CS425 /CSE424/ECE428 – Distributed Systems – Fall 2011

Leader Election

Material derived from slides by I. Gupta, M. Harandi, J. Hou, S. Mitra, K. Nahrstedt, N. Vaidya

Why Election?

- Example 1: Your Bank maintains multiple servers in their cloud, but for each customer, one of the servers is responsible, i.e., is the leader
  - What if there are two leaders per customer?
  - What if servers disagree about who the leader is?
  - What if the leader crashes?

Why Election?

- Example 2: sequencer for TO multicast, leader for mutual exclusion
- Example 3: Group of cloud servers replicating a file need to elect one among them as the primary replica that will communicate with the client machines
- Example 4: Group of NTP servers: who is the root server?

What is Election?

- In a group of processes, elect a Leader to undertake special tasks.
- What happens when a leader fails (crashes)
  - Some process detects this (how?)
  - Then what?
- Focus of this lecture: Election algorithm
  - 1. Elect one leader only among the non-faulty processes
  - 2. All non-faulty processes agree on who is the leader

Assumptions

- Any process can call for an election.
- A process can call for at most one election at a time.
- Multiple processes can call an election simultaneously.
  - *All of them together must yield a single leader only*
  - *The result of an election should not depend on which process calls for it.*
- Messages are eventually delivered.

Problem Specification

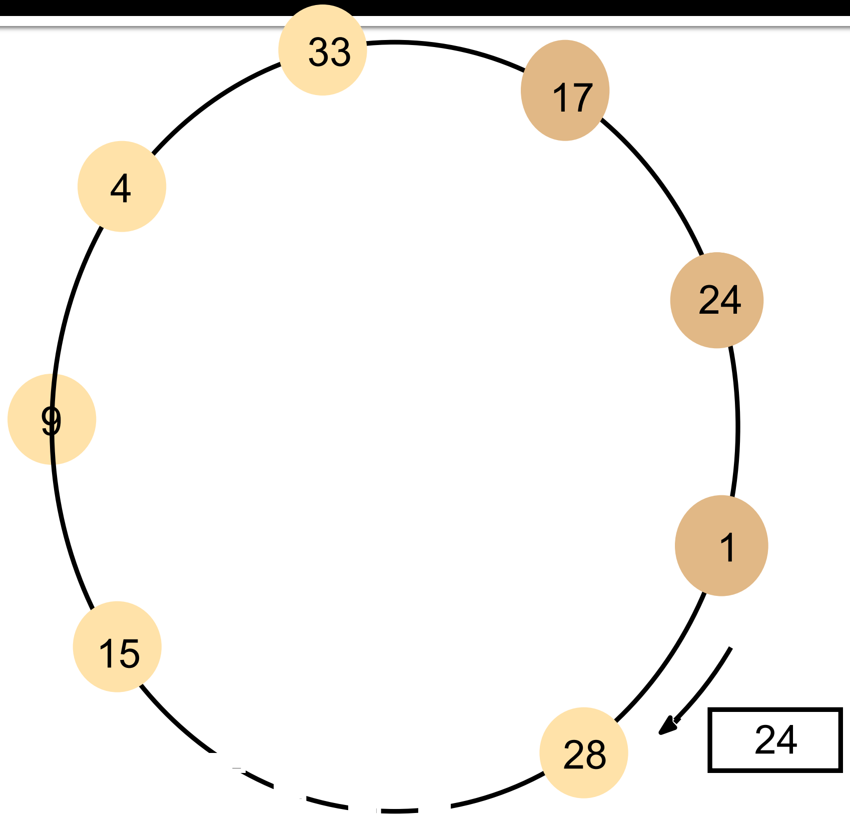
- At the end of the election protocol, the non-faulty process with the best (highest) election attribute value is elected.
  - Attribute examples: CPU speed, load, disk space, ID
  - Must be unique
- A run (execution) of the election algorithm must always guarantee at the end:
  - Safety: ∀ non-faulty p: (p's elected = (q: a particular non-faulty process with the best attribute value) or ⊥)
  - Liveness: ∀ election: (election terminates)
  - & ∀ p: non-faulty process, p's elected is not ⊥

Algorithm 1: Ring Election [Chang & Roberts'79]

