

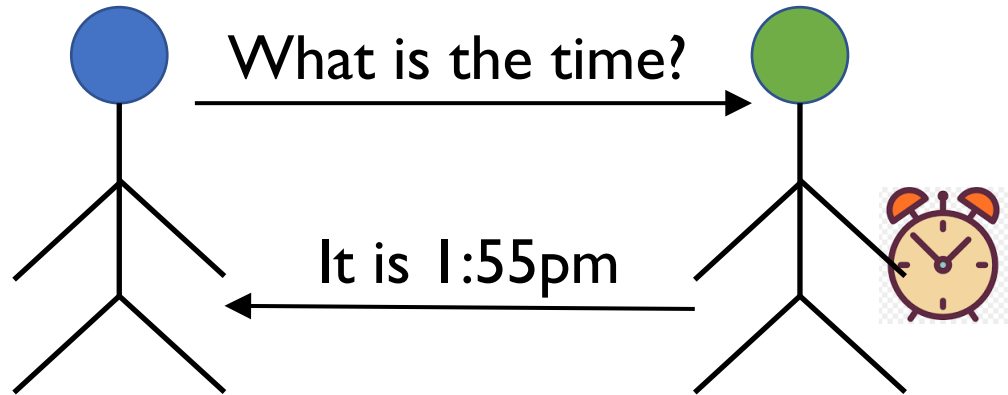
Distributed Systems

CS425/ECE428

Jan 25, 2022

Instructor: Radhika Mittal

While we wait...



Bluey does not own a clock, and wants to know the time. He sends a message to Greeny asking the time, and Greeny sends a response as soon as he receives the request.

Bluey records that it took 6 minutes for him to receive Greeny's response after sending his request.

Given this information, what time should Bluey assume it actually is when he receives Greeny's message? Can he be totally accurate?

Logistics Related

- Make sure you are on CampusWire.
- VM access should hopefully kick in by end of week.
- It takes many hours to upload lecture recordings, so please be patient.
- Unregistered students cannot access video on Echo360.
 - If auditing, make sure you are added to roster.
- HW I will be released this Thursday.

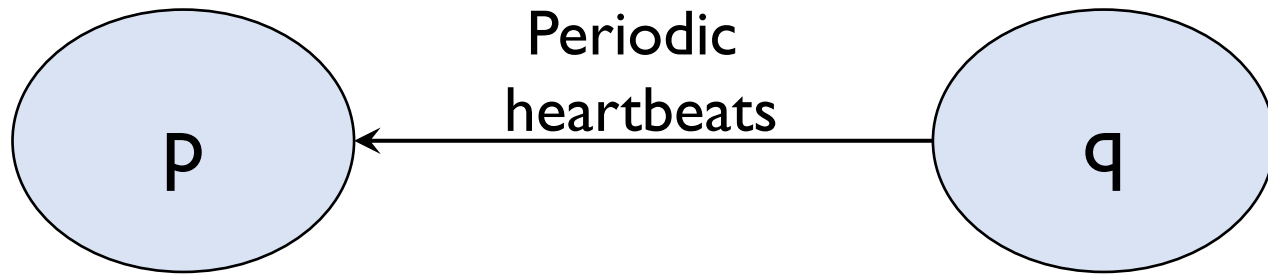
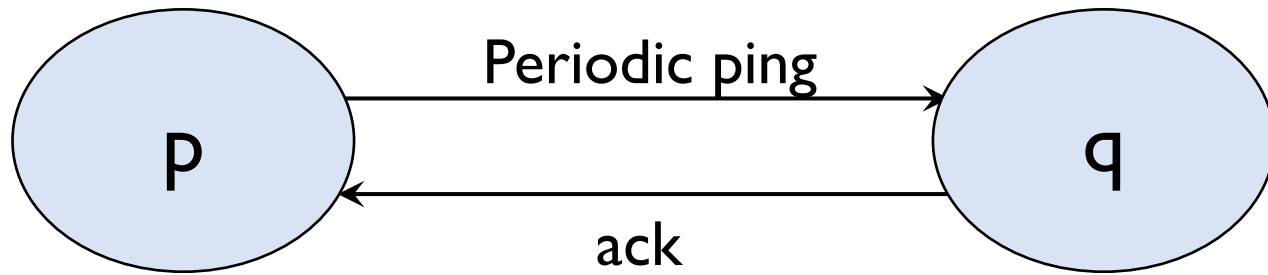
Today's agenda

- **Failure Detection**
 - Chapter 15.1
- **Time and Clocks**
 - Chapter 14.1-14.3

Recap

- Synchronous vs asynchronous systems.
- Failure detection via ping-ack and heartbeats.
 - Complete and accurate in synchronous system.
 - Impossible to achieve completeness and accuracy in asynchronous systems.
 - Setting a conservative timeout gives completeness but not accuracy.
 - Other metrics: failure detection time and bandwidth usage.

How to detect a crashed process?



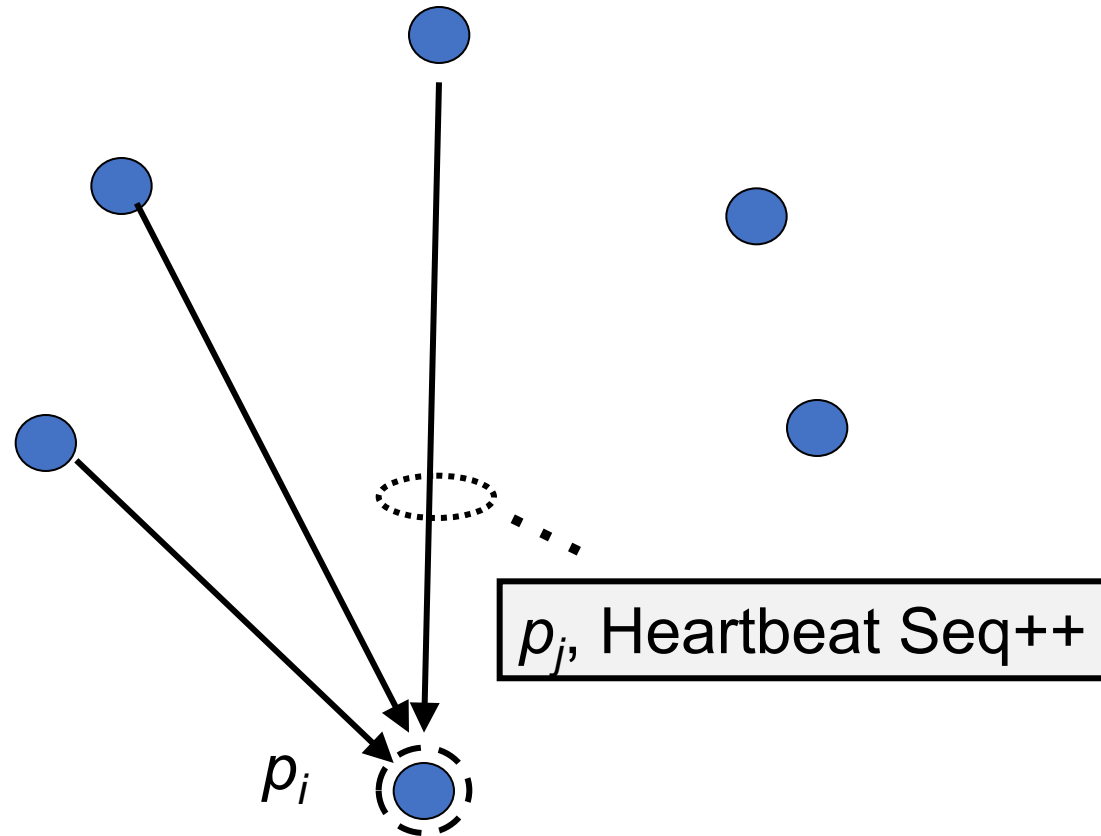
Extending heartbeats

- Looked at detecting failure between two processes.
- How do we extend to a system with multiple processes?

