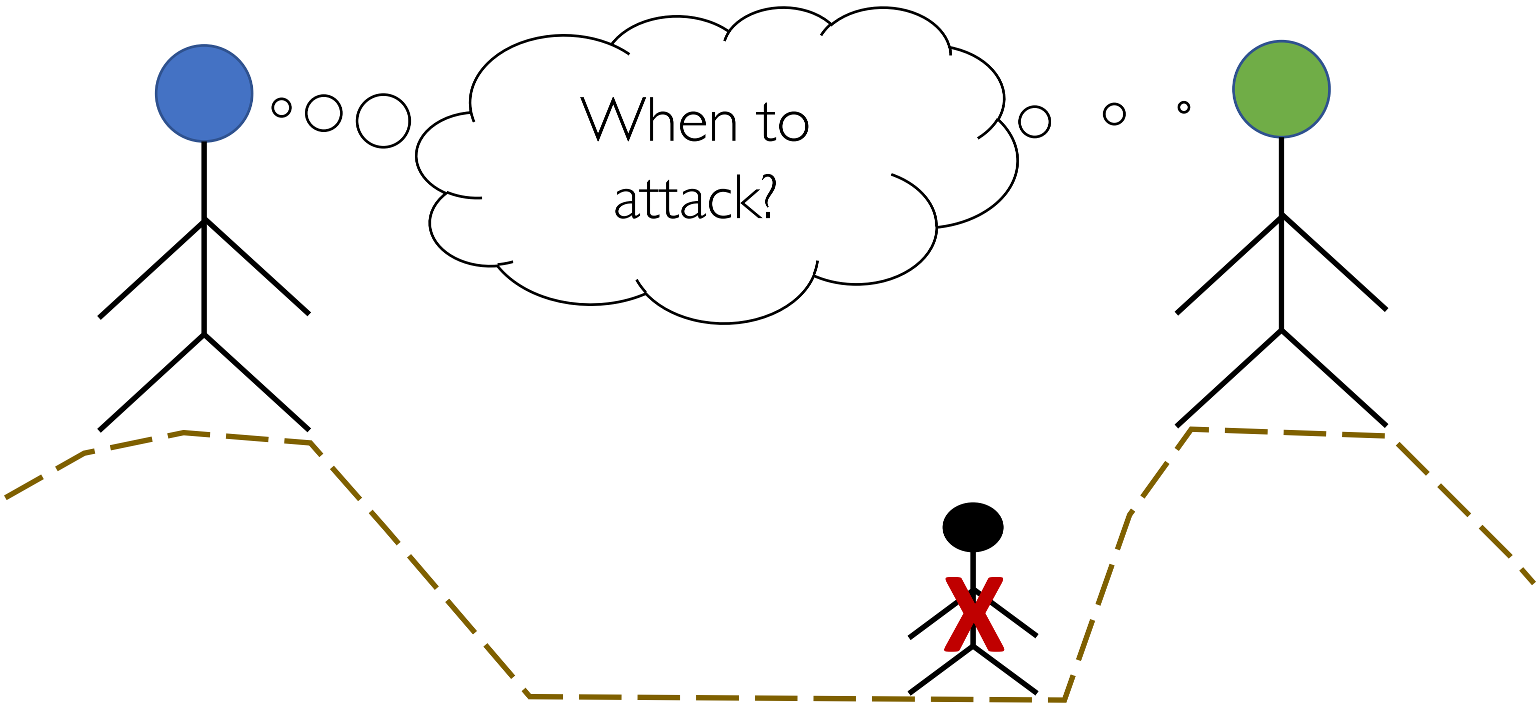
Distributed Systems

CS425/ECE428

Instructor: Radhika Mittal

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?

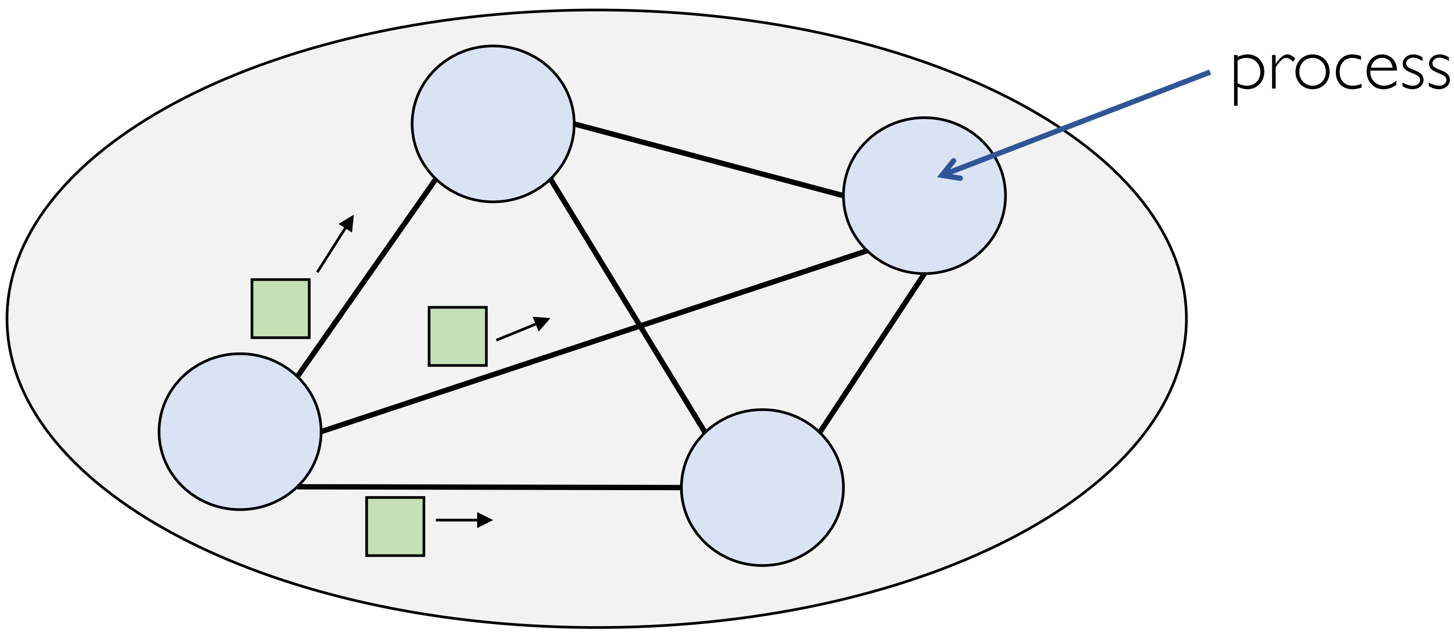
Logistics Related

- OHs information is up on website/course calendar
- Sign-up forms for VM clusters is available on CampusWire.
  - Please fill it up by Thursday, Jan 25th, Thursday, 11:59pm.
- MP0 will be released on Wednesday.
- Lecture recordings on MediaSpace should be accessible to all registered students.