- N Processes are organized in a logical ring
  - p_i has a communication channel to $p_{i+1 \bmod N}$.
  - All messages are sent clockwise around the ring.
- To start election
  - Send "election" message with my ID
- When receiving message ("election",id)
  - If id > my ID: forward message
    - Set state to "participating"
  - If id < my ID: send ("election", my ID)
    - Skip if already "participating"
    - Set state to "participating"
  - If id = my ID: I am elected (why?) send "elected" message
    - "elected" message forwarded until it reaches leader

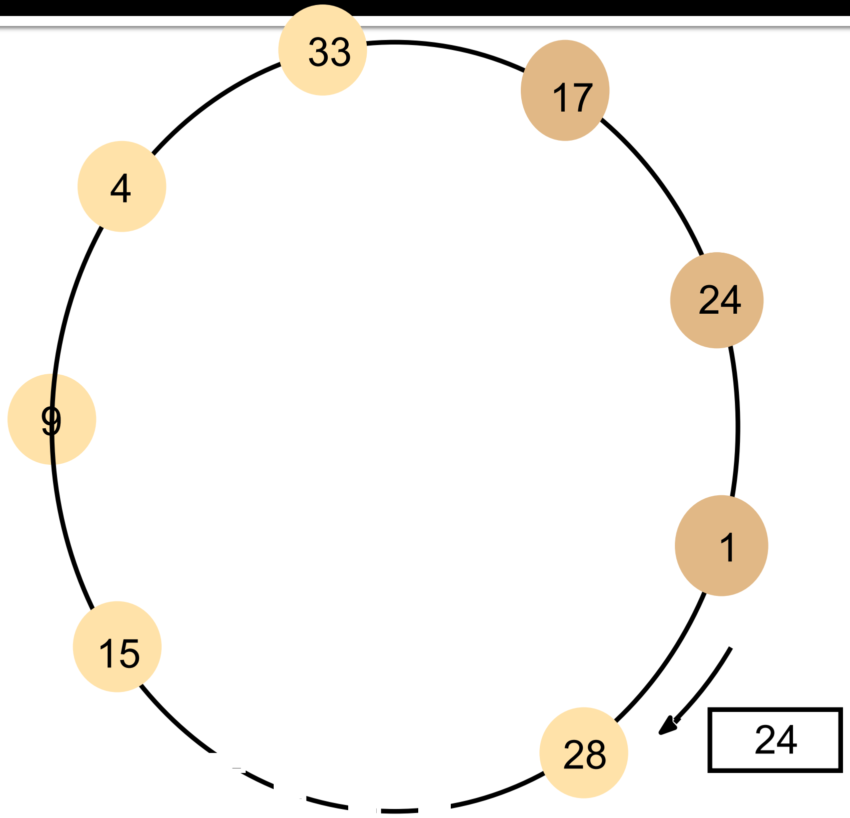
Ring-Based Election: Example

- The worst-case scenario occurs when the counter-clockwise neighbor (@ the initiator) has the highest attr.
- In the example:
  - The election was started by process 17.
  - The highest process identifier encountered so far is 24
  - (final leader will be 33)



Ring-Based Election: Analysis

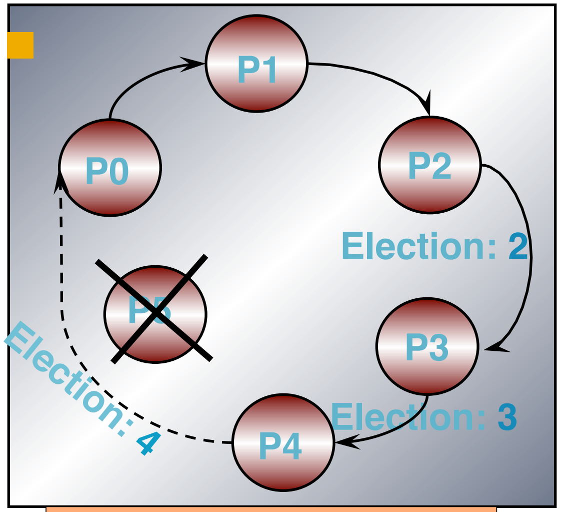
- In a ring of N processes, in the worst case:
  - N-1 election messages to reach the new coordinator
  - Another N election messages before coordinator decides it’s elected
  - Another N elected messages to announce winner
- Total Message Complexity = 3N-1
- Turnaround time = 3N-1



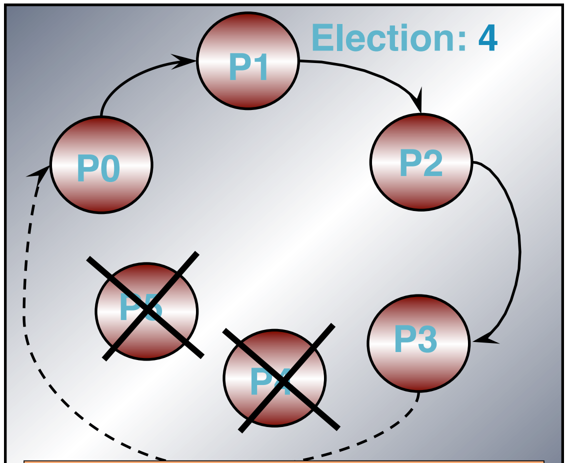
Correctness?