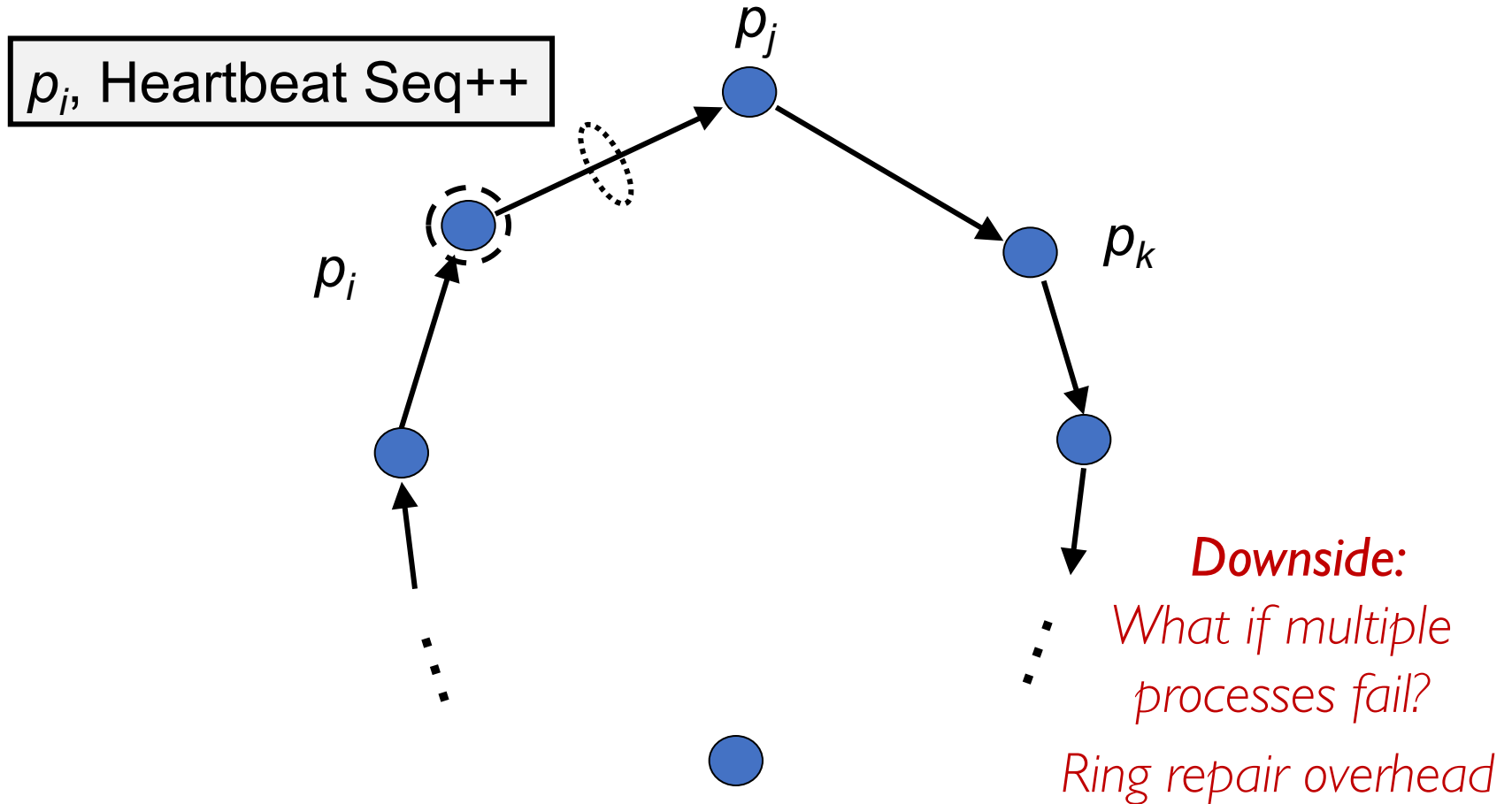
Centralized heartbeating

Downside:

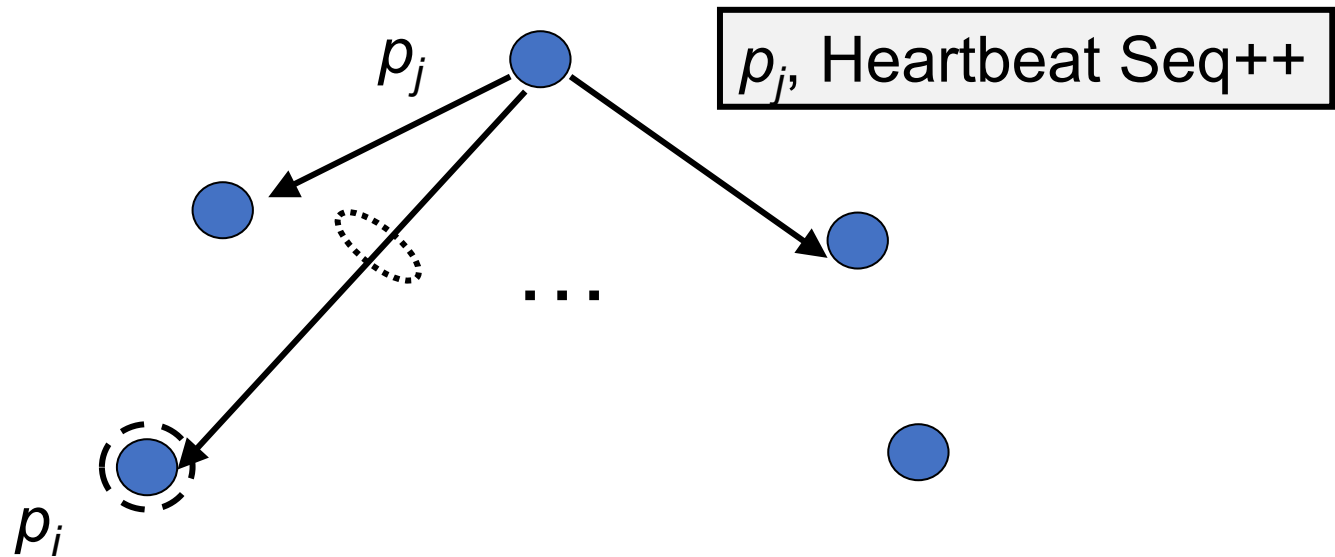
What if p_i fails?



Ring heartbeating



All-to-all heartbeats



Everyone can keep track of everyone.

Downside:

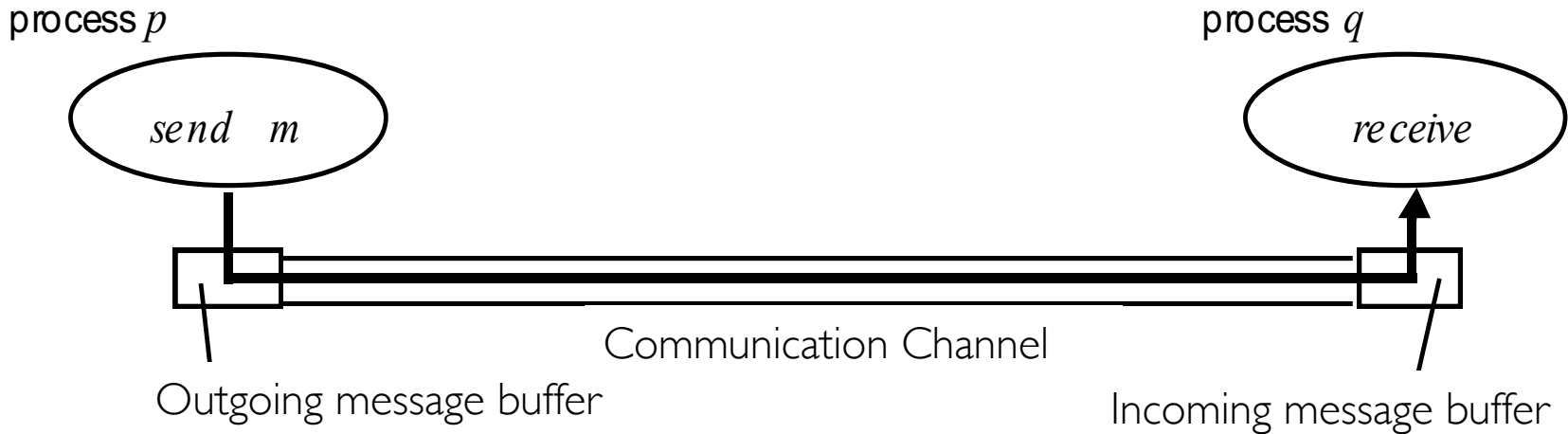
Extending heartbeats

- Looked at detecting failure between two processes.
- How do we extend to a system with multiple processes?
 - Centralized heartbeating: *not complete.*
 - Ring heartbeating: *not entirely complete, ring-repair overhead.*
 - All-to-all: *complete, but more bandwidth usage.*

