Atomic Broadcast
CASD Protocols

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Outline

- Introduction
- CASD Protocols
  - Basic CASD protocol
  - Second Protocol, Tolerant of timing failures
  - Third Protocol, Tolerant of authentication-detectable Byzantine failures
- Discuss on Δ

Intro.

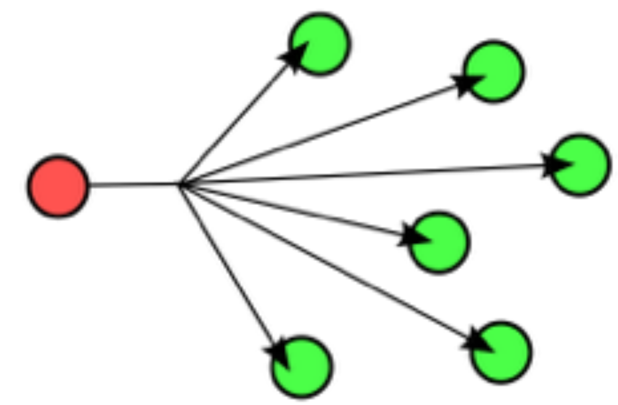
- It’s hard to perform a reliable broadcast with real-time and other guarantees (total order, atomicity) within a distributed system
  - random failure
  - communication delay
- **Goal**: ensure the *correct* processes participating in a broadcast to attain *consistent* information.
  - Atomic broadcast
  - CASD (**C**ristian, **A**ghili, **S**trong, **D**olev) Protocols

The CASD protocol suite

- Also known as the “ Δ-T” protocols
- Developed by Cristian and others at IBM, was intended for use in the (ultimately, failed) FAA project
- Goal is to implement a timed atomic broadcast tolerant of Byzantine failures

Flaviu Cristian
1951-1999

What's atomic broadcast



- Broadcast: make all of them know
- Guarantees
  - Real-Time: all correct processes deliver at the same time and within a finite delay
  - Failure-Atomicity: all or none
  - Order: messages are delivered in same order among all correct processes
- Can be used to implement synchronous replicated storage

Caveats

- Imperfect clock should be acceptable
- A process may not be able to detect that its own clock is incorrect.
- When a process is faulty, the guarantees no longer apply to it.

Failure Classification

- Omission failures: Omit one or more response. E.g. crash, link down, link occasionally loses messages, etc.
- Timing failures: respond too early/late
- Byzantine failure: corrupted messages,
  - Authentication-detectable subset
- Nested

$$Omission \subset Timing \subset Byzantine$$

System Model

- G=(E,V)
- network diameter: *d*
- Primitives:
  - broadcast(σ): init a atomic broadcast
  - send(*m*) on *l*: send msg. *m* on link *l*
  - receive(*m*) from *i*: receive a msg. *m* on link *i*

Assumptions

- Share accurate clock $|C_p(t) - C_q(t)| < \epsilon$
- *n* processes, at most *k* of them may be faulty
- failures won't cause the network to be disconnected
- Transmission and processing delay $< \delta$
- number of lost packets is finite in a single run