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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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.

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

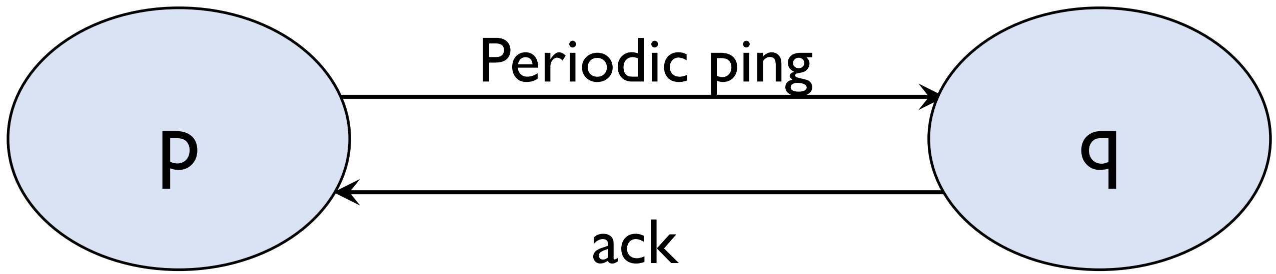
- Different processes (on different computers) have different clocks!

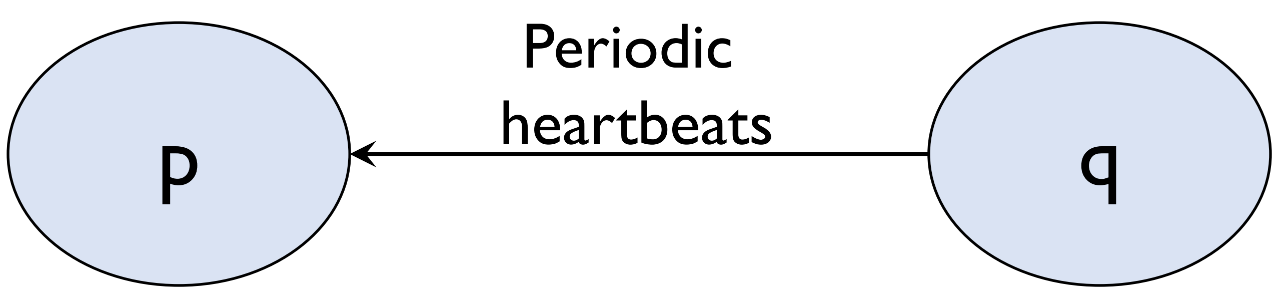
- Processes and communication channels may fail.

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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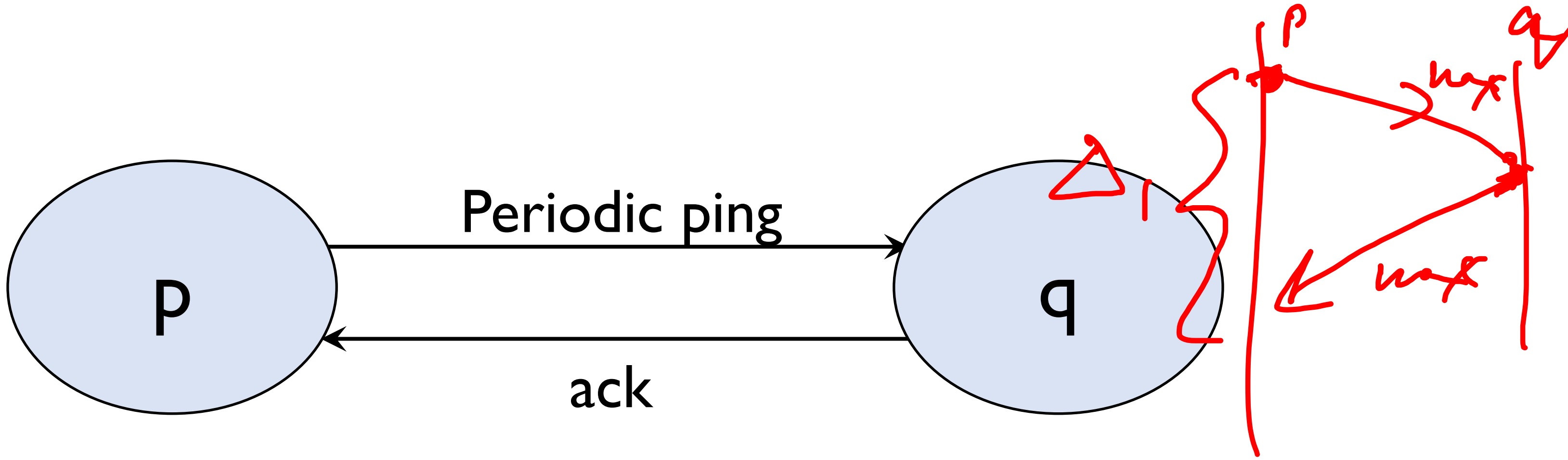


p sends pings to q every T seconds.

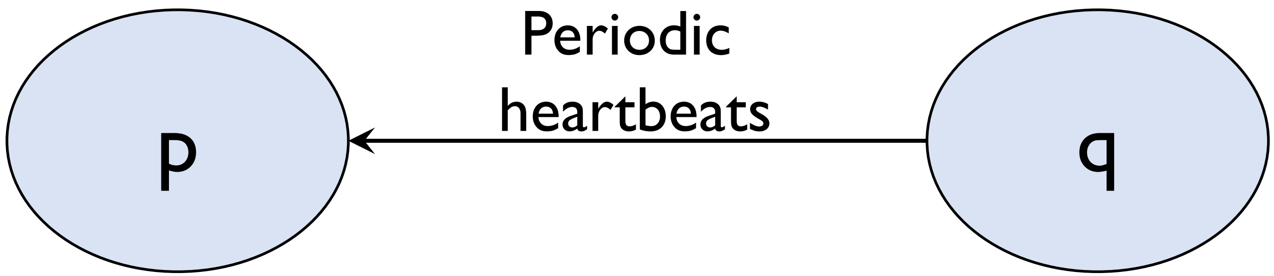
Δ_1 is the *timeout* value at p.

