CSE 486/586 Distributed Systems

Leader Election

Slides by Steve Ko
Computer Sciences and Engineering
University at Buffalo

Recap: Mutual Exclusion

- Centralized
- Ring-based
- Ricart and Agrawala's
- Maekawa's

Why Election?

- Example 1: sequencer for TO multicast
- Example 2: leader for mutual exclusion
- Example 3: 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 algorithms
  1) Elect one leader from among only the non-faulty processes
  2) All non-faulty processes agree on which is the leader
- We'll look at 3 algorithms

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 such elections combined must yield a single leader
  - Election results should not depend on which process called for it
- Messages are eventually delivered.

Problem Specification

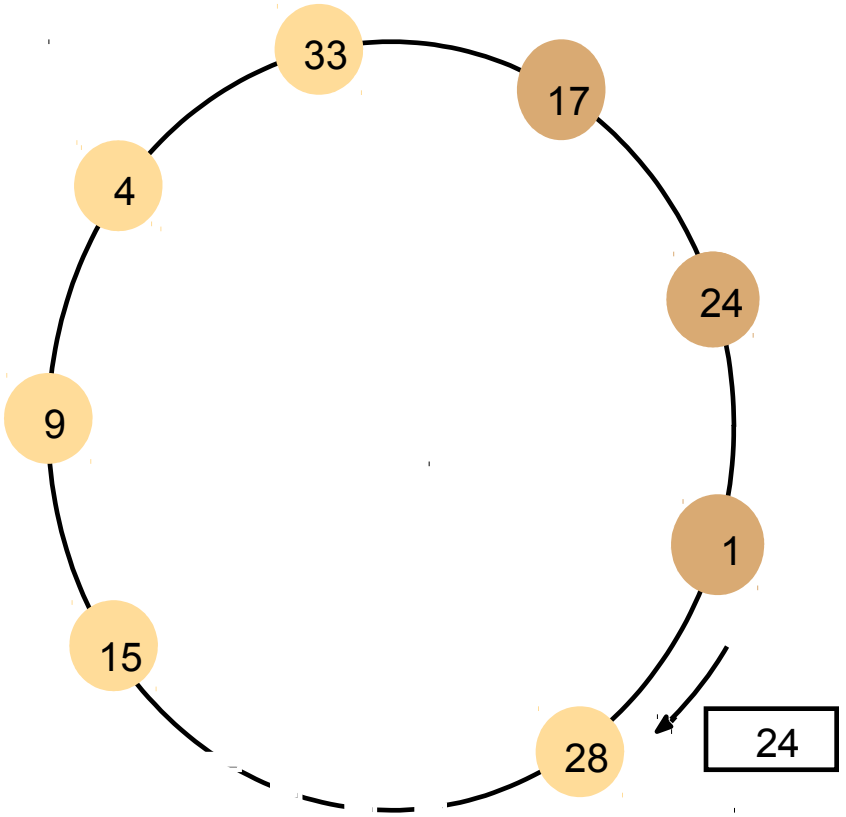
- An election protocol selects the non-faulty process with the "best" selected election attribute at termination.
  - Attribute examples: CPU speed, load, disk space, ID
  - Must be unique
- Each process maintains a variable *elected*.
- An execution of the election algorithm should ideally guarantee at the end:
  - Safety: For each non-faulty *p*: *p*'s *elected* = *q*: a particular non-faulty process with the best attribute value, or ⊘
  - Liveness: election terminates and for each non-faulty process *p*, *p*'s *elected* is eventually 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 mod 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 and state is not *participating*: send (*election*, my ID)
    - Set state to *participating*
  - If *id* = my ID: I am elected (why?) send *elected* message
    - *elected* message forwarded until it reaches leader again

