CSC2/458 Parallel and Distributed Systems
Mutual Exclusion and Leader Elections

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URCS

Outline

Mutual Exclusion Using Voting

Misra's Token Recovery Algorithm

Election Algorithms

Outline

From the previous lecture

- Does a process need to wait for all replicas to reply before checking majority?
  - No [it would NOT (thanks, Mohsen!) solve the problem raised by Andrew, but would lead to lower utilization]
- How many processes need to fail?
  - $f >= m - N/2$, where
  - $m = N/2 + 1$
- Does this mean mutual exclusion can be violated?
  - Yes (with very low probability, see Lin et al. 2014)

Different Types of Failures (Thomas)

- How does fail recovery compare with fail stop?
  - Fail stop: Process operates correctly, fails in a detectable way and remains failed
  - Fail recovery: Process fails and "restarts"

Outline

Recall Token-based Mutual Exclusion

- A token circulates in an (unidirectional) ring
  - Process i sends token to Process $i + 1$ (modulo N)
- A process holding the token can perform actions on shared resources
  - i.e. it is in the critical section
- A tokens can be lost
  - released by process i but not received by process j

Loss of token

- Two problems
  - Detecting loss
  - Regenerating a single token

One possible solution

- Detect loss of token using *timeouts*
- Perform leader election
  - Leader generates new token
- This solution in a few slides

Misra's algorithm for detecting token loss and regeneration

- Use two tokens X and Y
  - X is also the mutual exclusion token (but not Y)
  - X and Y detect the loss of each other
- Assume in order receipt

Key Insight

"A token at a process p_i can guarantee the other token is lost if since this token's last visit to p_i, neither this token nor p_i have seen the other token."

- Misra, 1983, Detecting Termination of Distributed Computations Using Markers, PODC

- What does it mean for:
  - a process to have seen a token?
  - for a token to have seen the other token?

The Algorithm: Setup

- Associate nX and nY, two integers with X and Y
- Initialize nX and nY to $+1$ and -1 respectively
- Each token carries its value with it (i.e nX or nY)
- Each process p_i contains a m_i initialized to zero
    - remembers the last token seen and its value

The Algorithm: Working

When tokens encounter each other:

```
nX = nX + 1
nY = nY - 1
```

When p_i encounters Y (analogous code to encountering X not shown):

```
if m_i == nY: /* token X is lost */
    /* regenerate token X */
    nY -= 1
    nX = -nY
else:
    m_i = nY
end if
```

Do we need infinite precision?

- nX can become arbitrarily large
- nY can become arbitrarily small
- Can we avoid this?
  - What is the invariant we need to maintain?
  - When are counters updated?
  - How many such events can happen between two visits to p_i?

Other notes

Misra proposed this algorithm for *termination* detection. We will revisit it.

But can you see how it may apply?

- All processes are in either IDLE or ACTIVE
- Receiving a message marks process as ACTIVE
- Processes can only quit when all of them are IDLE and there are no messages in flight

Outline

Electing Leaders

- Initiating an election
  - Anytime
- Detecting a winner and making sure everybody agrees on the same winner
  - Using process IDs to break ties for example

Ring-based Elections: Selective Extension

- (Logical) Unidirectional ring topology
- Two message types, both contain a process ID:
  - ELECTION
  - ELECTED

Algorithm: Part I

A process can initiate an election *anytime*. Process p_i does this by sending a ELECTION(p_i) to its neighbour and "marking itself" as participating in an election.