Types of failure

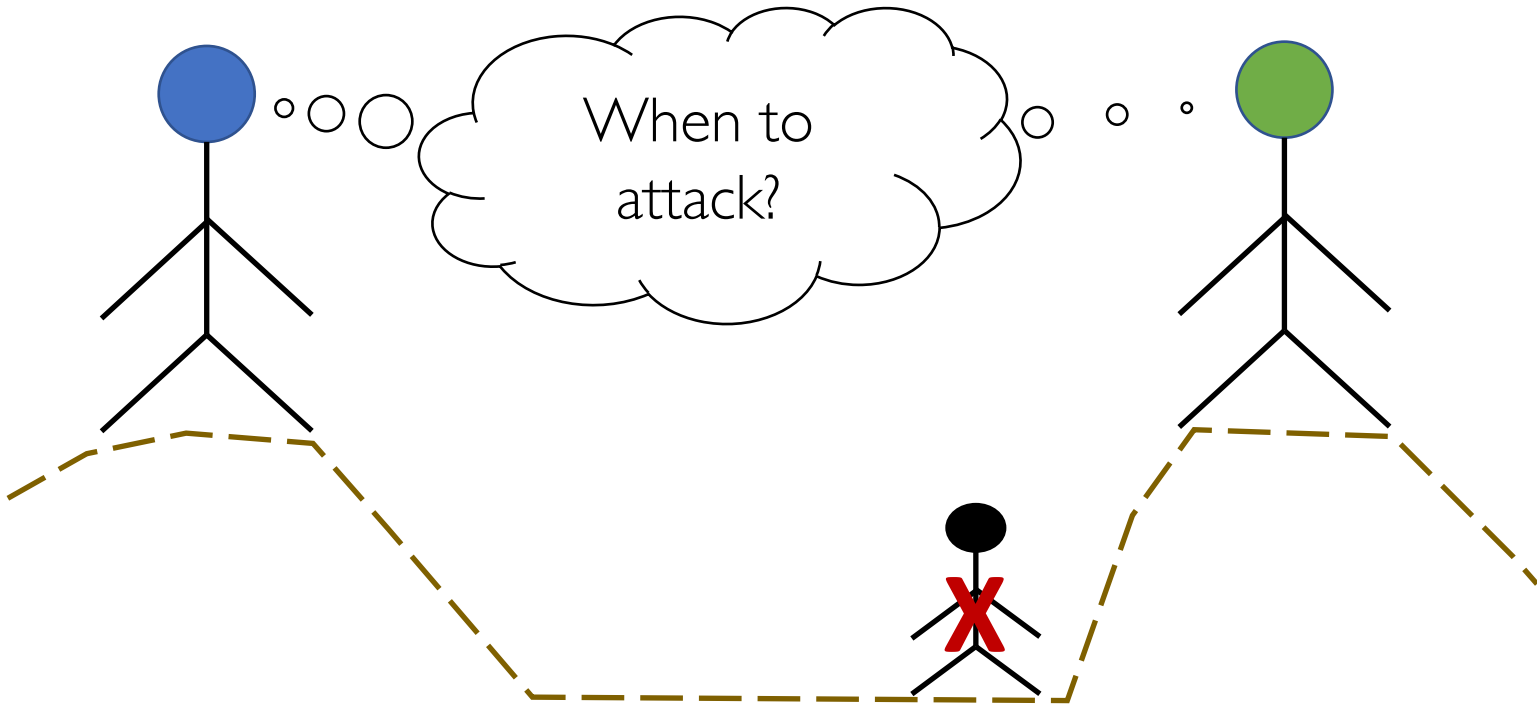
- **Omission:** when a process or a channel fails to perform actions that it is supposed to do.
 - Process may **crash**.
 - **Fail-stop:** if other processes can certainly detect the crash.
 - **Communication omission:** a message sent by process was not received by another.

Communication Omission

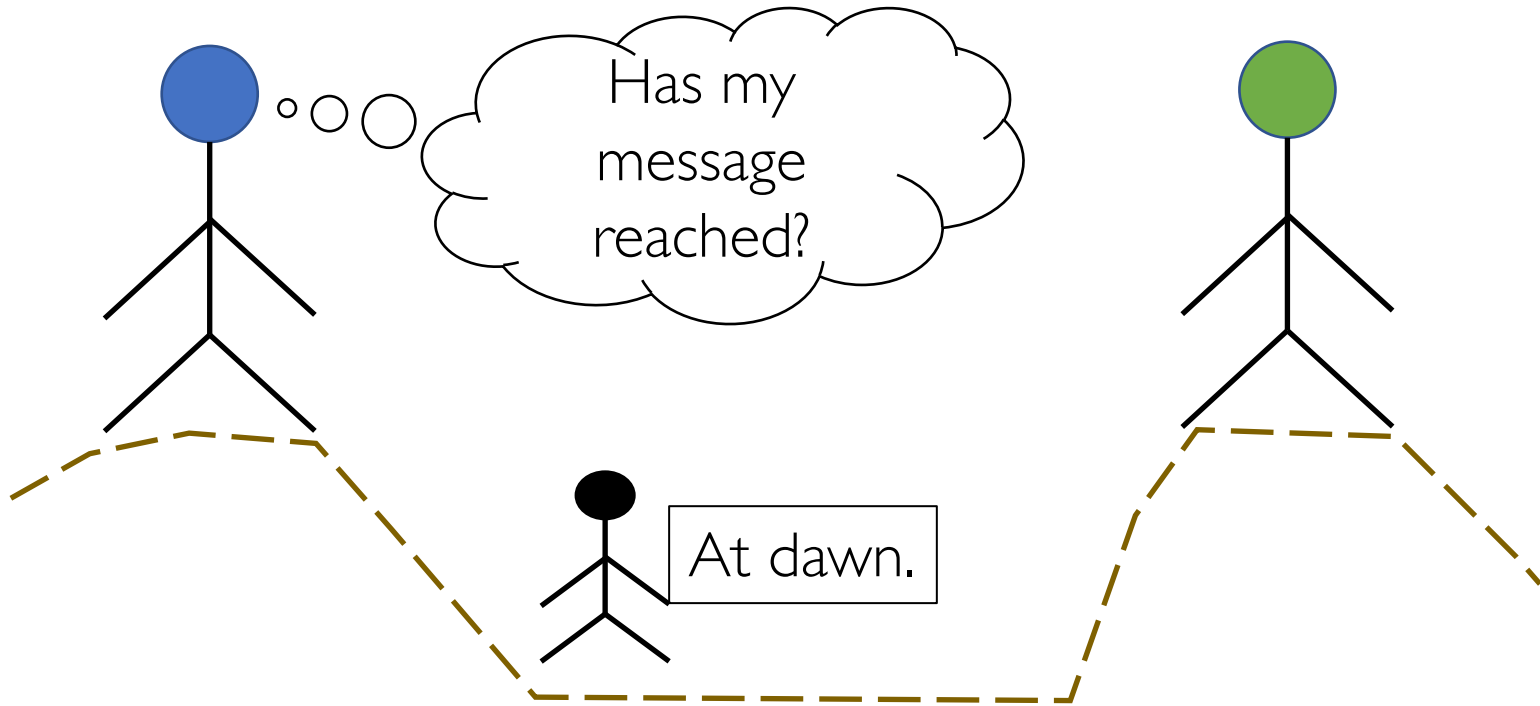


- Channel Omission: omitted by channel
- Send omission: process completes 'send' operation, but message does not reach its outgoing message buffer.
- Receive omission: message reaches the incoming message buffer, but not received by the process.