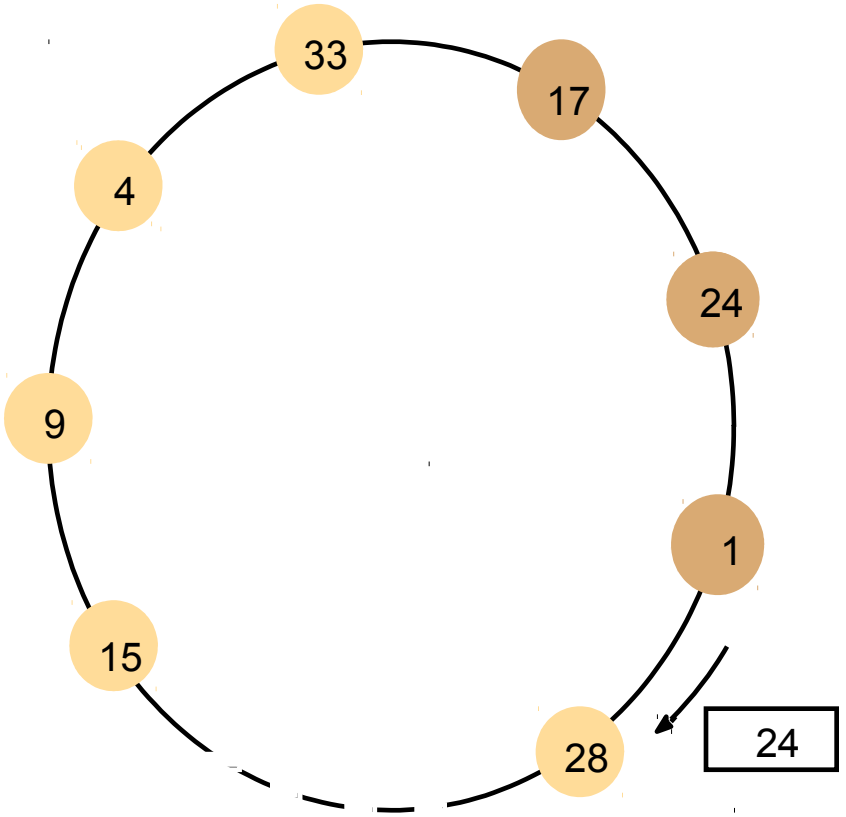
Ring-Based Election: Example

- The election was started by process 17.
- The highest process identifier encountered so far is 24
- (final leader will be 33)



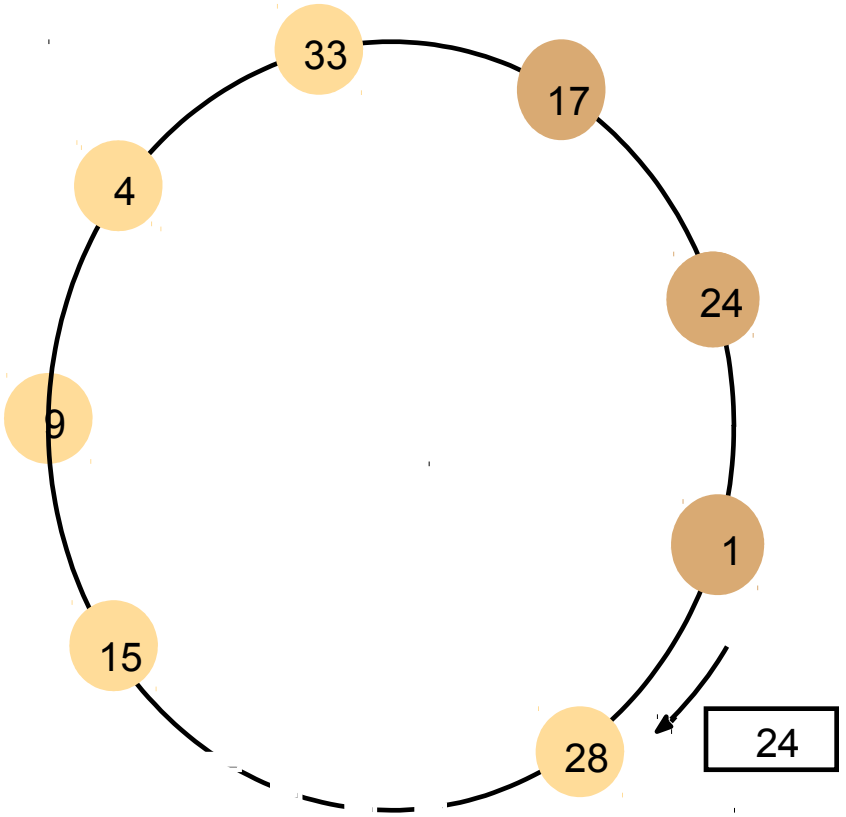
Ring-Based Election: Example

- The worst-case scenario occurs when?
  - the counter-clockwise neighbor (@ the initiator) has the highest attribute.
- 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