On receiving message ELECTION(X), a process p_j:

```
if X > p_j:
   participating = T
   send(ELECTION(X))
elif X < p_j:
   participating = T
   send(ELECTION(p_j))
elif X == p_j:
   send(ELECTED(p_j))
```

Algorithm: Part II

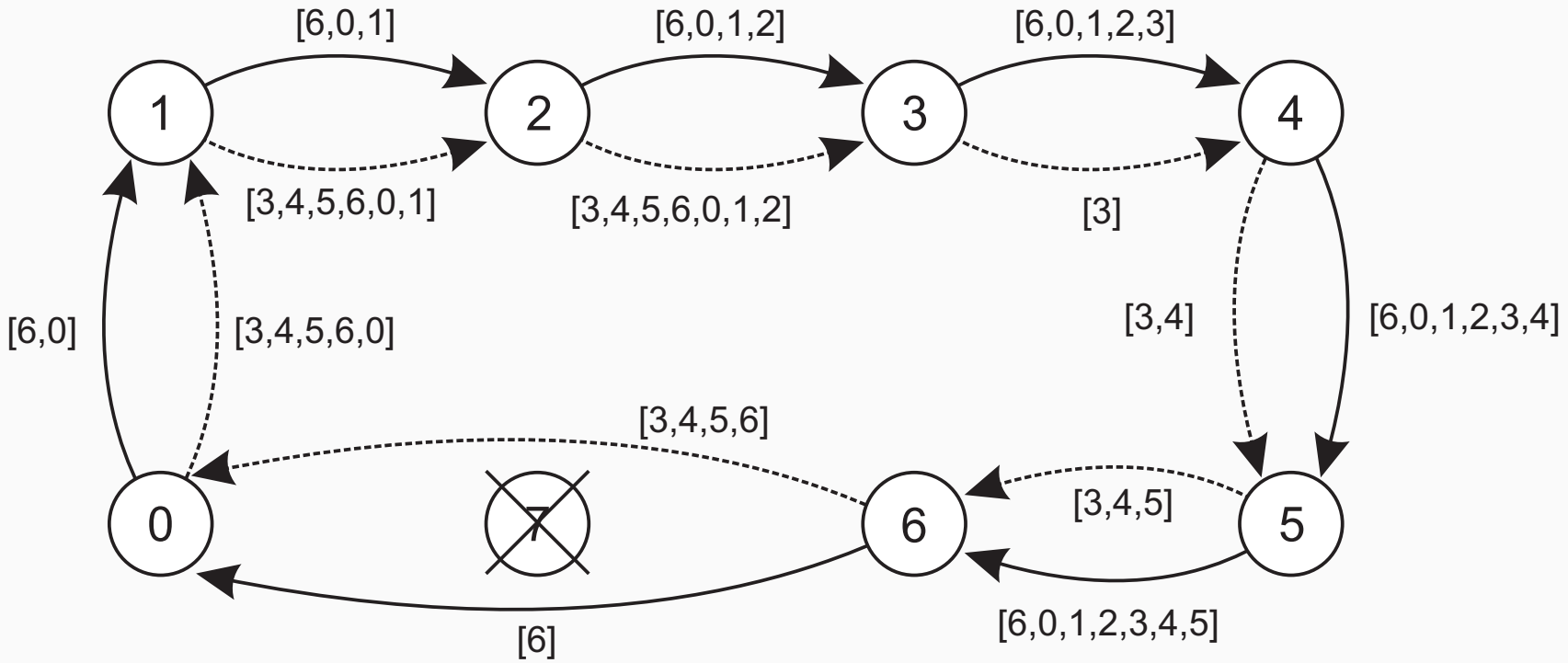
When receiving ELECTED(Y):

```
participating = F
coordinator = Y

if Y != p_j:
   send(ELECTED(Y))
```