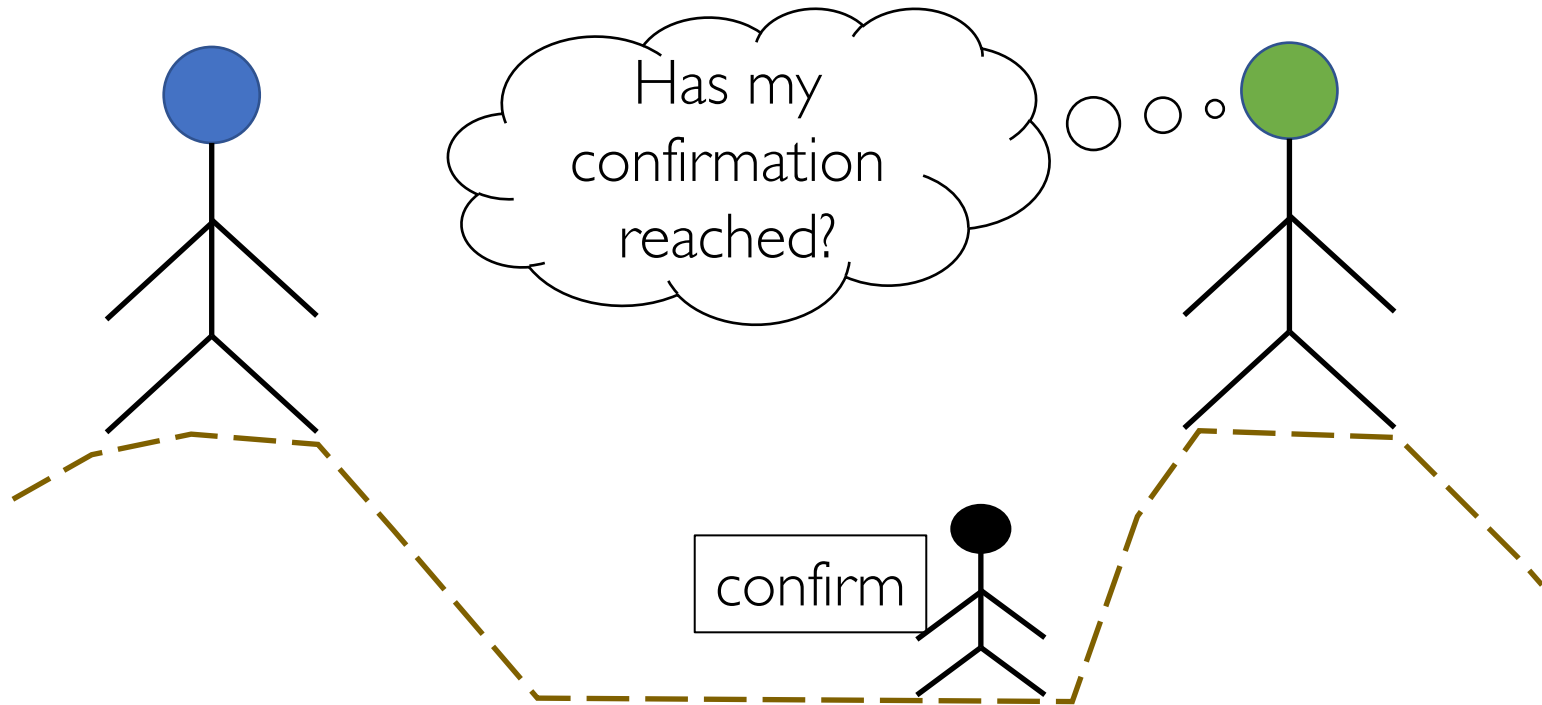
Two Generals Problem



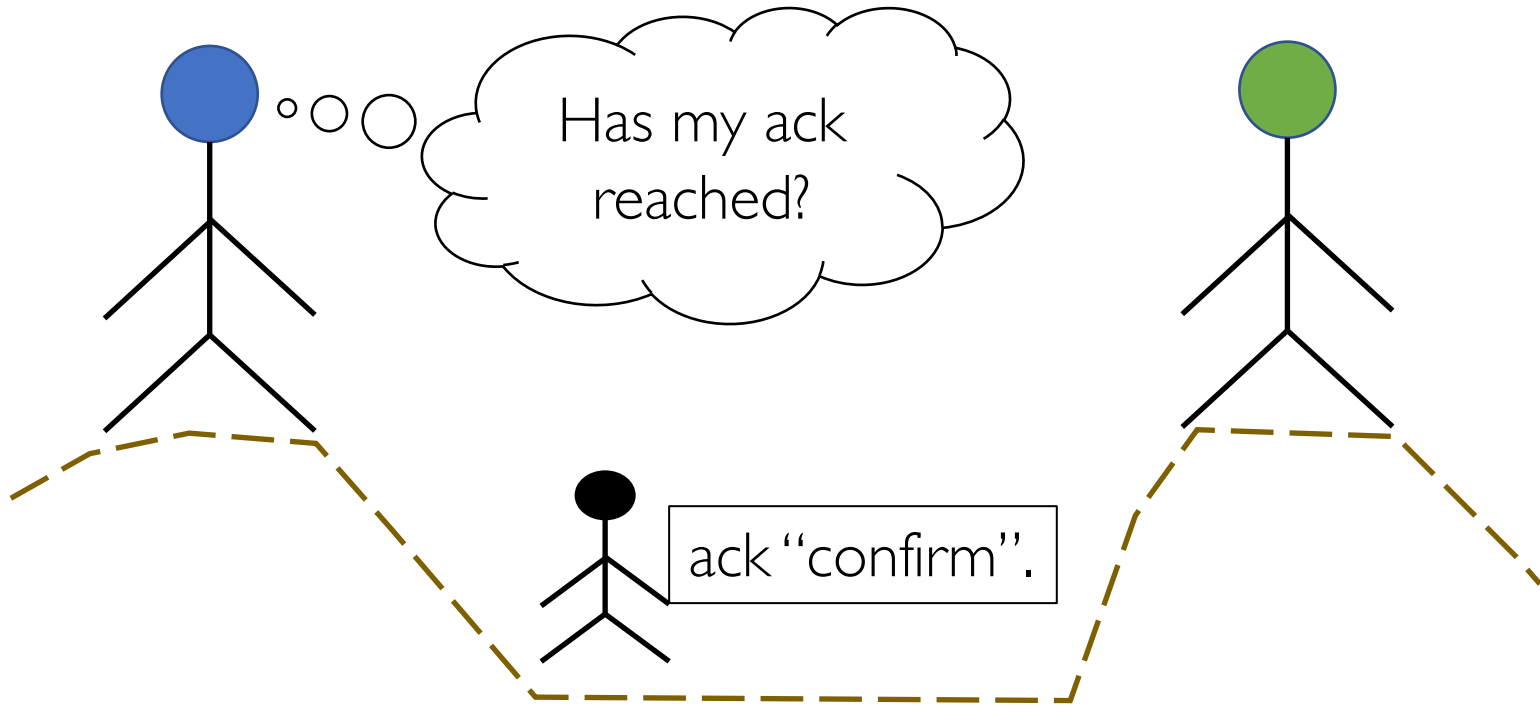
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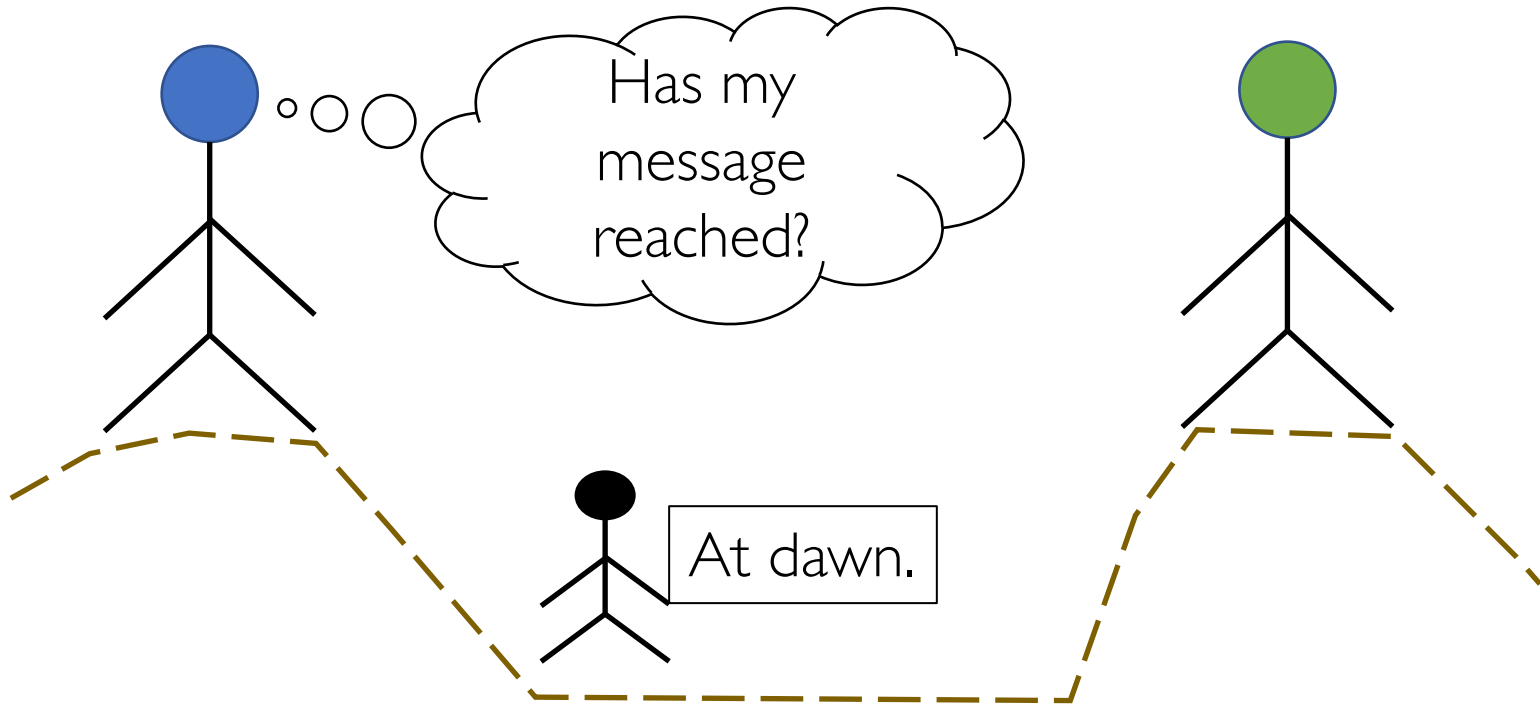
Two Generals Problem



