CSE 486/586 Distributed Systems
Leader Election

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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 only among the non-faulty processes
  - 2. All non-faulty processes agree on who 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 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
- Each process has a variable elected.
- 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 eventually not ⊥.
Algorithm 1: Ring Election  
[Chang & Roberts’79]

- N Processes are organized in a logical ring
  - \( p_i \) has a communication channel to \( p_{i \mod N} \)
  - All messages are sent clockwise around the ring.
- To start election
  - Send \text{election} message with my ID
- When receiving message \((\text{election}, \text{id})\)
  - If \text{id} > my ID: forward message
  - If \text{id} < my ID: send \((\text{election}, \text{my ID})\)
  - If \text{id} = my ID: I am elected (why?) send \text{elected} message

Ring-Based Election: Example

- The worst-case scenario occurs when?
  - the counter-clockwise neighbor (@ the initiator) has the highest \text{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 \text{election} messages to reach the new coordinator
  - Another N \text{election} messages before coordinator decides it’s elected
  - Another N \text{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

- PA2 due next week
- Midterm: 3/11 (Wednesday) in class
  - Multiple choices
  - Everything up to today
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
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: $4T + 3T_{process}$

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
Acknowledgements

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