Basic CASD

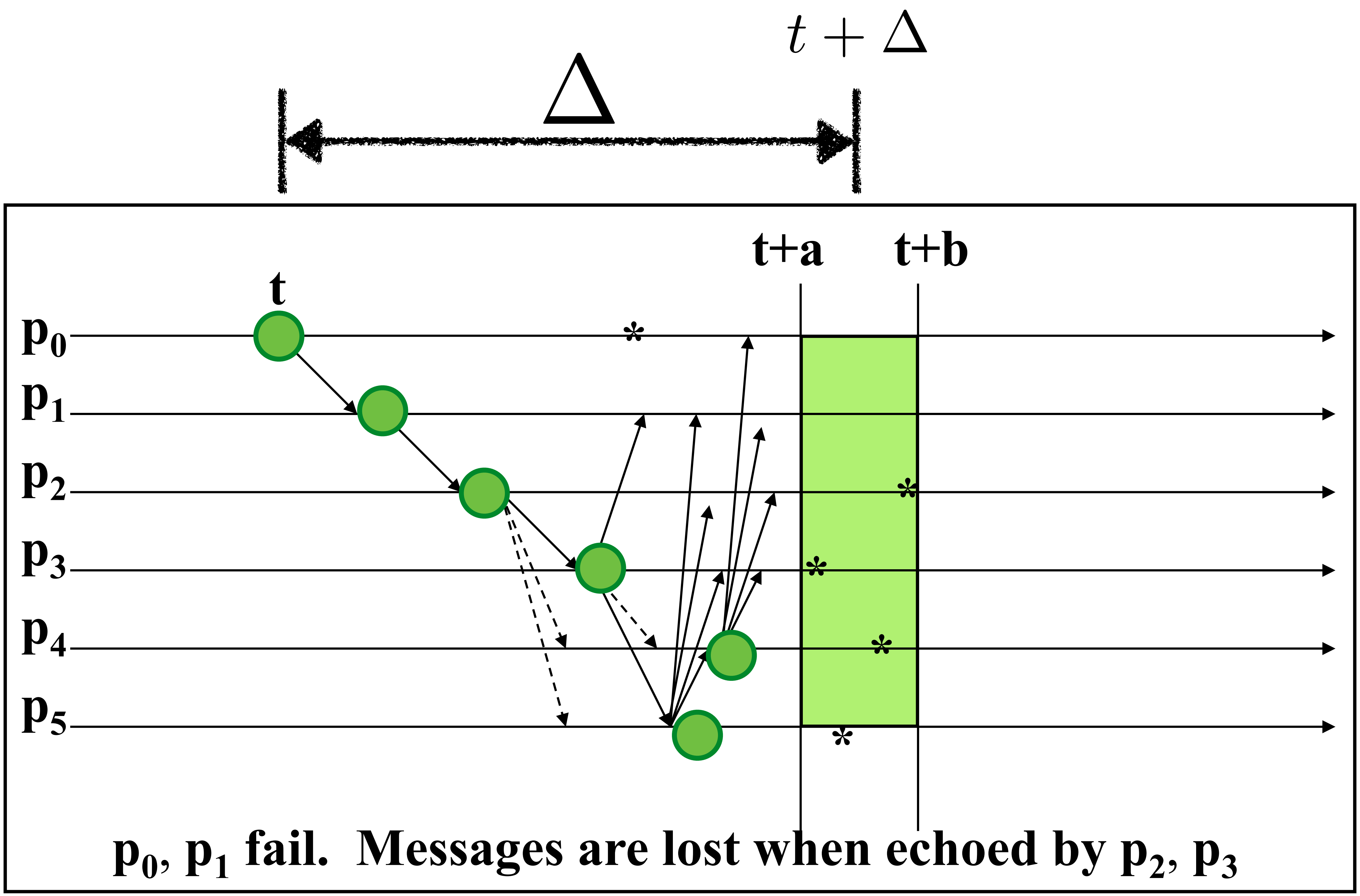
Tolerant of Omission

Basic CASD Protocol

- message = {msg, t, pid}
  - *msg*: body of message
  - *t*: timestamp (local to the sender)
  - *pid*: identification of the sender process
- receive and relay manner

Basic CASD Protocol

- A process *p* initiate a broadcast at *t* by creating message m={*msg*, *t*, *pid*}.
- *p* forwards m to all reachable processors
- Upon receipt of m at another processor *p*'
  - discard *m* if duplicated or out of feasible time range
  - reply *m* over all links except incoming one
- All process hold *m* until $t+\Delta$ and then deliver in the order of timestamp (break tie with pid)



Source: Slides for CS5412, Ken

get the msg.

* deliver the msg.