Textbook has slight modifications

- Sends lists instead of one number
- Skips dead nodes

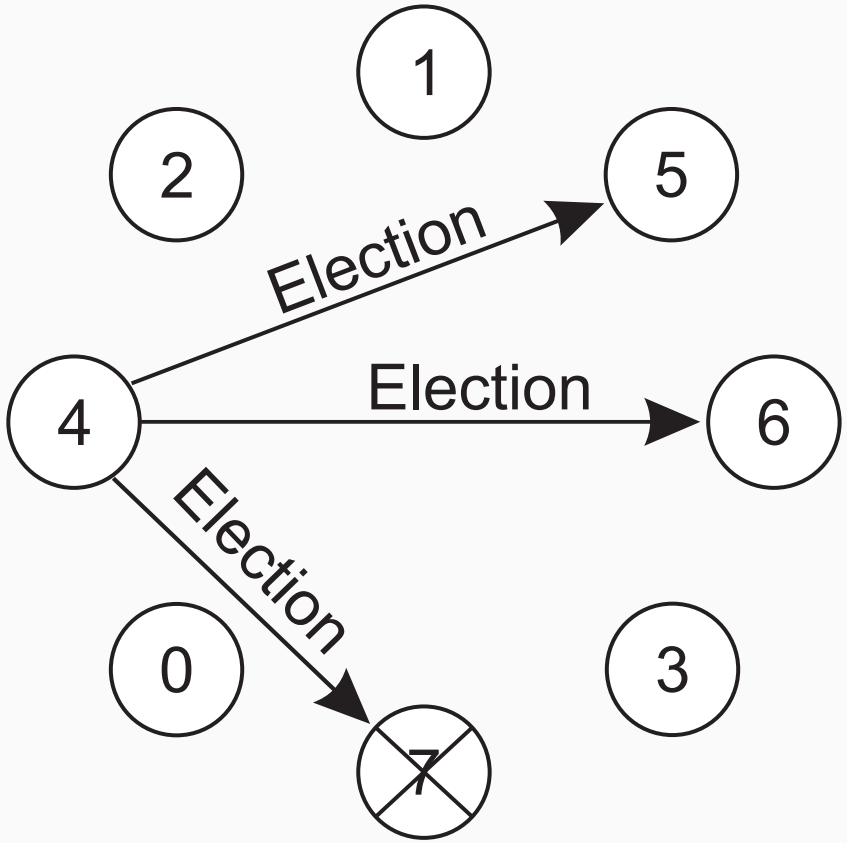


The Bully Algorithm

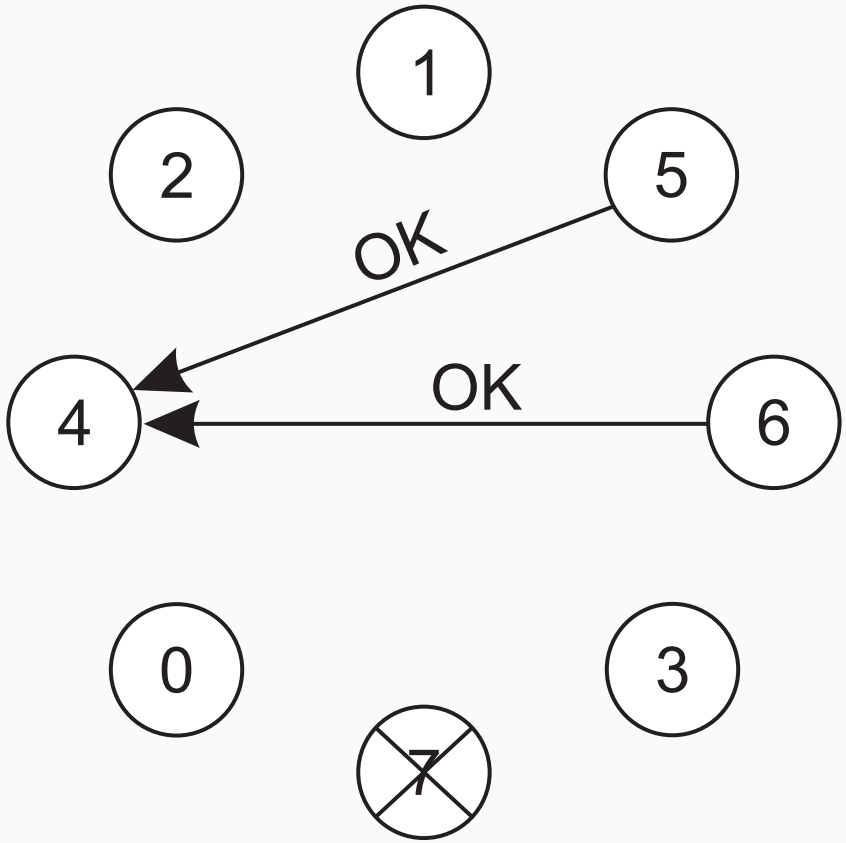
The coordinator with the highest process ID always wins.