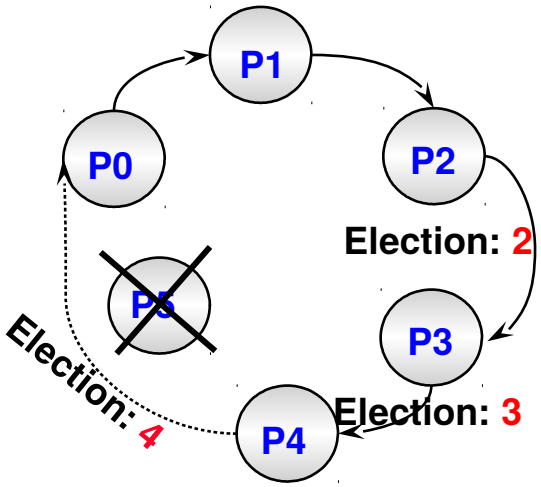
- In a ring of N processes, in the worst case:
  - N-1 *election* messages to reach the new coordinator
  - Another N *election* messages before coordinator decides it's elected
  - Another N *elected* messages to announce winner
- Total Message Complexity = 3N-1
- Turnaround time = 3N-1



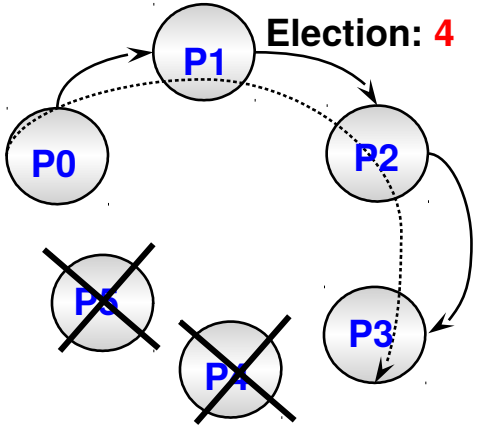
Correctness?

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

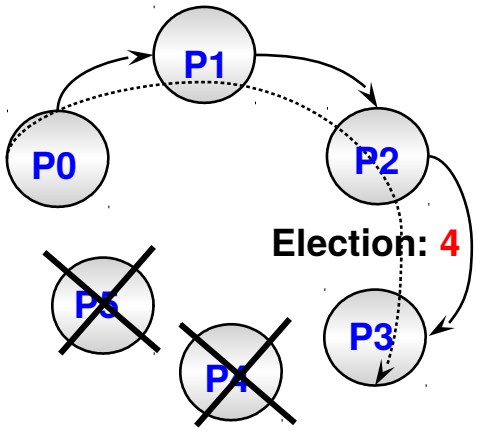
Example: Ring Election



1. P2 initiates election after old leader P5 failed



2. P2 receives "election", P4 dies



3. Election: 4 is forwarded forever?

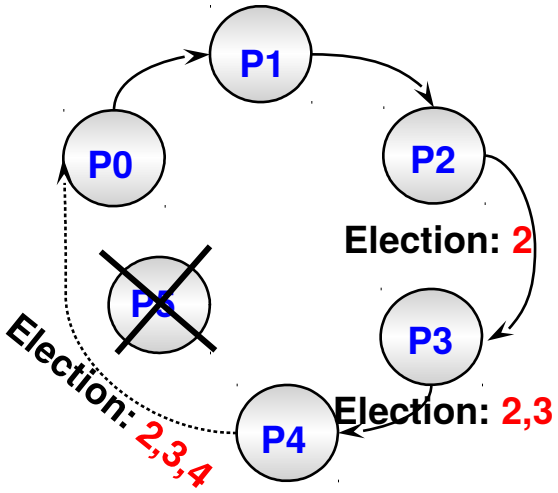
May not terminate when process failure occurs during the election!