- Safety: highest process elected
- Liveness: complete after 3N-1 messages
  - What if there are failures during the election run?

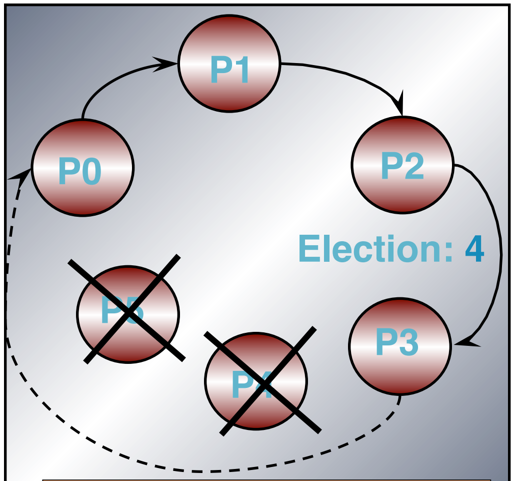
Example: Ring Election



1. P2 initiates election after old leader P5 failed



2. P2 receives "election", P4 dies



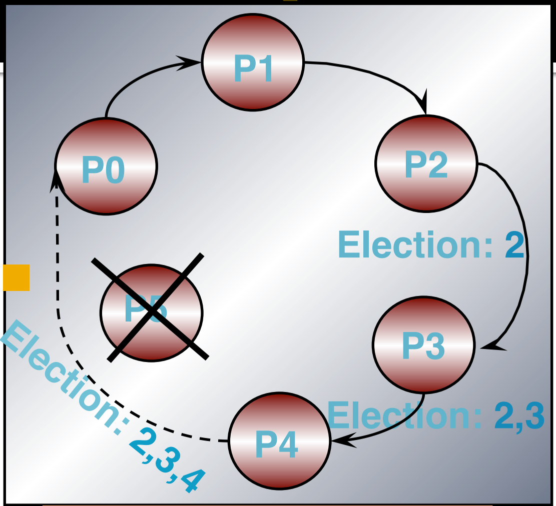
3. Election: 4 is forwarded for ever?

May not terminate when process failure occurs during the election!
Consider above example where attr==highest id

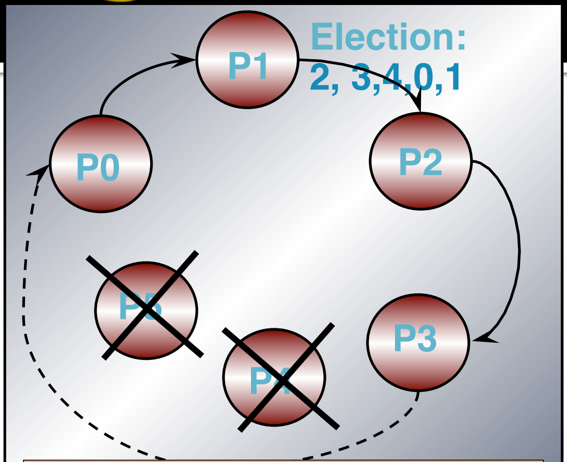
Algorithm 2: Modified Ring Election

- election message tracks *all* IDs of nodes that forwarded it, not just the highest
  - Each node appends its ID to the list
- Once message goes all the way around a circle, new coordinator message is sent out
  - Coordinator chosen by highest ID in election message
  - Each node appends its own ID to coordinator message
- When coordinator message returns to initiator
  - Election a success if coordinator among ID list
  - Otherwise, start election anew