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

If synchronous, Δ_1 = 2(max network delay)

If asynchronous, Δ_1 = k(max observed round trip time)

How to detect a crashed process?



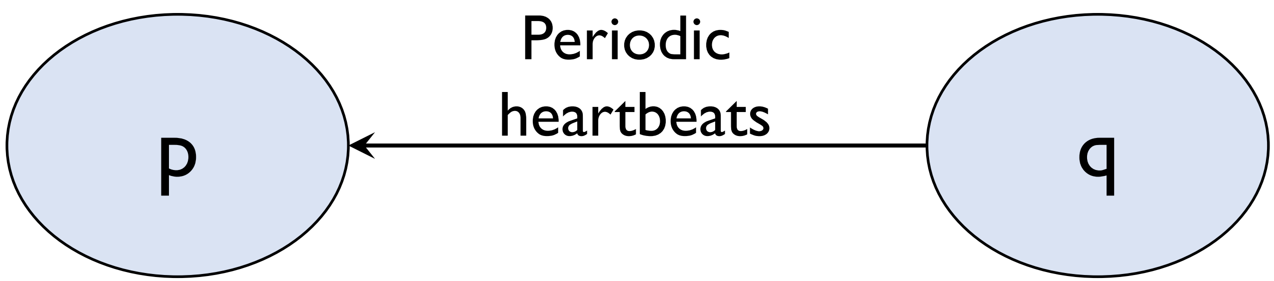
q sends heartbeats to p every T seconds.

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

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

If synchronous, $\Delta_2 =$ max network delay – min network delay

How to detect a crashed process?



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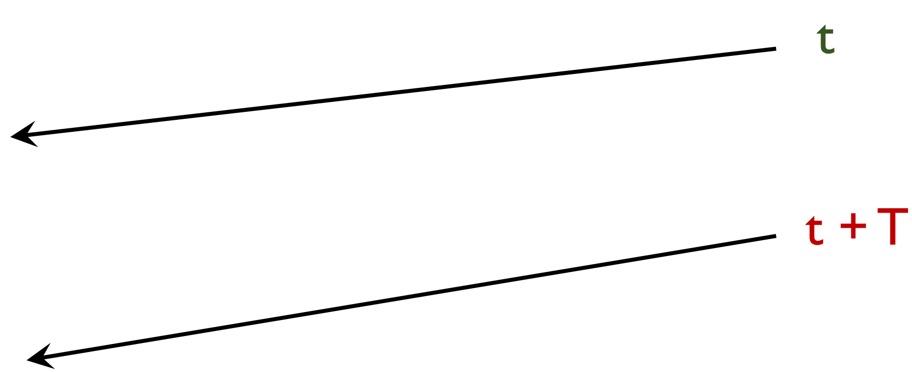

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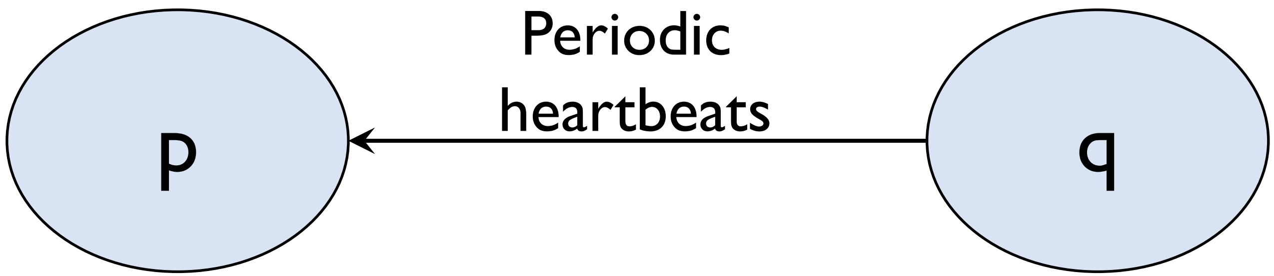

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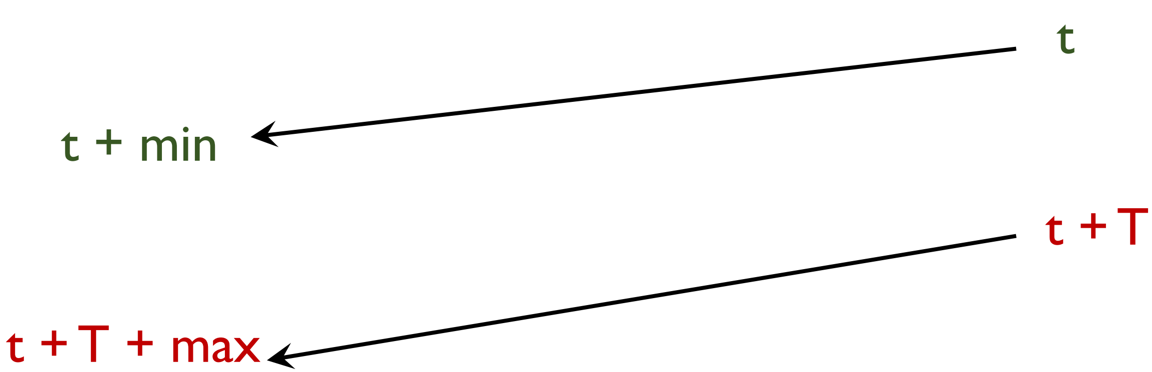

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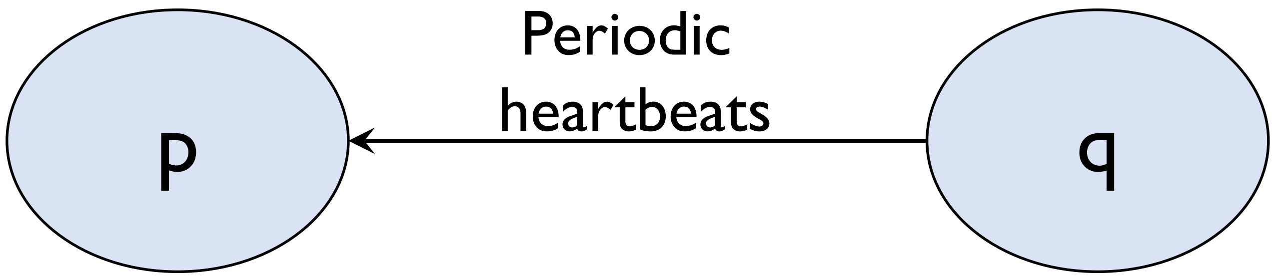

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If $(T + \Delta_2)$ time elapsed since last heartbeat, report q crashed.