Consider above example where attr==highest id

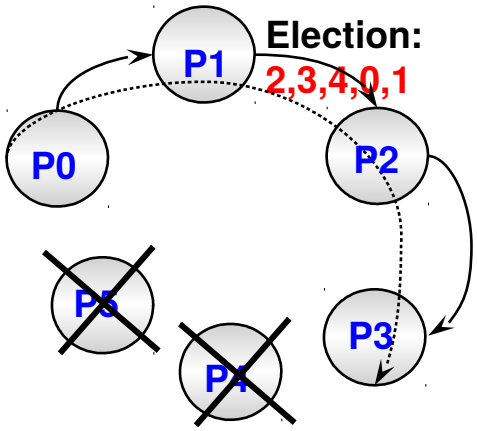
Algorithm 2: Modified Ring Election

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

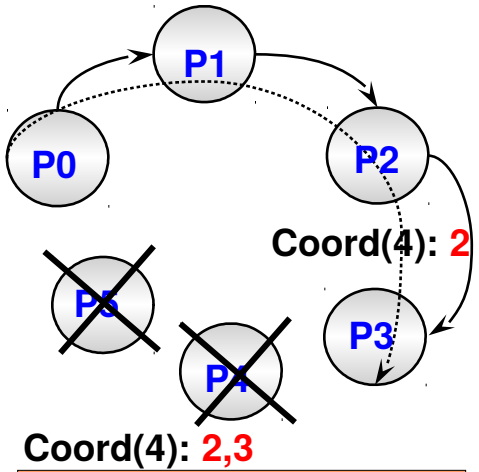
Example: Ring Election



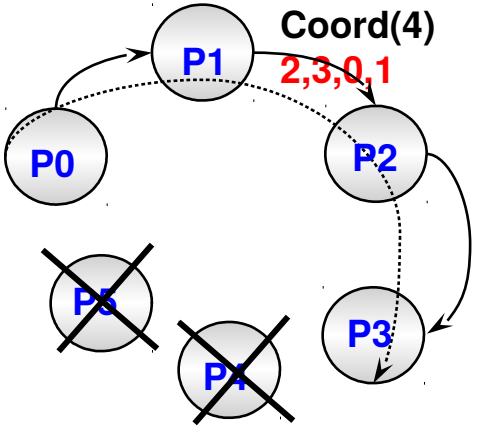
1. P2 initiates election



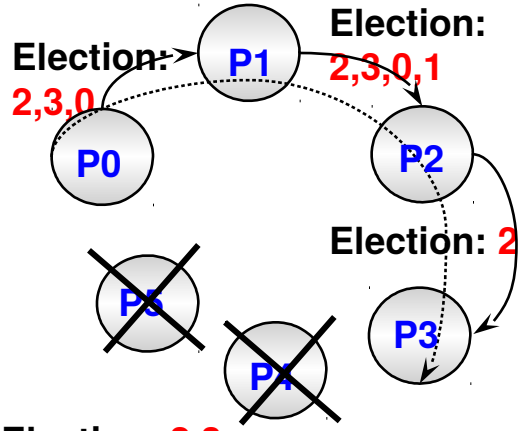
2. P2 receives "election", P4 dies



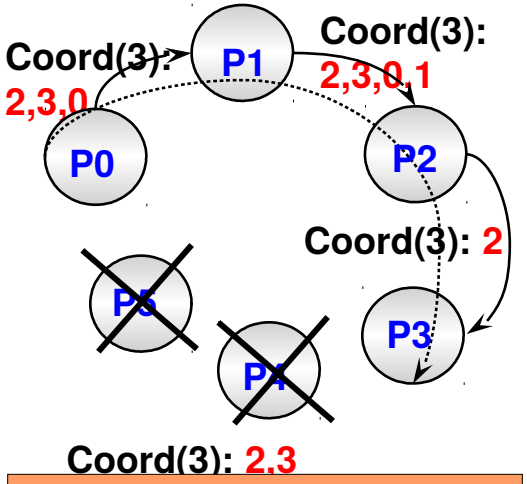
3. P2 selects 4 and announces the result



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 the 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?
  - Detecting leader failures
  - Ring reorganization

Algorithm 3: Bully Algorithm

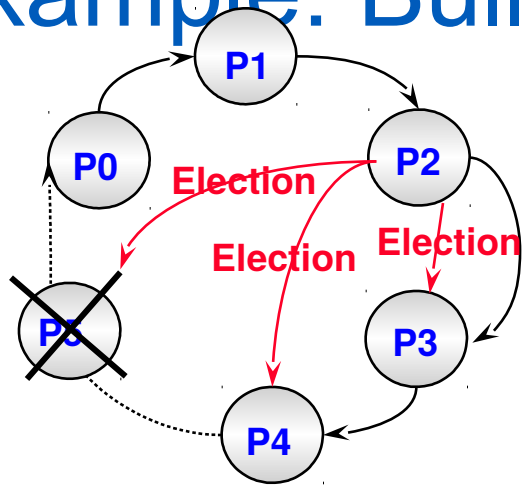
- Assumptions:
  - Synchronous system
  - Election attribute is process ID
  - Each process knows all the other processes in the system (and thus their IDs)