Two Generals Problem

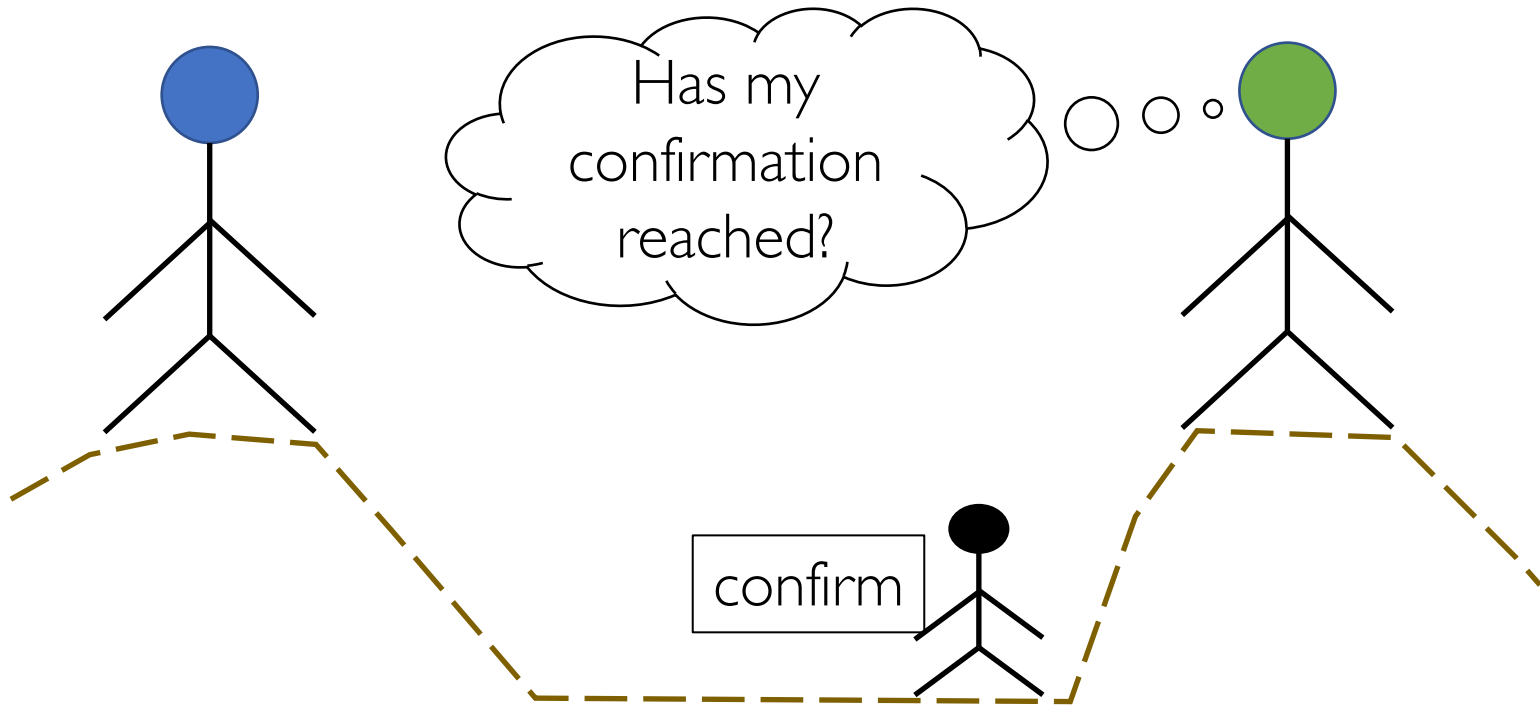


Two Generals Problem



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.

Types of failure

- **Omission:** when a process or a channel fails to perform actions that it is supposed to do, e.g. process crash and message drops.
- **Arbitrary (Byzantine) Failures:** any type of error, e.g. a process executing incorrectly, sending a wrong message, etc.
- **Timing Failures:** Timing guarantees are not met.
 - Applicable only in synchronous systems.

Failures

- Three types
 - omission, arbitrary, timing.
- Failure detection (detecting a crashed process):
 - Send periodic ping-acks or heartbeats.
 - Report crash if no response until a timeout.
 - Timeout can be precisely computed for synchronous systems and estimated for asynchronous.
 - Metrics: *completeness, accuracy, failure detection time, bandwidth.*
 - Failure detection for a system with multiple processes:
 - Centralized, ring, all-to-all
 - Trade-off between completeness and bandwidth usage.

Today's agenda

- Failure Detection
 - Chapter 15.1
- **Time and Clocks**
 - Chapter 14.1-14.3

Why are clocks useful?

- How long did it take my search request to reach Google?
 - Requires my computer's clock to be *synchronized* with Google's server.
- Use timestamps to order events in a distributed system.
 - Requires the system clocks to be *synchronized* with one another.
- At what day and time did Alice transfer money to Bob?
 - Require *accurate* clocks (*synchronized* with a global authority).

Clock Skew and Drift Rates

- Each process has an internal **clock**.
- Clocks between processes on different computers differ:
 - Clock **skew**: relative difference between two clock values.
 - Clock **drift rate**: change in skew from a perfect reference clock per unit time (measured by the reference clock).
 - Depends on change in the frequency of oscillation of a crystal in the hardware clock.
- Synchronous systems have bound on **maximum drift rate**.