If synchronous, $\Delta_2 =$ max network delay – min network delay

If asynchronous, $\Delta_2 =$ 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*
  - Impossible to achieve both completeness and accuracy.
  - Can we have an accurate but incomplete algorithm?
    - *Never report failure.*

Metrics for failure detection

Try deriving these before next class!

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

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?

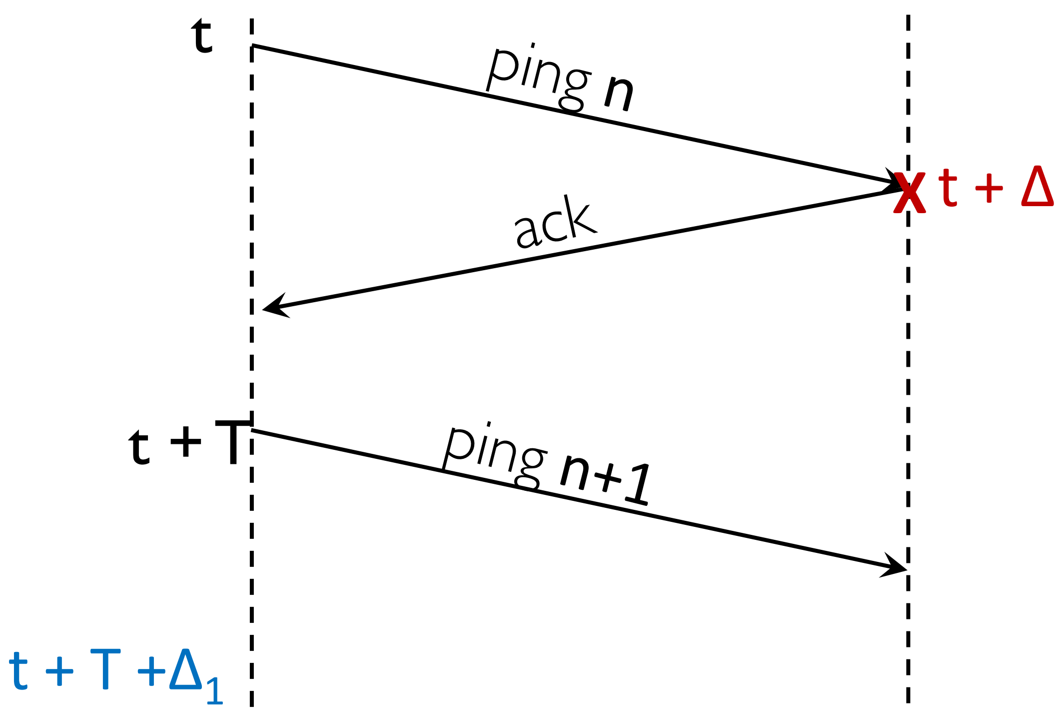
Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$ where Δ is time taken for the 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 the 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

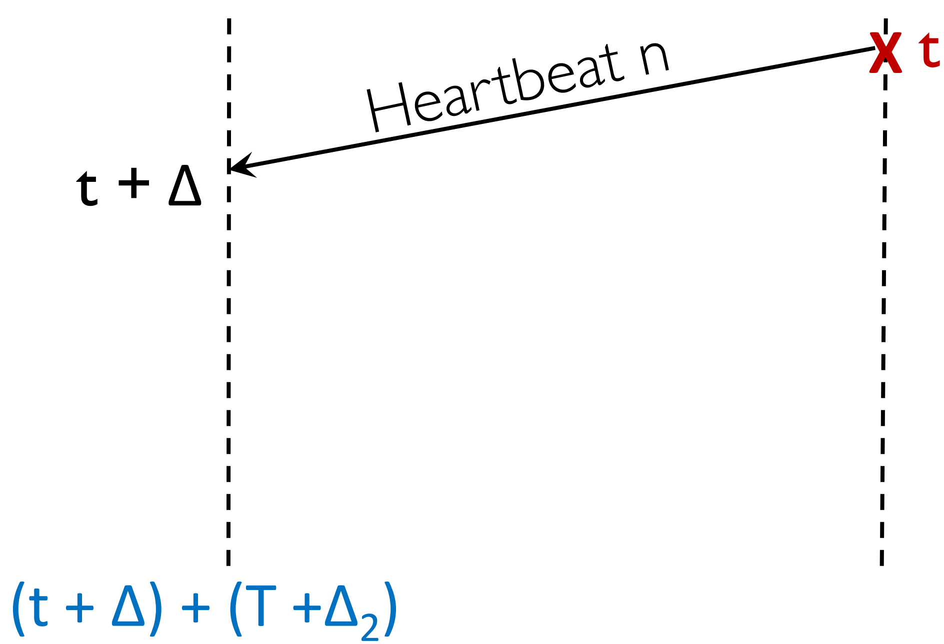
- Worst case failure detection time
  - Heartbeat: $T + \Delta_2 + \Delta$ where Δ is time taken for last heartbeat from q to reach p
    T is the time period for heartbeats, and $T + \Delta_2$ is the timeout.

Try deriving this!

Metrics for failure detection

- Worst case failure detection time
  - Heartbeat: $T + \Delta_2 + \Delta$ where Δ is time taken for last heartbeat from q to reach p

    T is the time period for heartbeats, and $T + \Delta_2$ 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: $T + \Delta_1 - \Delta$(where Δ is time taken for last ping from p to reach q before crash)
  - Heartbeat: $T + \Delta_2 + \Delta$ (where Δ is time taken for last heartbeat from q to reach p)

Metrics for failure detection

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

Metrics for failure detection

- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$ (where Δ is time taken for previous ping from p to reach q)
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Effect of decreasing T?

Metrics for failure detection

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

Decreasing T decreases failure detection time,
but increases bandwidth usage.