- Three types of messages:
  - ELECTION (initiation)
  - OK (resolution)
  - COORDINATOR (verdict)

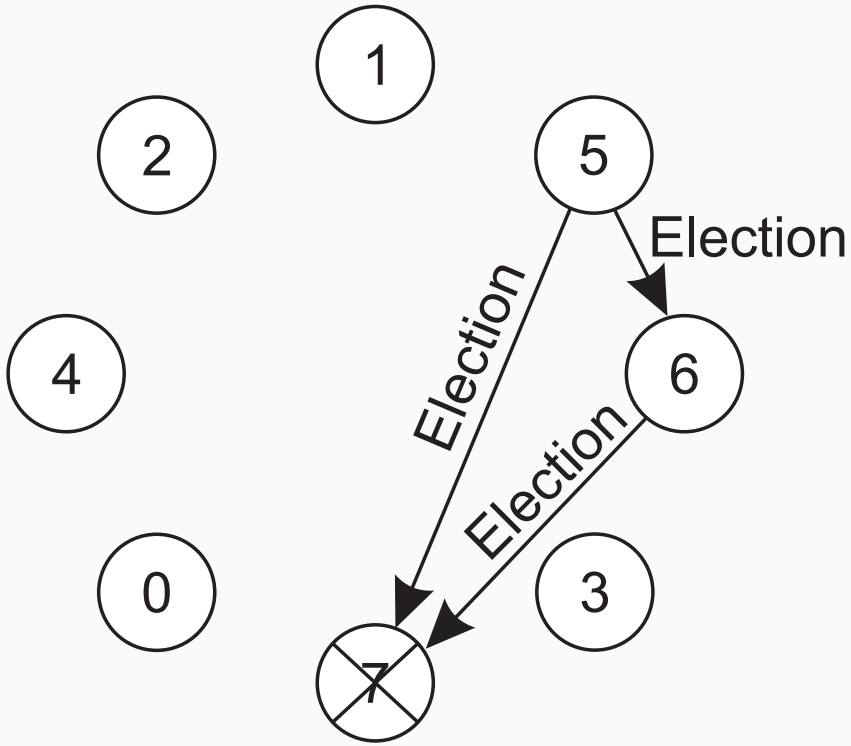
Bully Algorithm in Action: Initiation



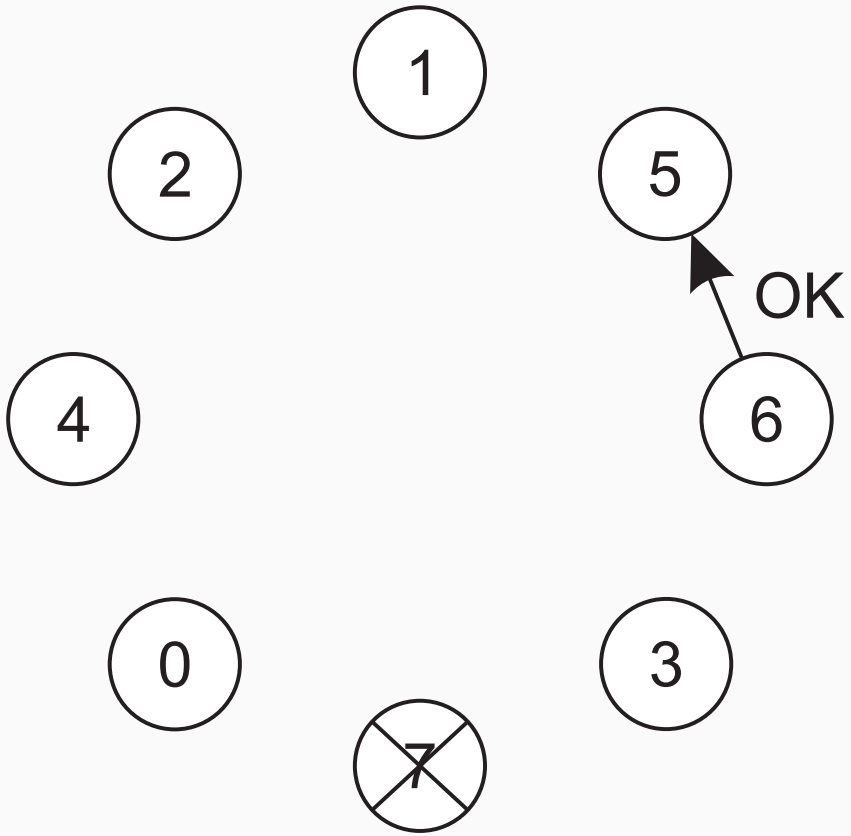