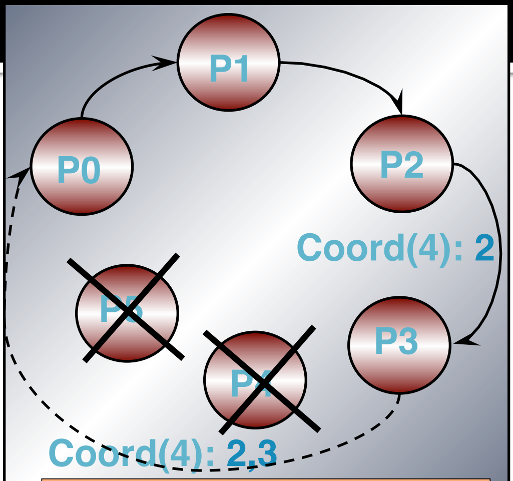
Example: Ring Election



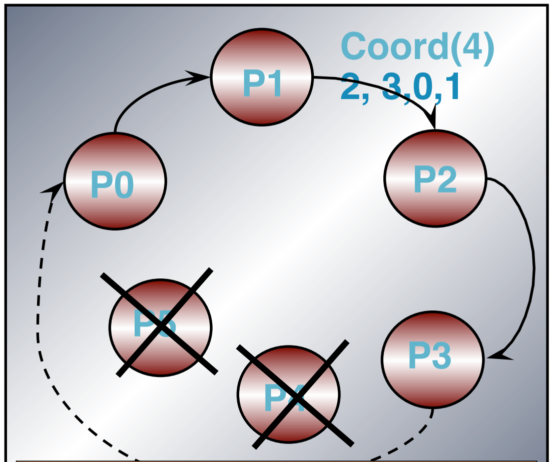
1. P2 initiates election



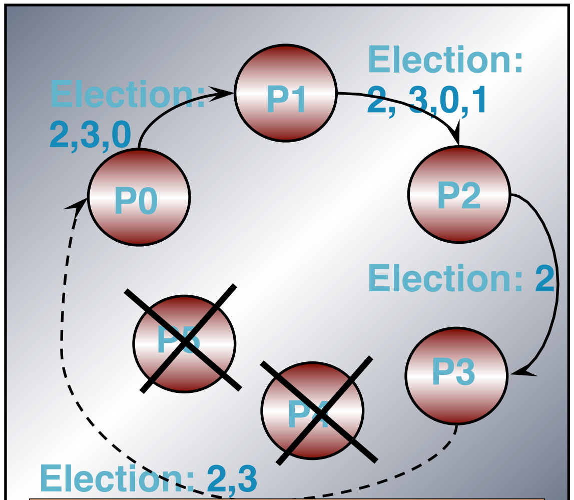
2. P2 receives "election", P4 dies



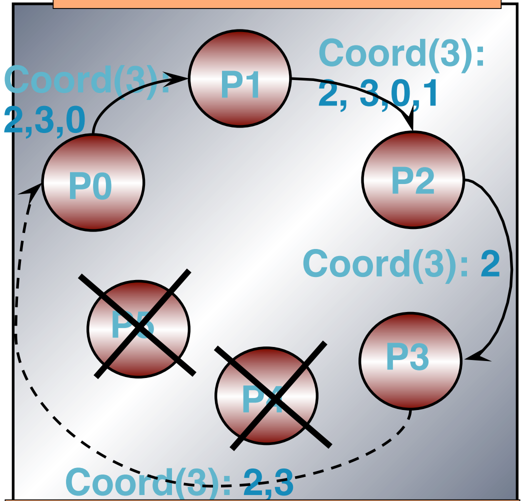
3. P2 selects 4 and announces the result



4. P2 receives "Coord", but P4 is not included



5. P2 re-initiates election



6. P3 is finally elected

Modified Ring Election

- How many messages?
  - 2N
- Is this better than original ring protocol?
  - Messages are larger
- Reconfiguration of ring upon failures
  - Can be done if all processes "know" about all other processes in the system
- What if initiator fails?
  - Successor notices a message that went all the way around (how?)
  - Starts new election
- What if two people initiate at once
  - Discard initiators with lower IDs

What about that Impossibility?