Metrics for failure detection

- Worst case failure detection time
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  - Heartbeat: $T + \Delta_2 + \Delta$ (where Δ is time taken for last heartbeat from q to reach p)
- Bandwidth usage:
  - Ping-ack: 2 messages every T units
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Effect of increasing Δ_1 or Δ_2?

Metrics for failure detection

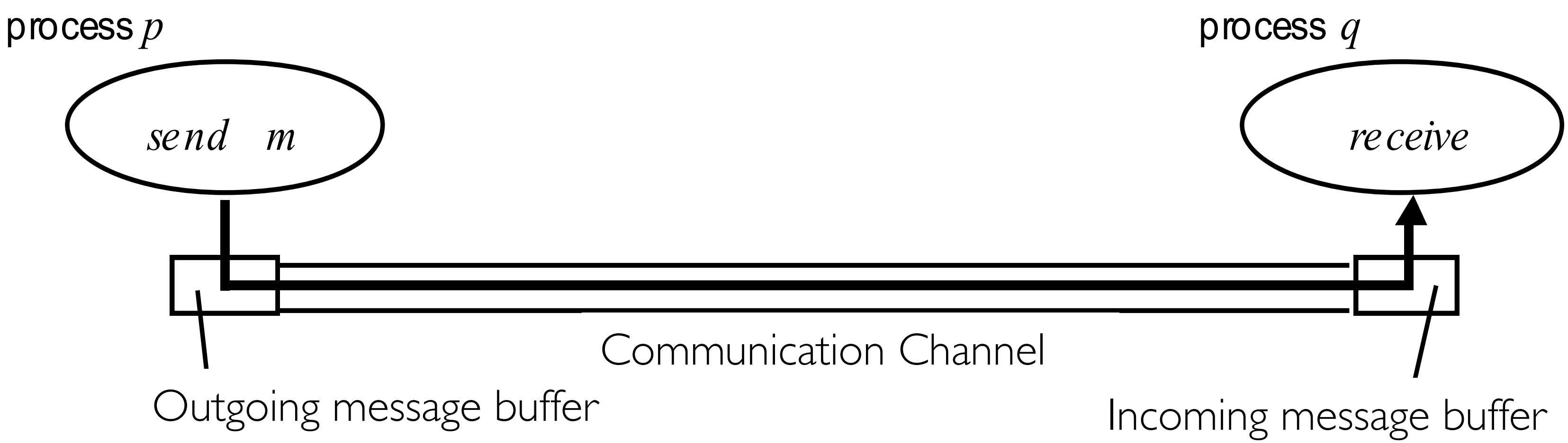
- Worst case failure detection time
  - Ping-ack: $T + \Delta_1 - \Delta$ (where Δ is time taken for previous ping from p to reach q)
  - Heartbeat: $T + \Delta_2 + \Delta$ (where Δ is time taken for last heartbeat from q to reach p)
- Bandwidth usage:
  - Ping-ack: 2 messages every T units
  - Heartbeat: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

Increasing Δ_1 or Δ_2 increases accuracy (in an asynchronous system)
but also increases failure detection time.

Types of failure

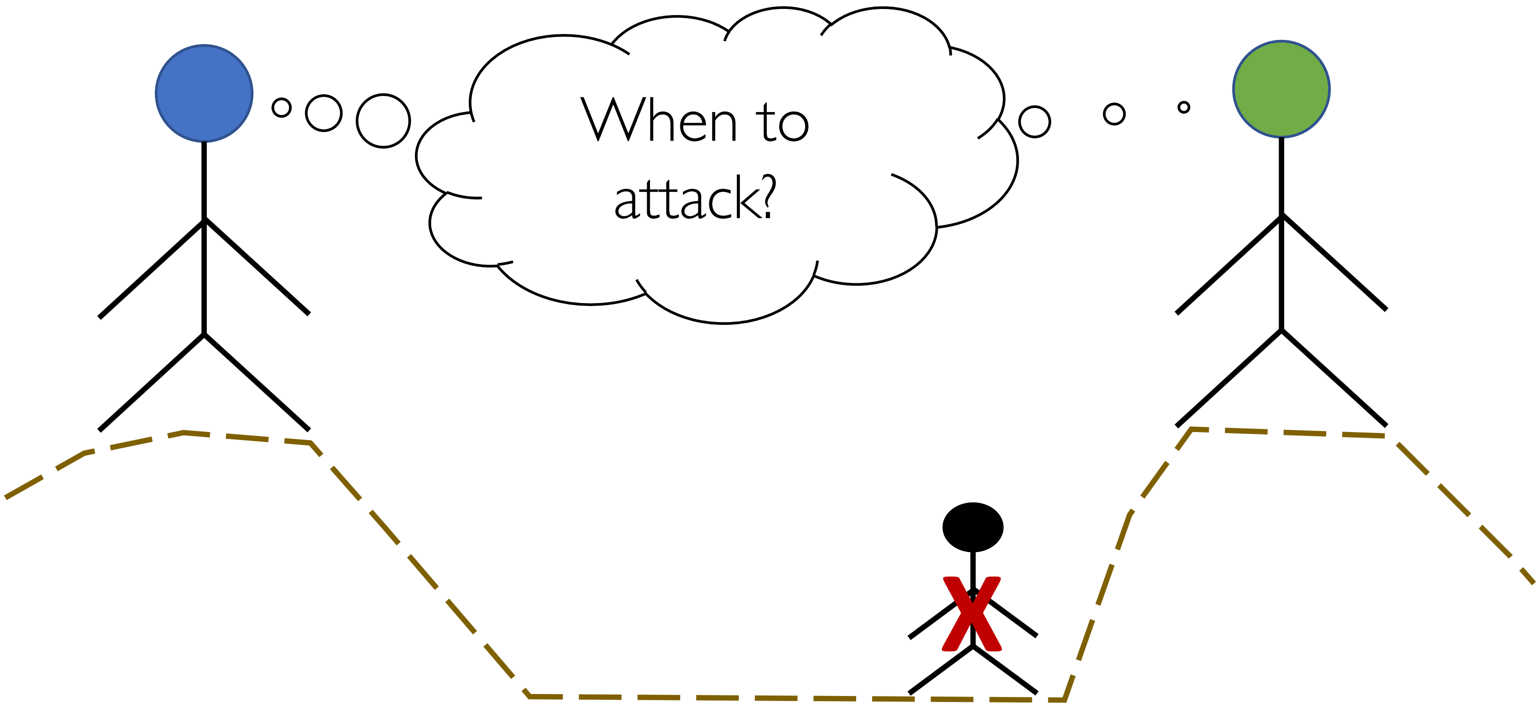
- **Omission:** when a process or a channel fails to perform actions that it is supposed to do.
  - Process may **crash**.
  - **Fail-stop**: if other processes can certainly detect the crash.
  - **Communication omission**: a message sent by process was not received by another.