Ordinary and Authoritative Clocks

- Ordinary quartz crystal clocks:
 - Drift rate is about 10^{-6} seconds/second.
 - Drift by 1 second every 11.6 days.
 - Skew of about 30minutes after 60 years.
- High precision atomic clocks:
 - Drift rate is about 10^{-13} seconds/second.
 - Skew of about 0.18ms after 60 years.
 - Used as standard for real time.
 - Universal Coordinated Time (UTC) obtained from such clocks.

Two forms of synchronization

- External synchronization
 - Synchronize time with an authoritative clock.
 - When accurate timestamps are required.
- Internal synchronization
 - Synchronize time internally between all processes in a distributed system.
 - When internally comparable timestamps are required.
- If all clocks in a system are externally synchronized, they are also internally synchronized.

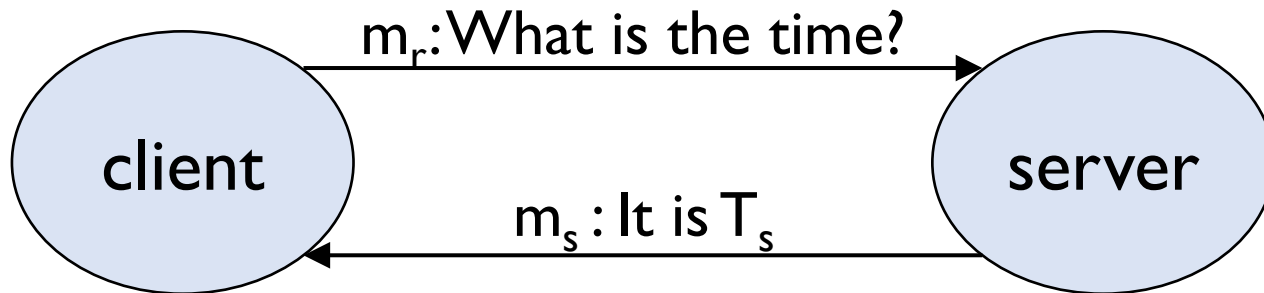
Synchronization Bound

- Synchronization bound (D) between two clocks A and B over a real time interval I .
 - $|A(t) - B(t)| < D$, for all t in the real time interval I .
 - $\text{Skew}(A, B) < D$ during the time interval I .
 - A and B agree within a bound D .
 - If A is authoritative, D can also be called *accuracy bound*.
 - B is *accurate* within a bound of D .
- Synchronization/accuracy bound (D) at time 't'
 - worst-case skew between two clocks at time 't'
 - $\text{Skew}(A, B) < D$ at time t

Q: If all clocks in a system are externally synchronized within a bound of D , what is the bound on their skew relative to one another?

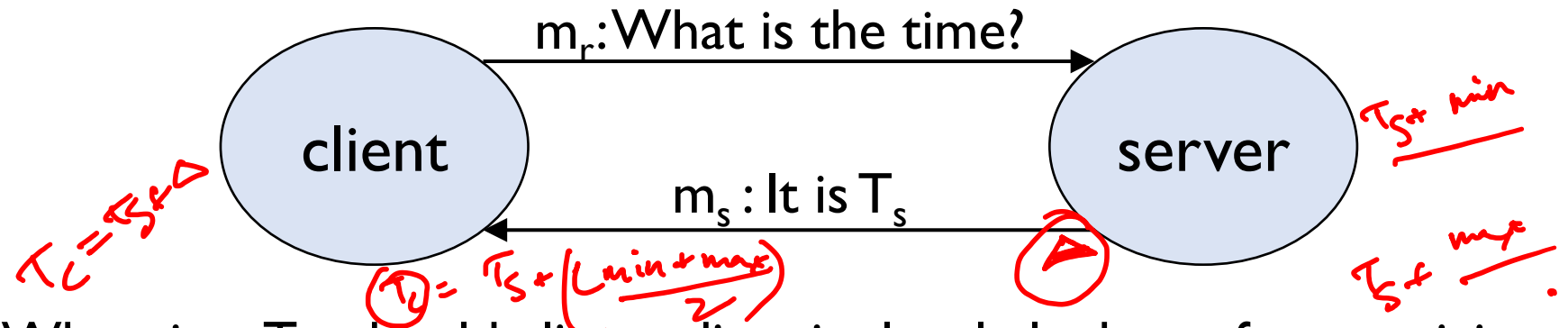
A: $2D$. So the clocks are internally synchronized within a bound of $2D$.

Synchronization in synchronous systems



What time T_c should client adjust its local clock to after receiving m_s ?

Synchronization in synchronous systems



What time T_c should client adjust its local clock to after receiving m_s ?

Let max and min be maximum and minimum network delay.

If $T_c = T_s$, $skew(client, server) \leq max$.

If $T_c = (T_s + max)$, $skew(client, server) \leq (max - min)$

If $T_c = (T_s + min)$, $skew(client, server) \leq (max - min)$

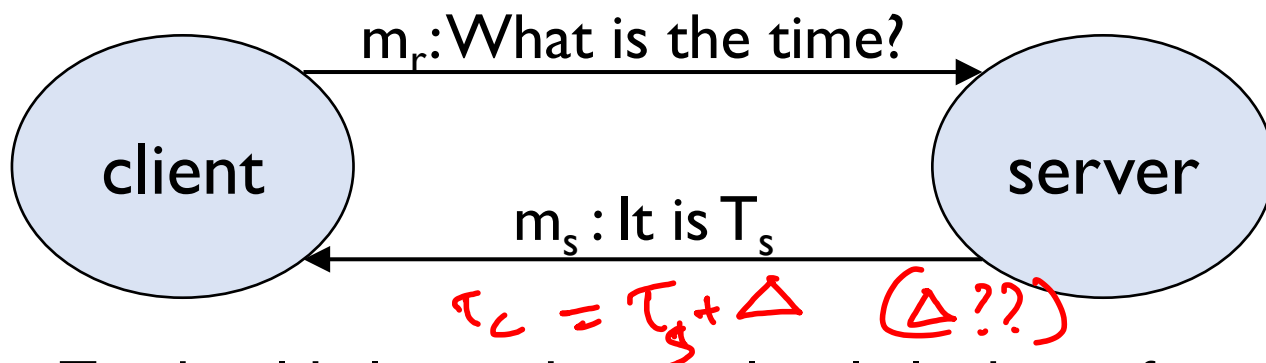
If $T_c = (T_s + (min + max)/2)$, $skew(client, server) \leq (max - min)/2$

Provably the best you can do!

Synchronization in asynchronous systems

- Cristian Algorithm
- Berkeley Algorithm
- Network Time Protocol

Cristian Algorithm



What time T_c should client adjust its local clock to after receiving m_s ?

Client measures the round trip time (T_{round}).

$$T_c = T_s + (T_{\text{round}} / 2)$$

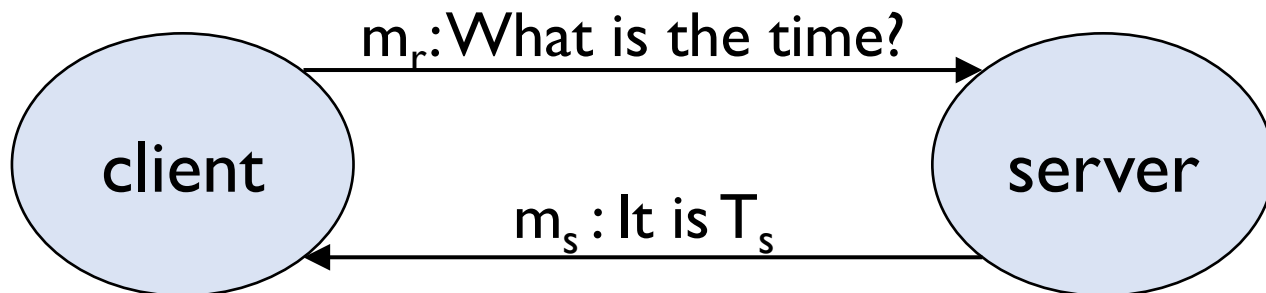
$$\text{skew} \leq (T_{\text{round}} / 2) - \text{min}$$
$$\leq (T_{\text{round}} / 2)$$

(min is minimum one way network delay which is atleast zero).