Ideas

- Assume known limits on number of processes that fail during protocol, number of messages lost
- Using these and the temporal assumptions, deduce worst-case scenario
- Now now that if we wait long enough, all (or no) correct process will have the message
- Then schedule delivery using original time plus a delay computed from the worst-case assumptions

Δ "*deliver deadline*"

- broadcast begins at *t*, all processes deliver at *t*+Δ
- Δ is an estimated amount, based on configuration
- How big Δ should be?
  - Big enough for all ***correct*** processes to receive *m* at t+Δ
  - Small enough for whole system to be efficient

Reasoning Δ

- Ensure Δ is large enough even in worst case
  - Msg. is created by faulty process and go through *all faulty processes* before reach the first correct process
  - Faulty processes are very faulty — they just forward the msg. *to one neighbor* (if zero, the broadcast would fail)— kδ
  - Msg. diffuses among correct processes for longest possible time — dδ

$$\Delta = k\delta + d\delta + \epsilon$$

faulty *diffuse* *clock skew*

Second Protocol

Tolerant of Timing Failure

Idea

- In first protocols, the “acceptance window” is fixed
  - accept if $t < T+\Delta$ & no duplicate
  - A msg. might be “too late” for (early) correct processes yet “in time” for other (late) correct processes.
- Must ensure all correct neighbors behave coherently

- if p accept m(@tp), p's neighbor q should accept m if p receive m(@tq)
  - $-\epsilon < tp - tq < \delta + \epsilon$
    - $-\epsilon$: p is ϵ behind q, delay is zero
    - $\delta+\epsilon$: q is ϵ earlier than q, delay is δ
- msg = (msg *m*, timestamp *T*, #hop *h*)
- Timeliness Acceptance: $T - h\epsilon < t < T + h(\delta + \epsilon)$
- Deliver deadline: $\Delta = k(\delta + \epsilon) + d\delta + \epsilon$