- Can we have a totally correct election algorithm in a fully asynchronous system (no bounds)
  - No! Election can solve consensus
- Where might you run into problems with the modified ring algorithm?
  - Detect leader failures
  - Ring reorganization

Algorithm 3: Bully Algorithm

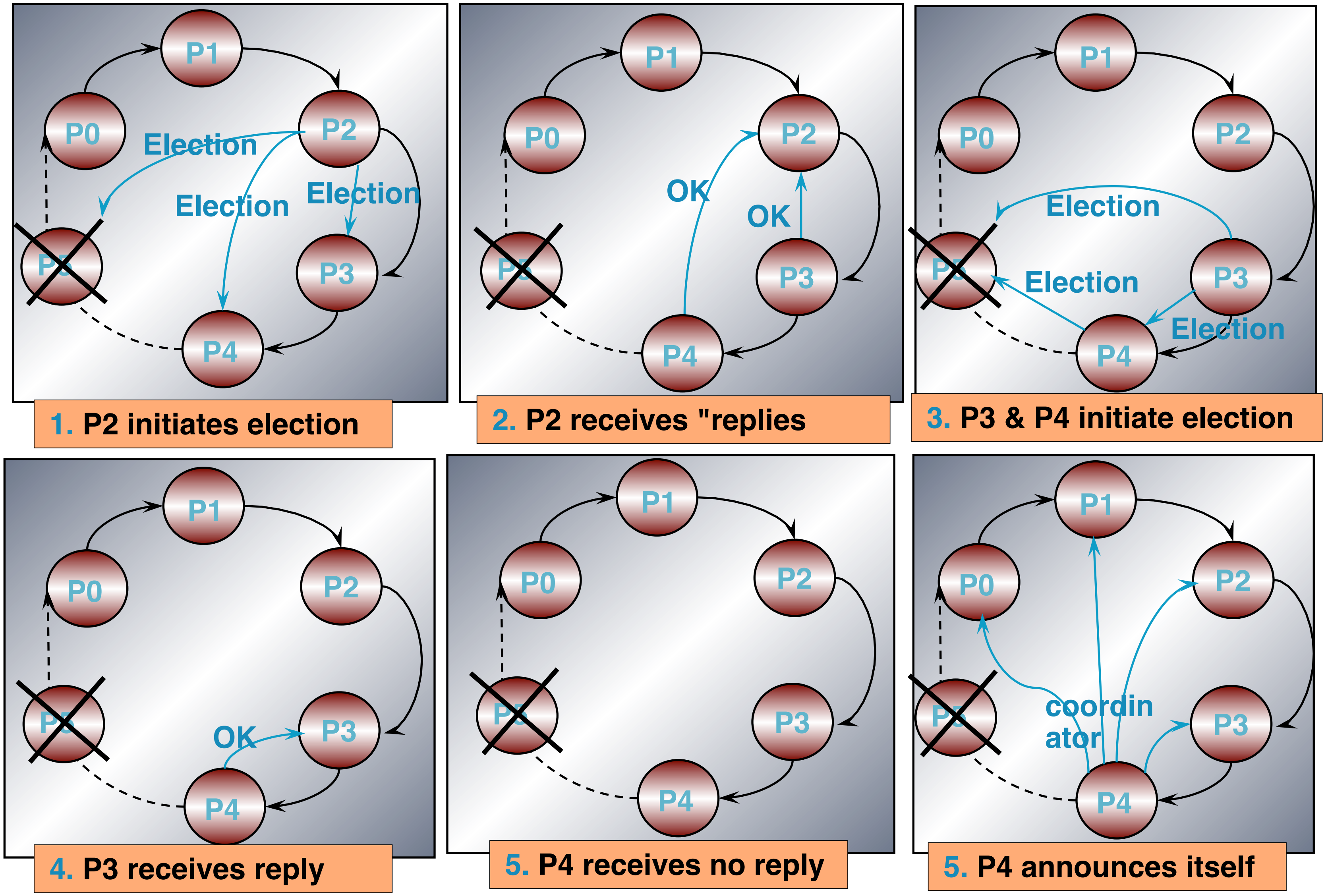
- Assumptions:
  - Synchronous system
  - attr=id
  - Each process knows all the other processes in the system (and thus their id's)

Algorithm 3: Bully Algorithm

- 3 message types
  - Election – starts an election
  - Answer – acknowledges a message
  - Coordinator – declares a winner
- Start an election
  - Send election messages *only* to processes with higher IDs than self
  - If no one replies after timeout: declare self winner
  - If someone replies, wait for coordinator message
    - Restart election after timeout
- When receiving election message
  - Send answer
  - Start an election yourself
    - If not already running