Communication Omission



- Channel Omission: omitted by channel
- Send omission: process completes 'send' operation, but message does not reach its outgoing message buffer.
- Receive omission: message reaches the incoming message buffer, but not received by the process.

Two Generals Problem



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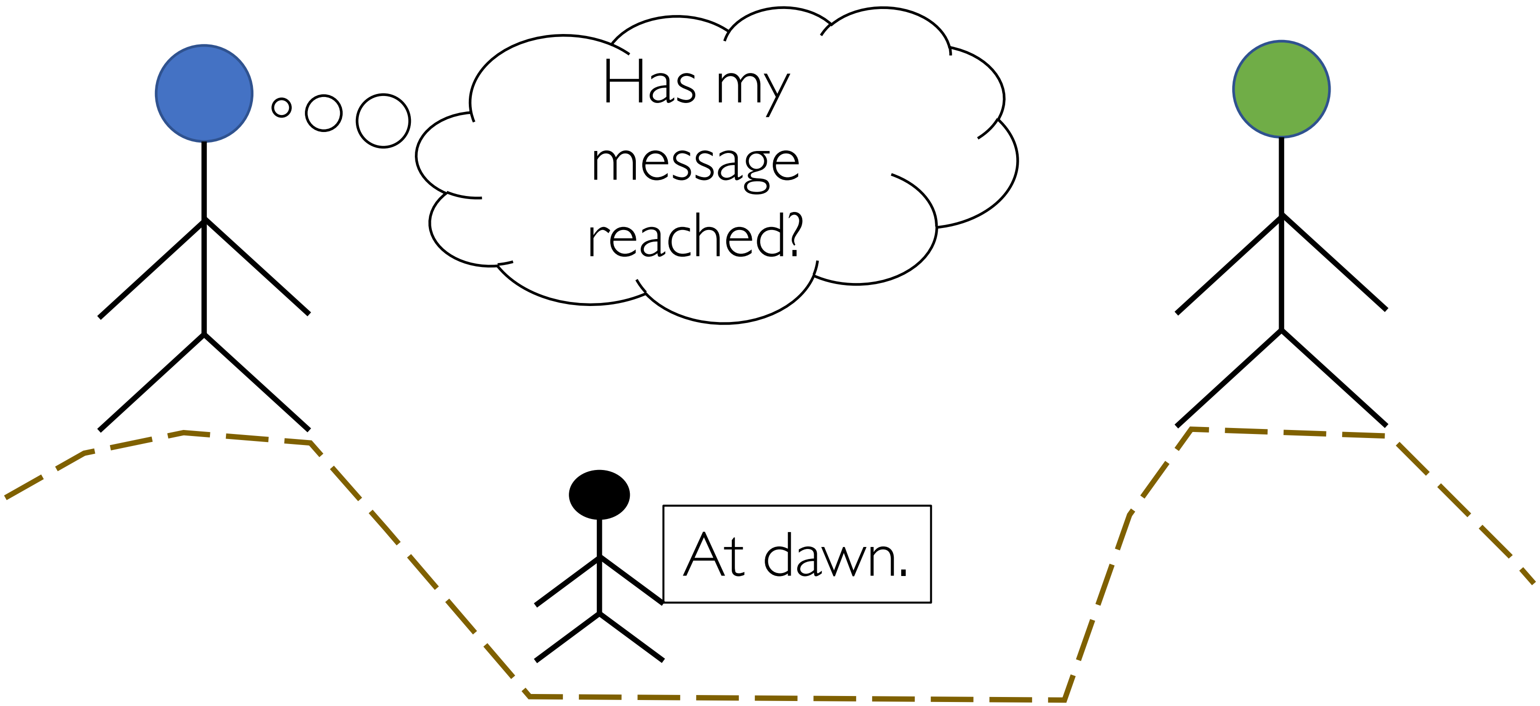

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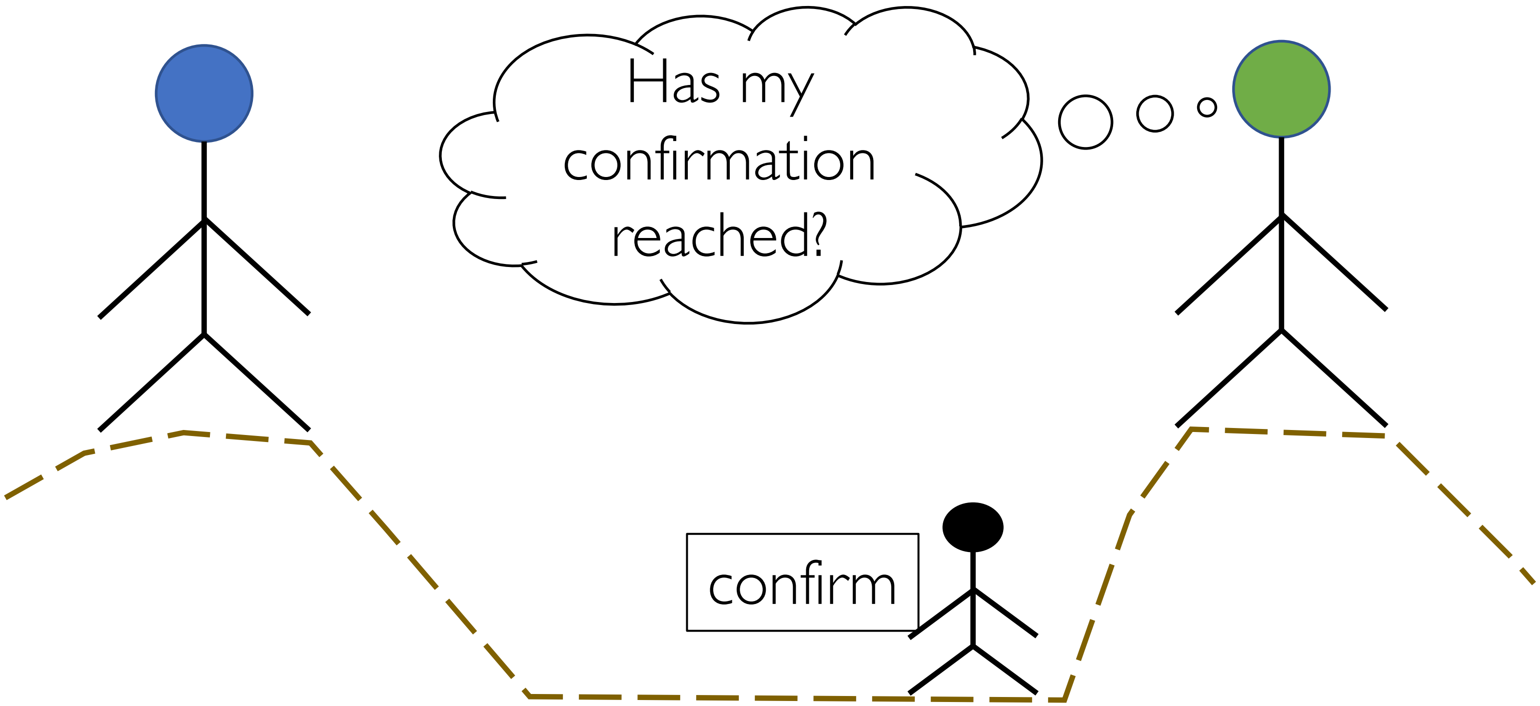