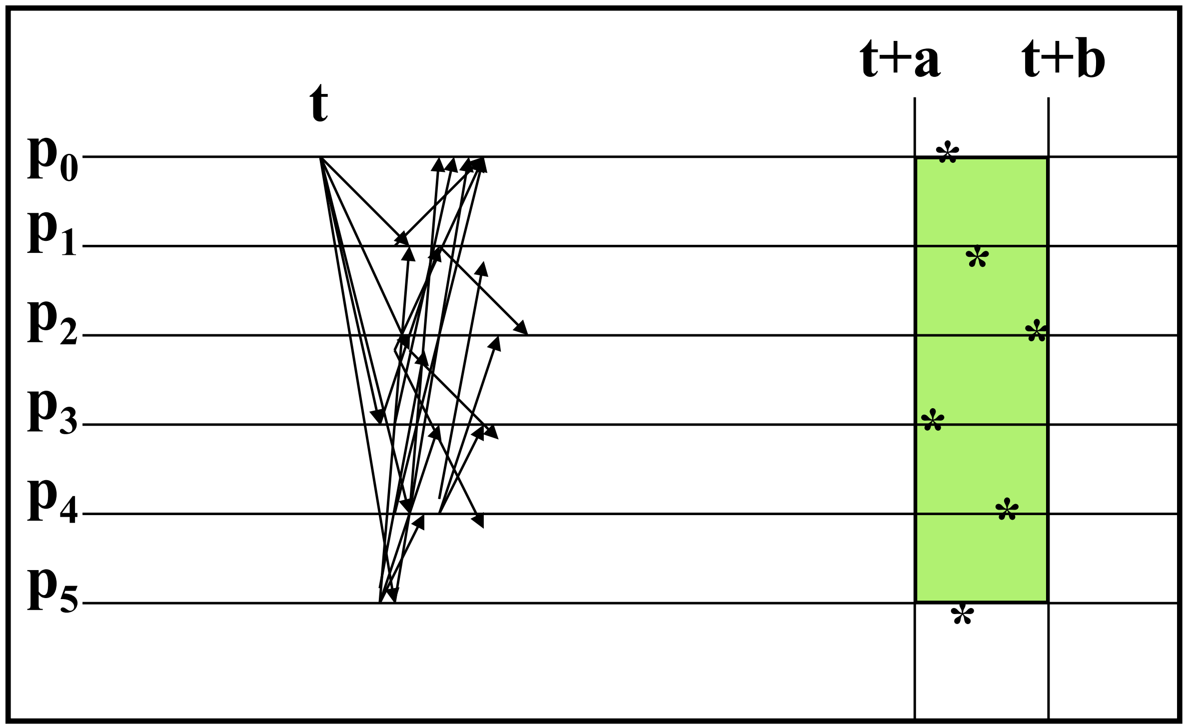
Third Protocol

Tolerating Authentication-Detectable Byzantine

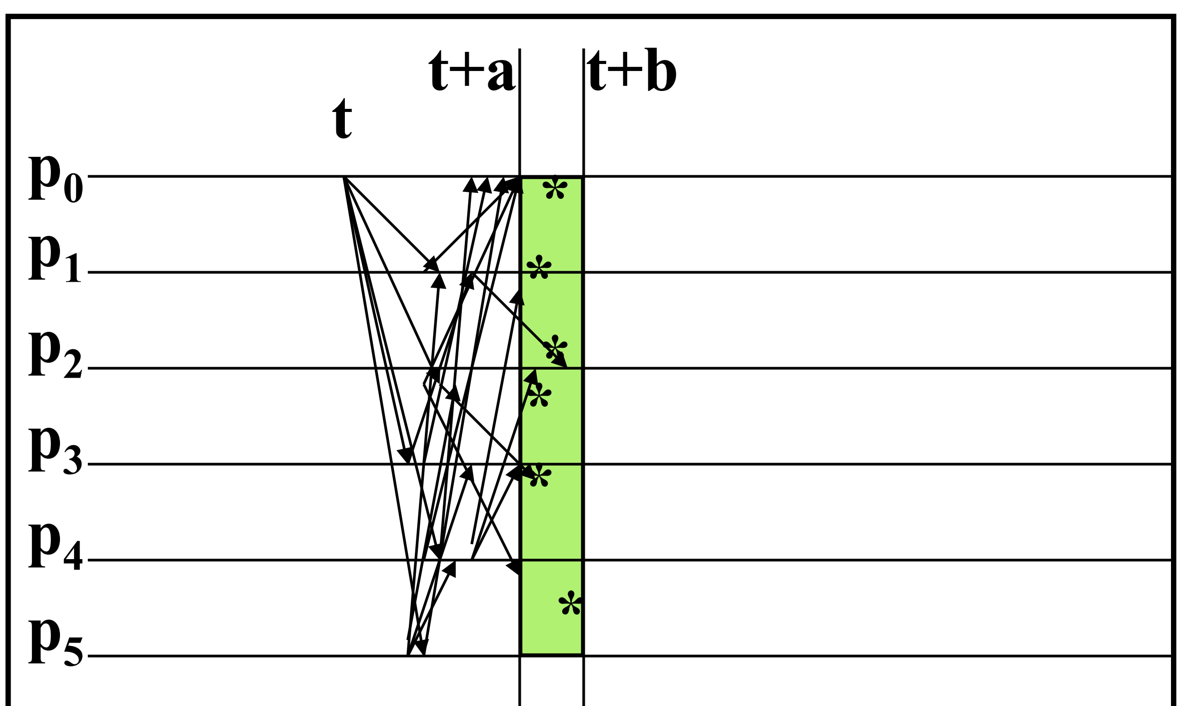
Idea

- Use authentication to determine if the msg. is corrupted
  - Sender *signs* the msg.
  - Relayers *authenticate* the msg. then *co-sign* & relay it
    - *deliver* only if the msg. can be authenticated
    - *discard* corrupted messages
- Termination time is same as the second protocol
  - But msg. processing delay increases (~10 times)