Try deriving the worst case skew!

Hint: client is assuming its one-way delay from server is $\Delta = (T_{\text{round}}/2)$. How off can it be?

Cristian Algorithm



What time T_c should client adjust its local clock to after receiving m_s ?

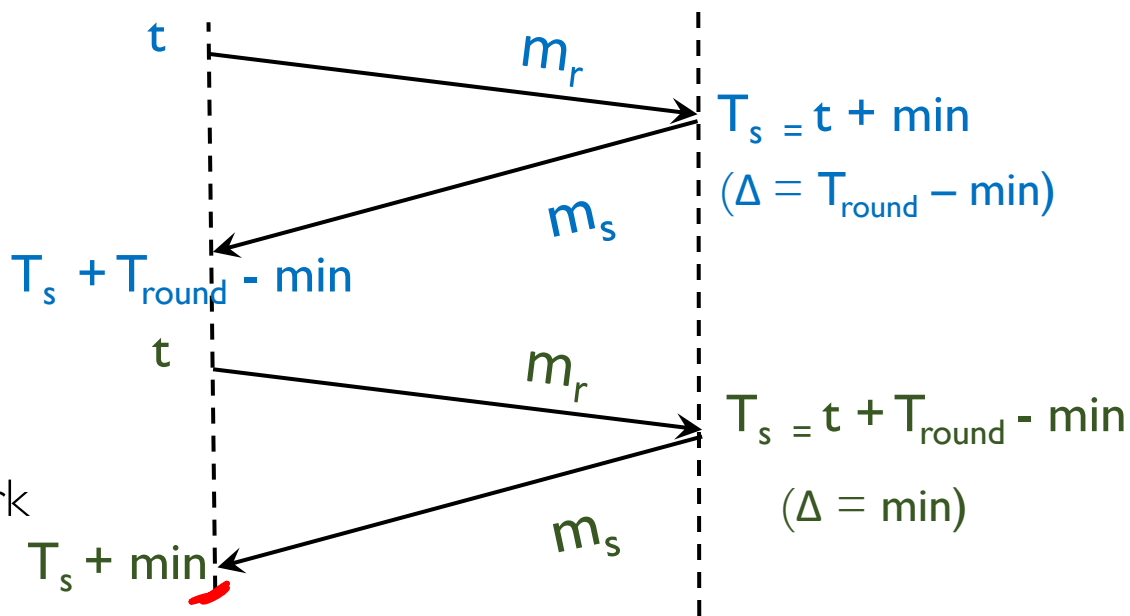
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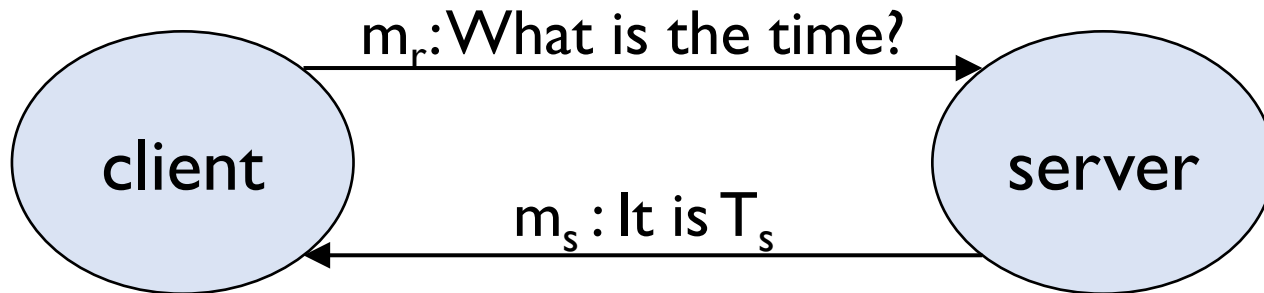
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Cristian Algorithm



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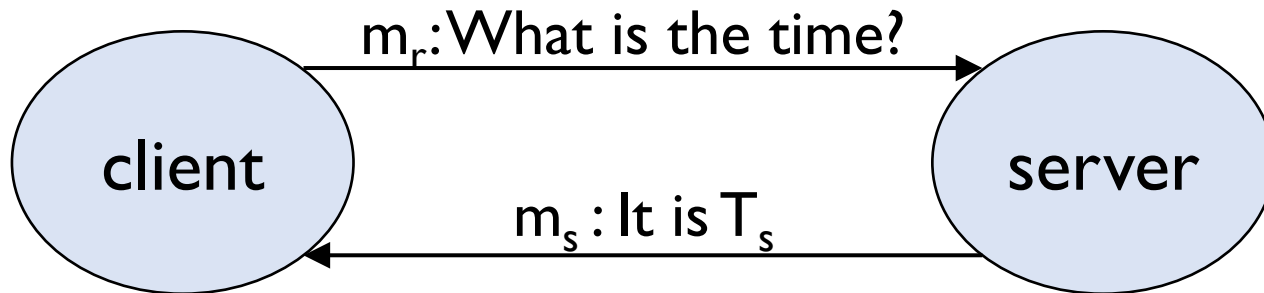
$$\text{skew} \leq (T_{\text{round}} / 2) - \text{min}$$
$$\leq (T_{\text{round}} / 2)$$

(*min* is minimum one way network delay which is atleast zero).

Improve accuracy by sending multiple spaced requests and using response with smallest T_{round} .

Server failure: Use multiple synchronized time servers.

Cristian Algorithm



What time T_c should client adjust its local clock to after receiving m_s ?

Client measures the round trip time (T_{round}).

$$T_c = T_s + (T_{\text{round}} / 2)$$

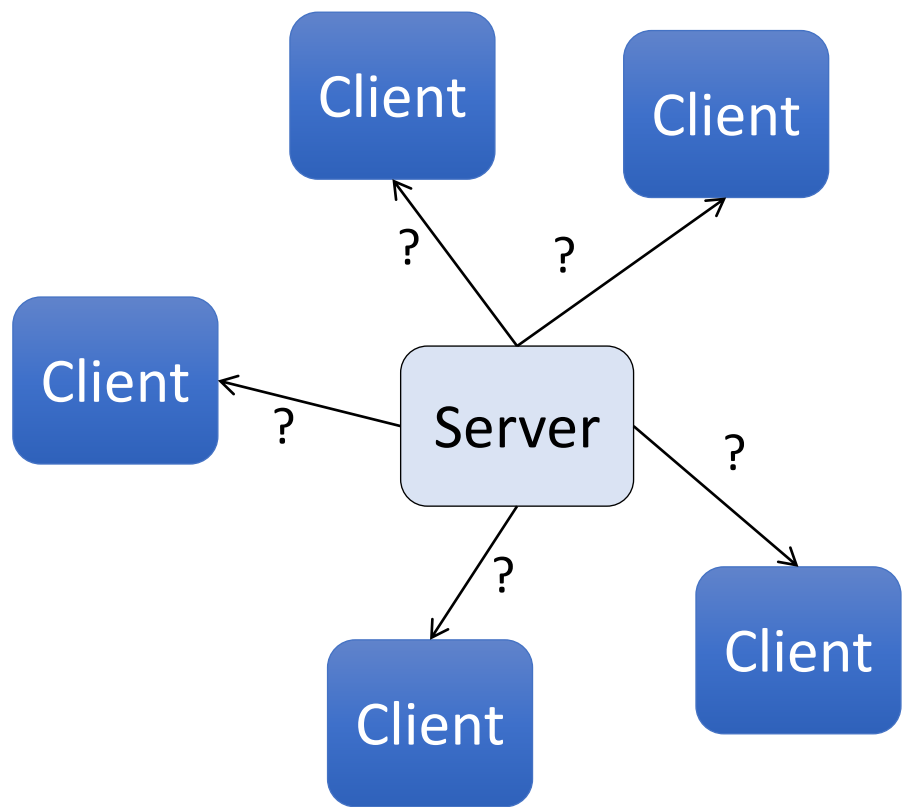
$$\text{skew} \leq (T_{\text{round}} / 2) - \text{min}$$
$$\leq (T_{\text{round}} / 2)$$

(*min* is minimum one way network delay which is atleast zero).