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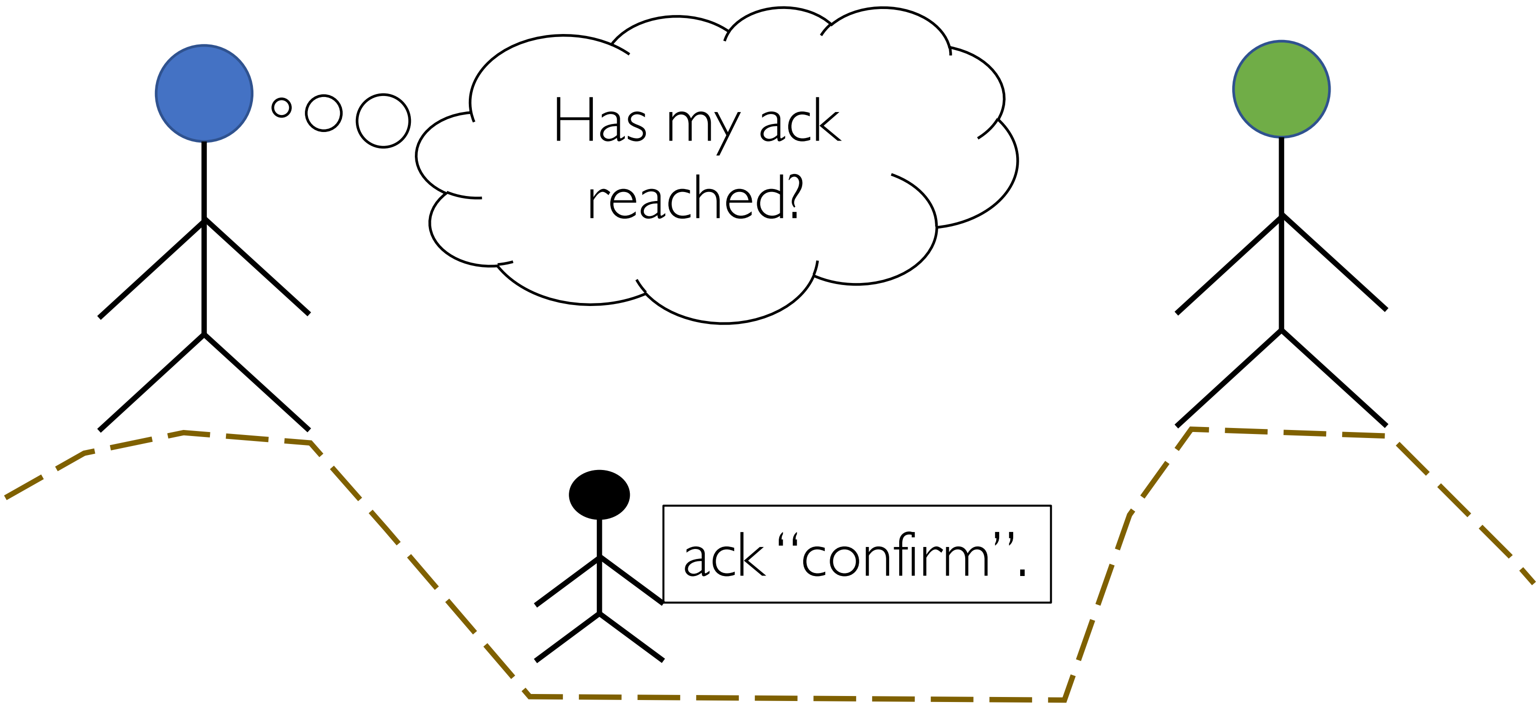