Delta



Over relaxed! Keep waiting unnecessarily



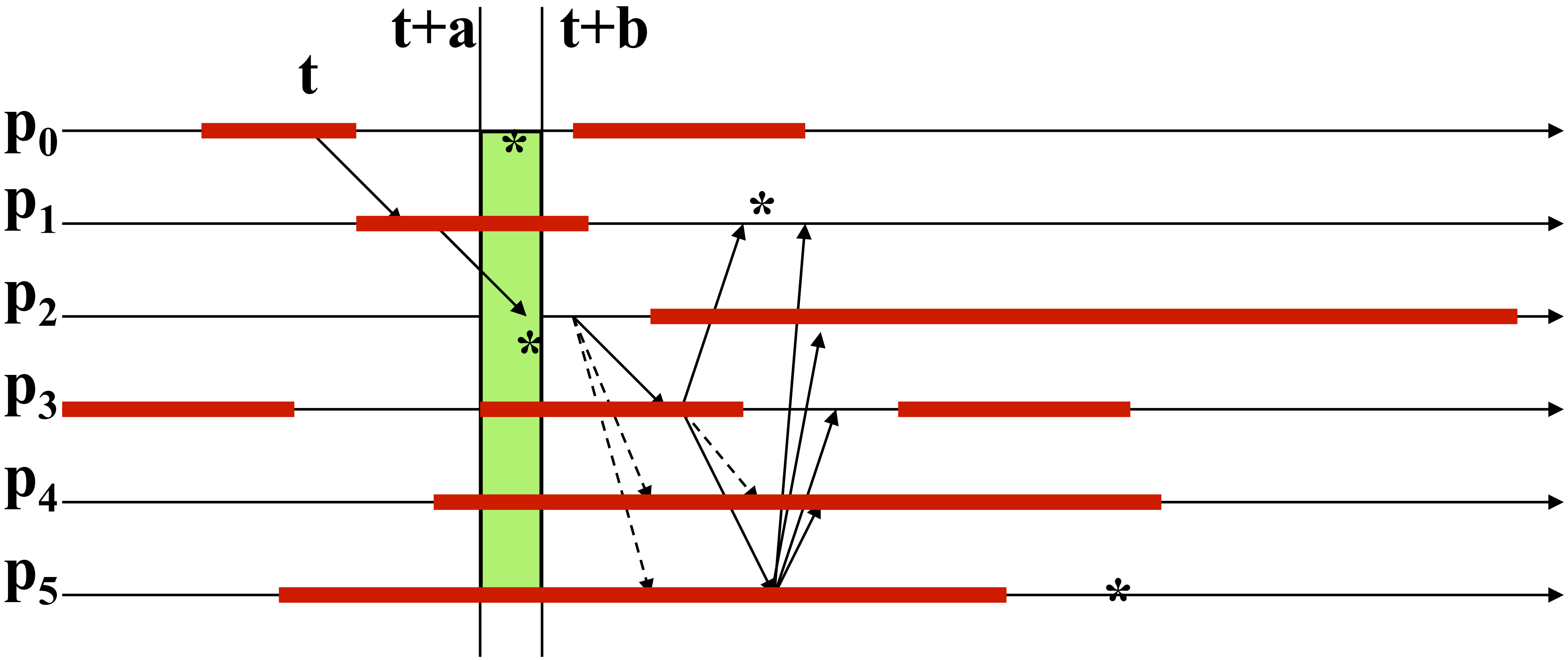
Aggressive?

Reduce Δ

- Δ is essentially a minimum latency for the protocol
  - Δ=3s, in LAN used by CS Cornell
- How to squeeze $\Delta = k\delta + d\delta + \epsilon$
  - Assume (almost) fully connected d = 1
  - Assume processes and communication is reliable (k)
  - Clocks are closely synchronized
  - Δ can be reduced to 100-150ms

Problems

- Reduce Δ will cause more process to be considered "faulty"
  - Not really faulty, but only in protocol's eye
  - Guarantees no longer hold for such processes
- Thus, CASD is weak because the processes using it has no way to know whether or not it's one of the correct ones.
- **Probabilistically reliable**



all processes look “incorrect” (red) from time to time

Problem

- Incorrect processes can still operate even without any guarantee
  - divergence of states occurs
- Incorrect processes are not excluded from the system
  - They can still initiate messages
  - Their inconsistency can spread
- **No way for inconsistent system to coverage back to a consistent state.**

Repair

- “silent” failures
- static membership with subsets who are faulty but with them notified in some way (So that the faulty processes will know about their failure)
  - Byzantine problem?
- managed membership (in which you can only treat a process as faulty if you are prepared to first exclude that process from the system completely)
  - Another global state?

Summary

- Atomic broadcast: real-time, total ordered and atomicity.
- Could be quite slow if we use conservative parameter settings
  - But with aggressive settings, either process could be deemed “faulty” by the protocol
  - If so, it might become inconsistent
- Merit: In reliable environment, the CASD protocols are guaranteed to satisfy their real-time properties.

Thanks!