Example: Bully Election

answer=OK



1. P2 initiates election

2. P2 receives "replies

3. P3 & P4 initiate election

4. P3 receives reply

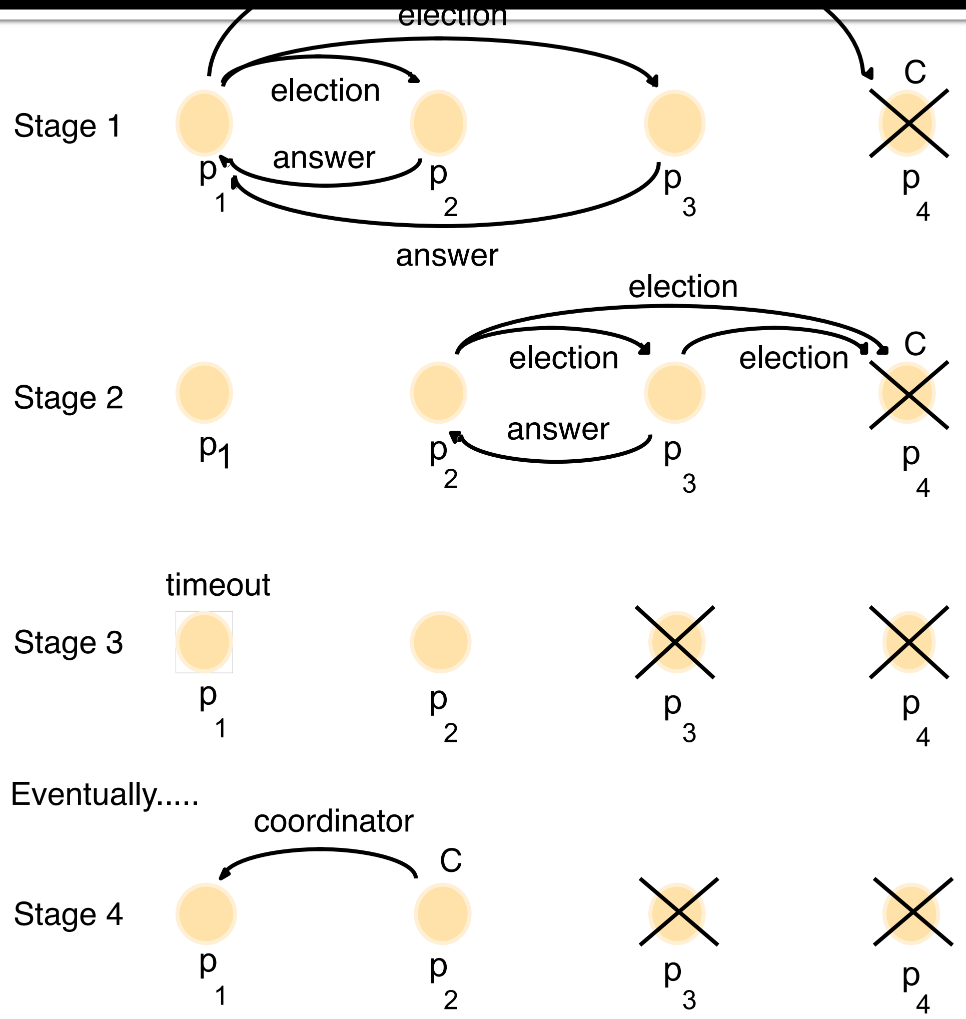
5. P4 receives no reply

5. P4 announces itself

The Bully Algorithm

The coordinator p_4 fails and p_1 detects this

p_3 fails



Analysis of The Bully Algorithm

- Best case scenario: The process with the second highest id notices the failure of the coordinator and elects itself.
  - N-2 coordinator messages are sent.
  - Turnaround time is one message transmission time.

Analysis of The Bully Algorithm

- Worst case scenario: When the process with the lowest id in the system detects the failure.
  - N-1 processes altogether begin elections, each sending messages to processes with higher ids.
  - The message overhead is $O(N^2)$.

Turnaround time

- All messages arrive within T units of time (synchronous)
- Turnaround time:
  - Election message from lowest process (T)
  - Timeout at 2nd highest process (X)
  - Coordinator message from 2nd highest process (T)
- How long should the timeout be?
  - $X = 2T + T_{process}$
  - Total turnaround time: $4T + 3T_{process}$
- How long should election restart timeout be?
  - $X + T + T_{process} = 3T + 2T_{process}$

Summary

- Coordination in distributed systems requires a leader process
- Leader process might fail
- Need to (re-) elect leader process
- Three Algorithms
  - Ring algorithm
  - Modified Ring algorithm
  - Bully Algorithm

Readings and Announcements

- Readings:
  - For today's lecture: Section 12.3 / 15.3