Algorithm 3: Bully Algorithm

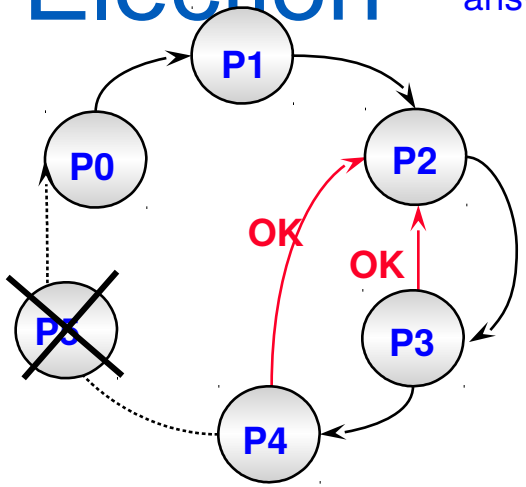
- 3 message types
  - election – starts an election
  - answer – acknowledges a message
  - coordinator – declares a winner
- Start an election
  - Send election messages to processes with higher IDs than self
  - If no one replies after timeout: declare self winner
  - If someone replies, wait for coordinator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

Example: Bully Election

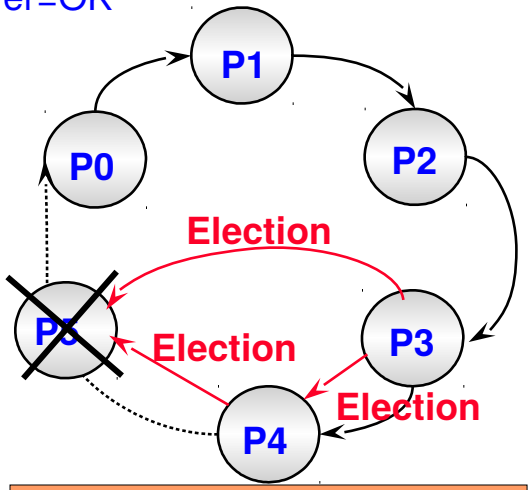
answer=OK



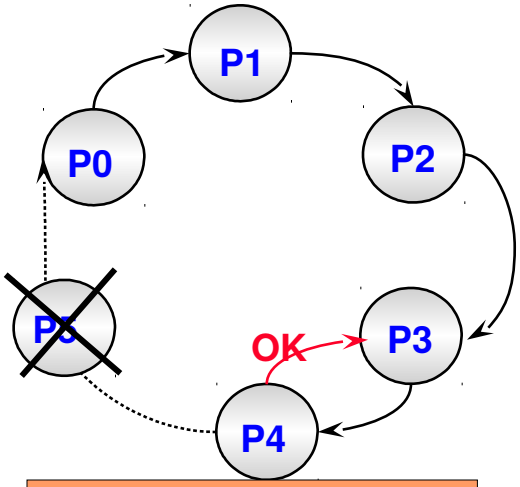
1. P2 initiates election



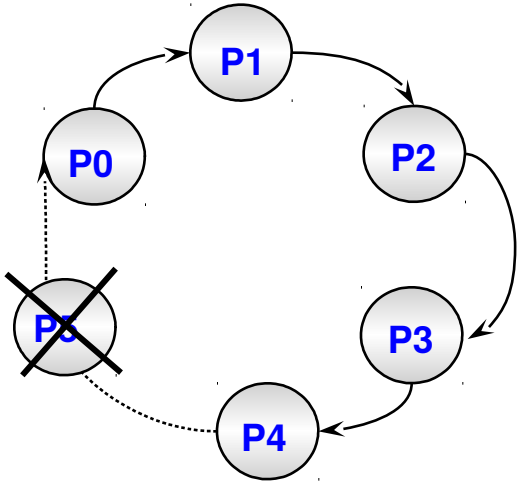
2. P2 receives replies



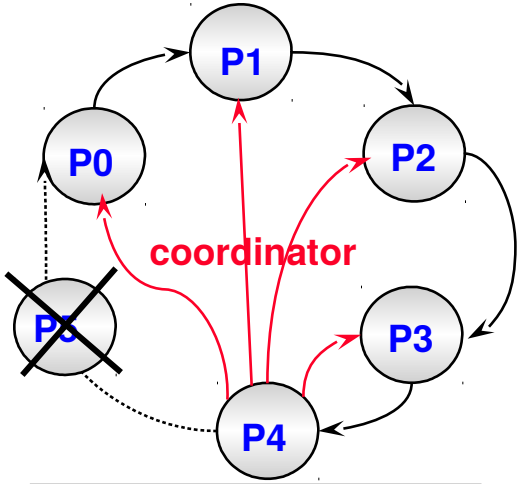