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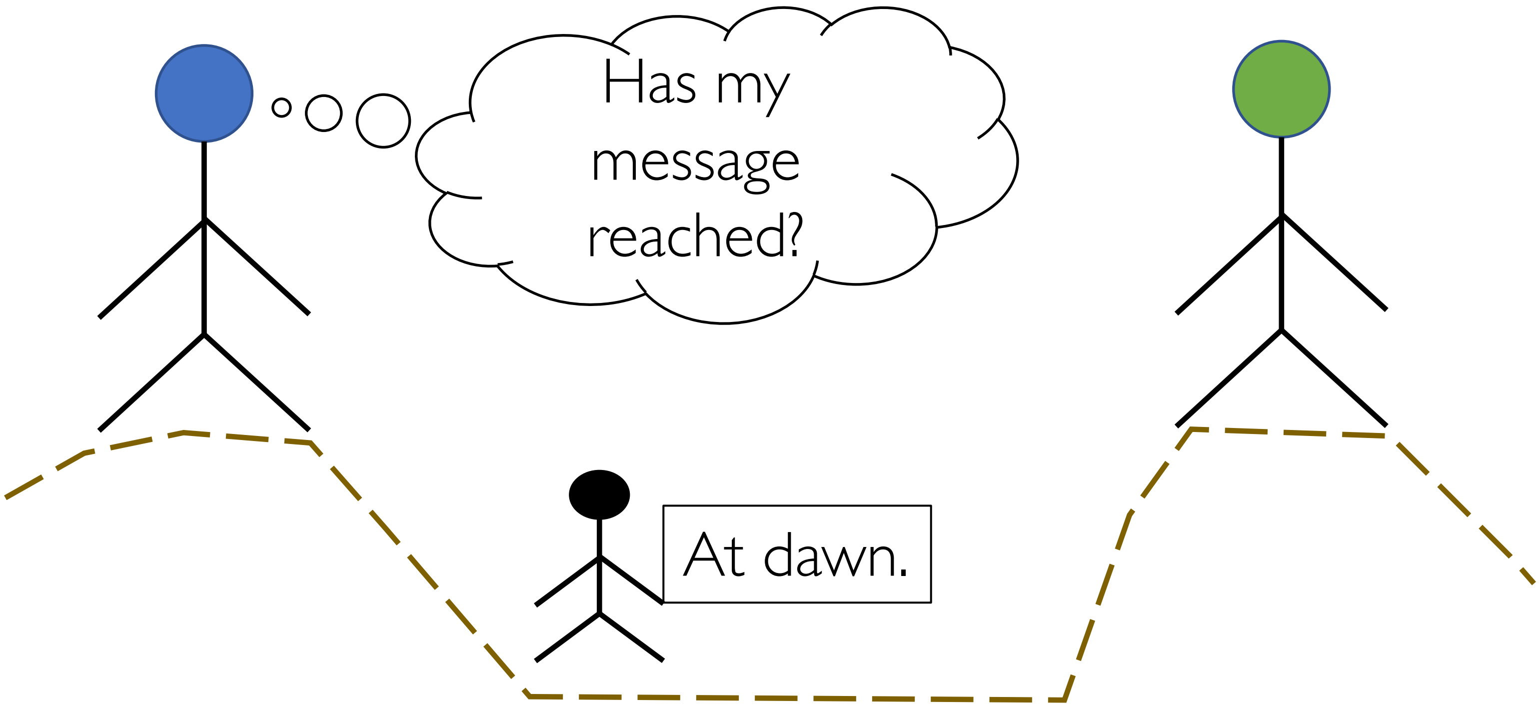
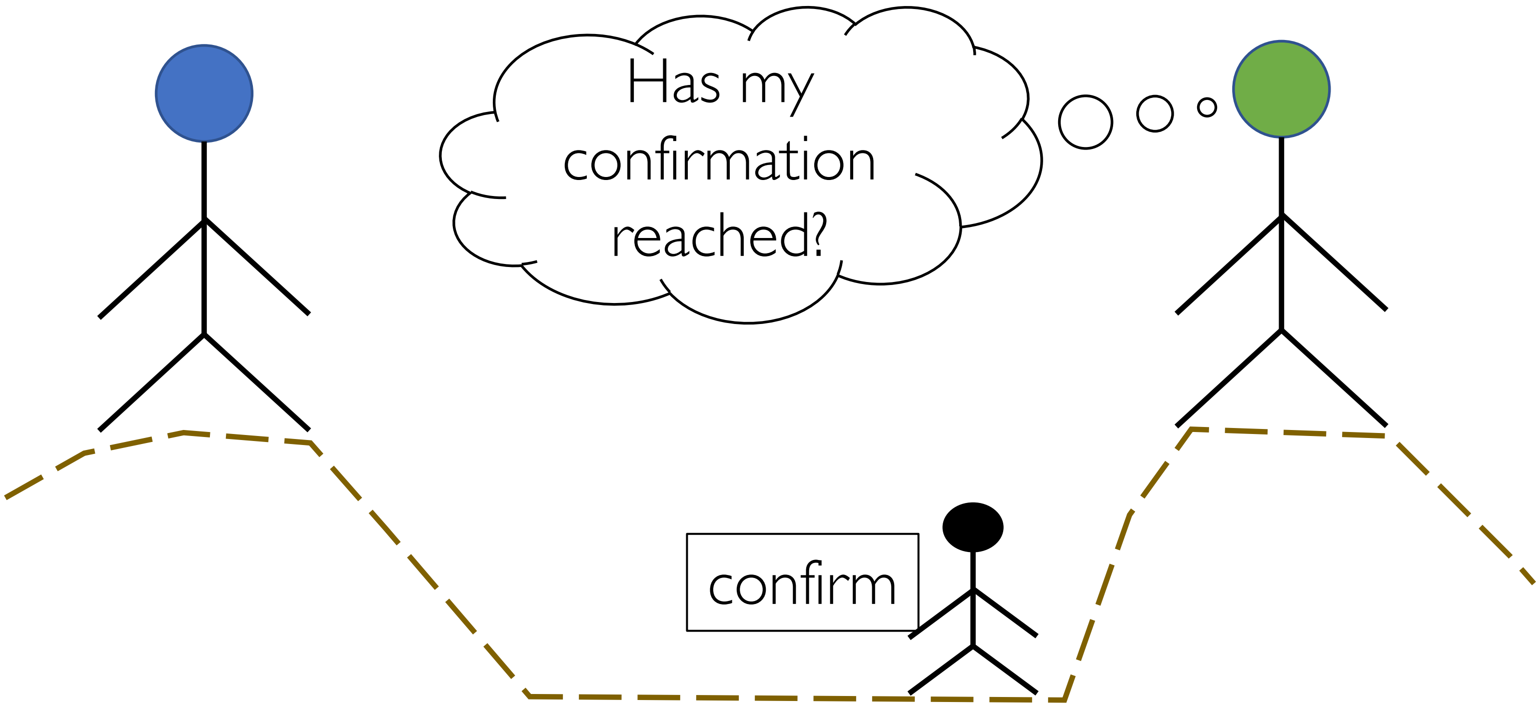


Keep sending the message until confirmation arrives.

Two Generals Problem



Assume confirmation has reached in the absence of a repeated message.

Still no guarantees! But may be good enough in practice.

Types of failure

- **Omission:** when a process or a channel fails to perform actions that it is supposed to do.
  - Process may **crash**.
  - **Fail-stop**: if other processes can detect that the process has crashed.
  - **Communication omission**: a message sent by process was not received by another.

Message drops (or omissions) can be mitigated by network protocols.

Summary

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