**Cannot handle
faulty time
servers.**

Berkeley Algorithm

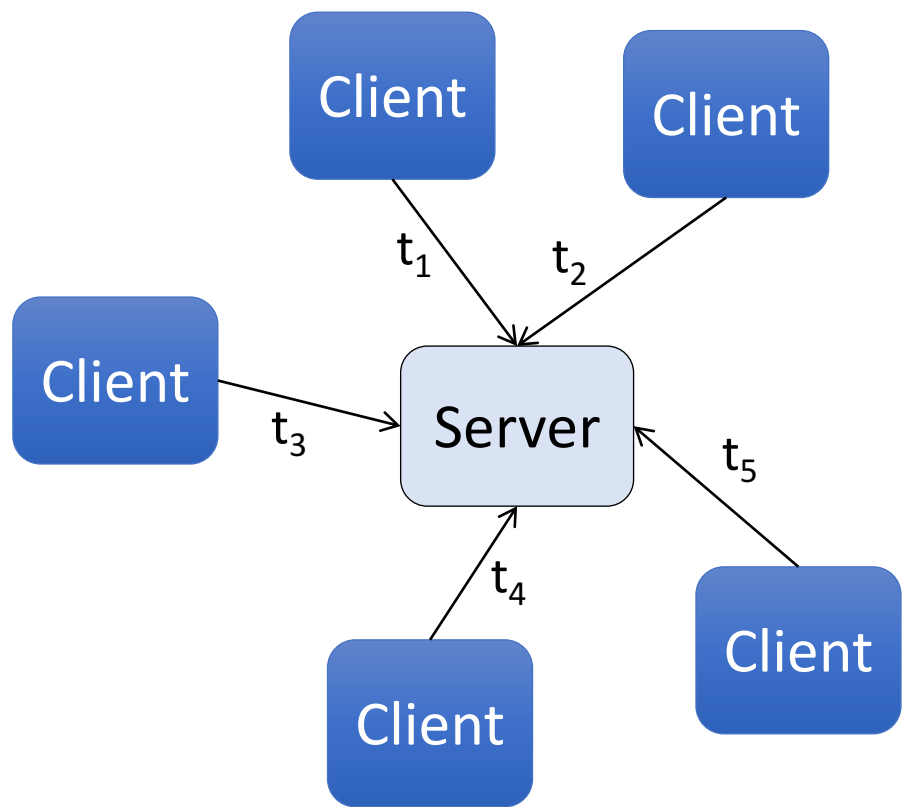
Only supports internal synchronization.



- I. Server periodically polls clients:
"what time do you think it is?"

Berkeley Algorithm

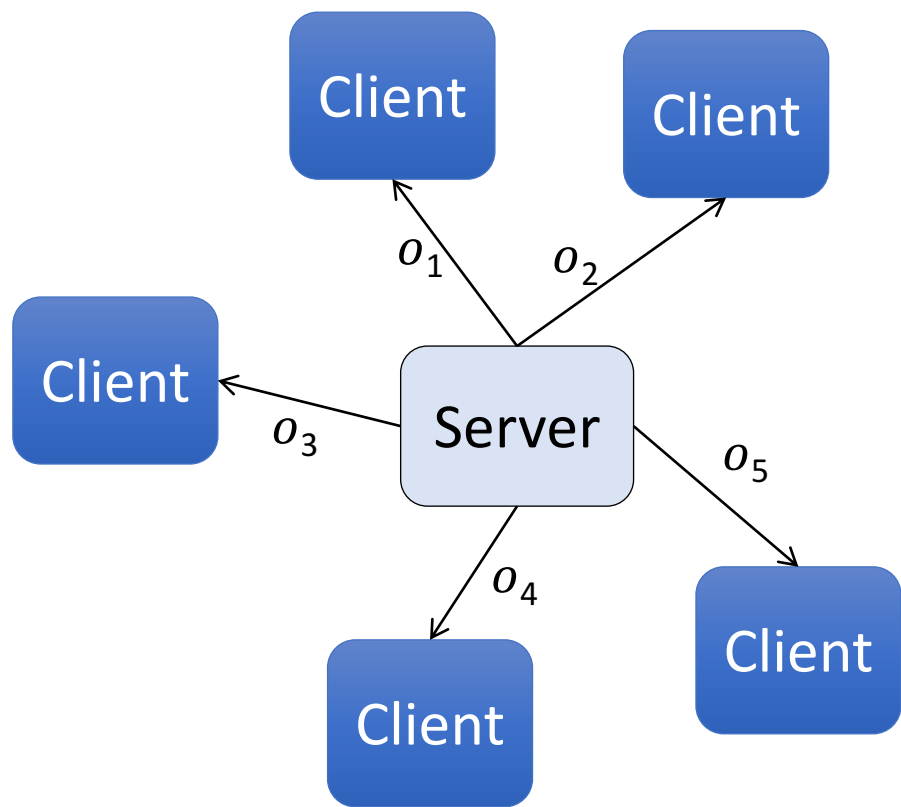
Only supports internal synchronization.



1. Server periodically polls clients: *“what time do you think it is?”*
2. Each client responds with its local time.
3. Server uses Cristian algorithm to estimate local time at each client.
4. Average all local times (including its own) – use as updated time.

Berkeley Algorithm

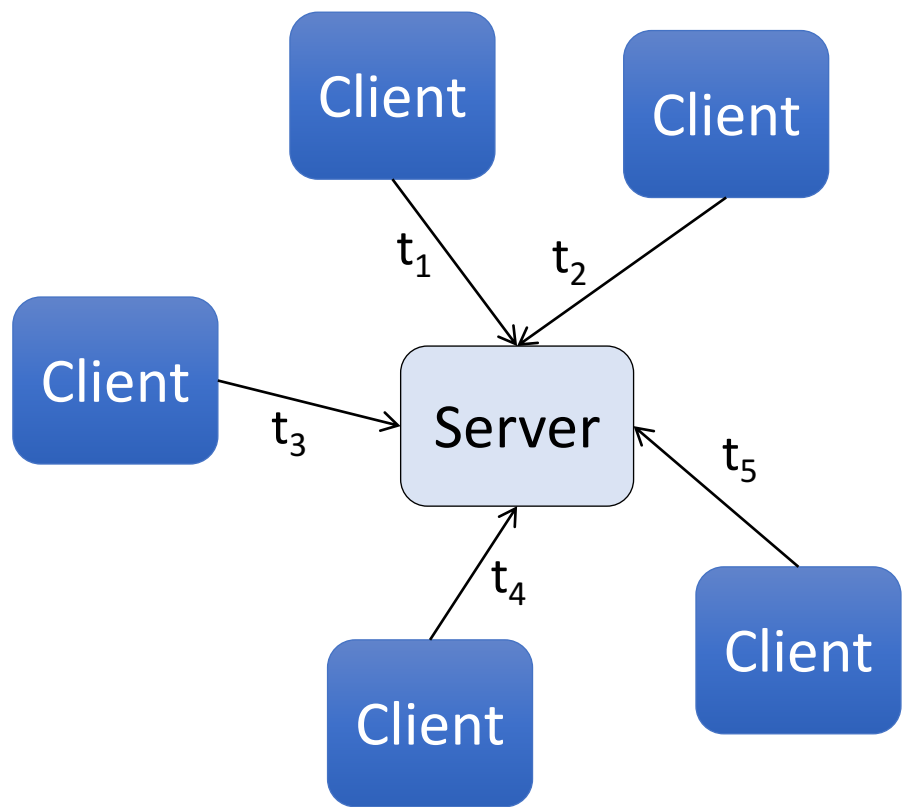
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1. Server periodically polls clients: *"what time do you think it is?"*
2. Each client responds with its local time.
3. Server uses Cristian algorithm to estimate local time at each client.
4. Average all local times (including its own) – use as updated time.
5. Send the offset (amount by which each clock needs adjustment).

Berkeley Algorithm

Only supports internal synchronization.



Handling faulty processes:
Only use timestamps within
some threshold of each other.

Handling server failure:
Detect the failure and elect a
new leader.