3. P3 & P4 initiate election



4. P3 receives reply



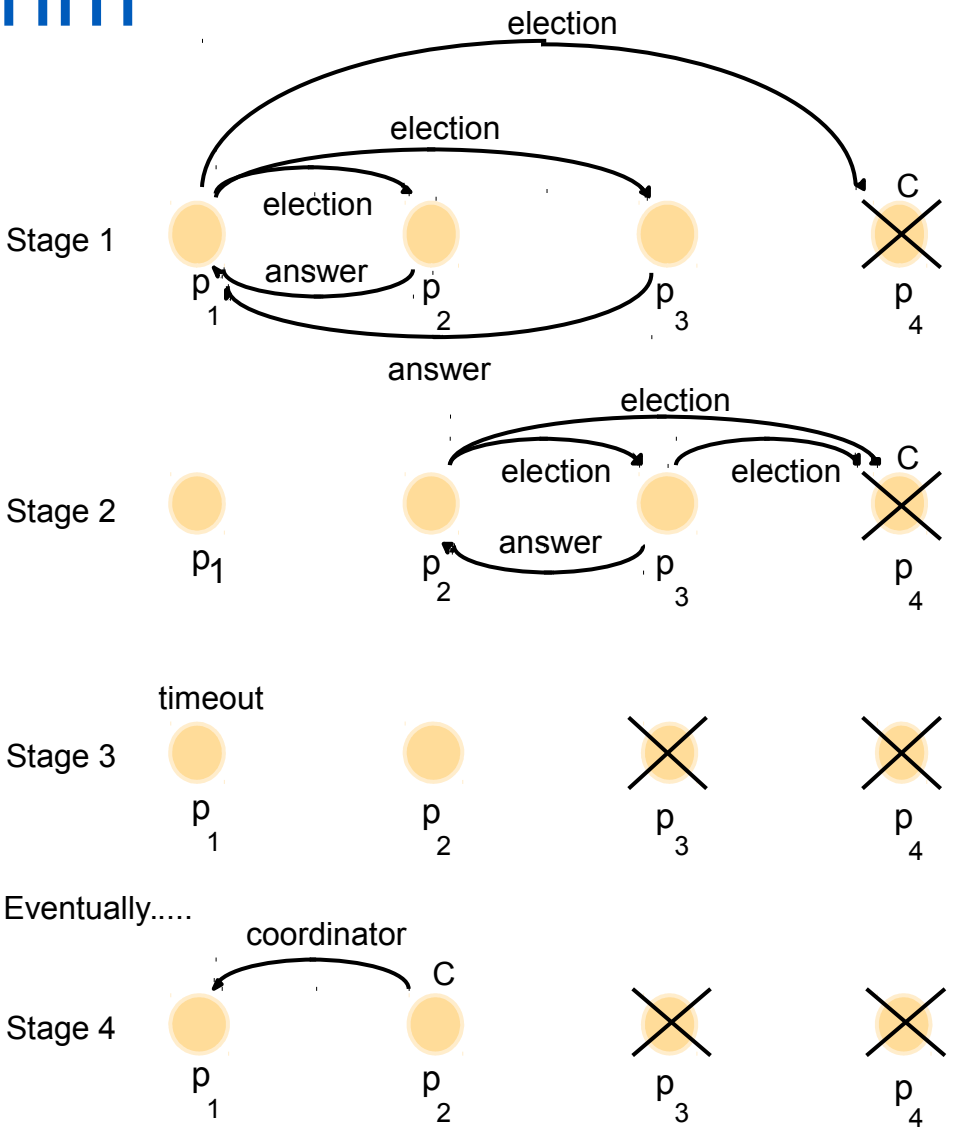
5. P4 receives no reply



5. P4 announces itself

The Bully Algorithm

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 immediately.
  - 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 ultimately begin elections, each sending messages to all processes with higher IDs.
  - The message overhead is $O(N^2)$.

Summary

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

References

- Textbook Section 15.3. **Required Reading.**

Acknowledgements

- These slides by Steve Ko, used and lightly modified with permission by Ethan Blanton
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