Bully Algorithm in Action: Resolution



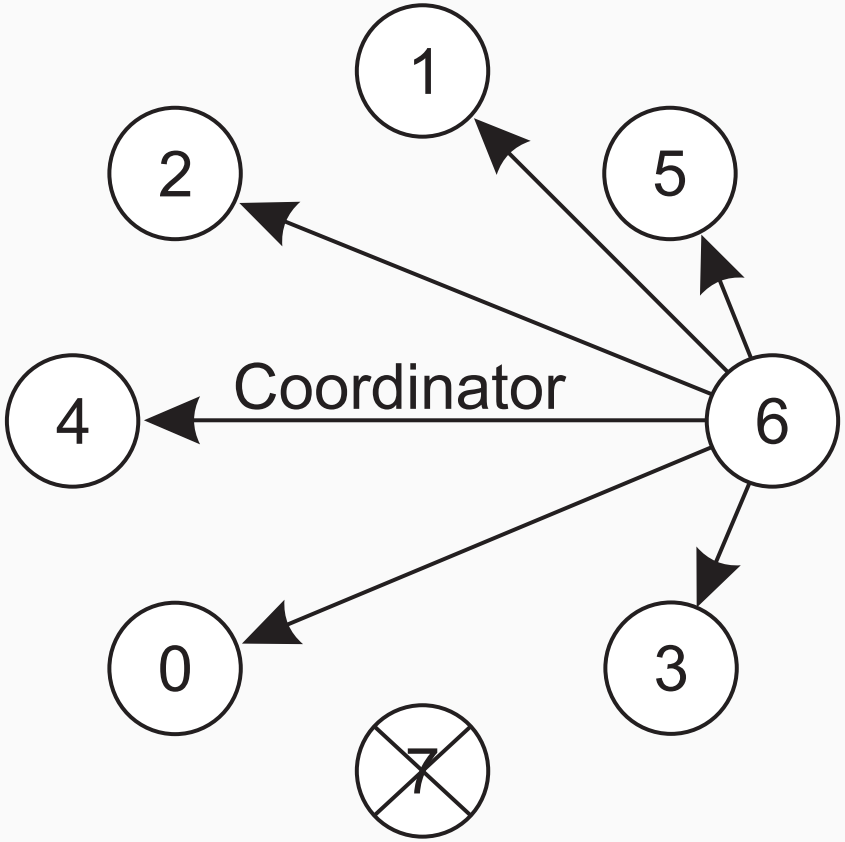
Bully Algorithm in Action: Further Elections



Bully Algorithm in Action: Resolution



Bully Algorithm in Action: Final Verdict



Algorithm

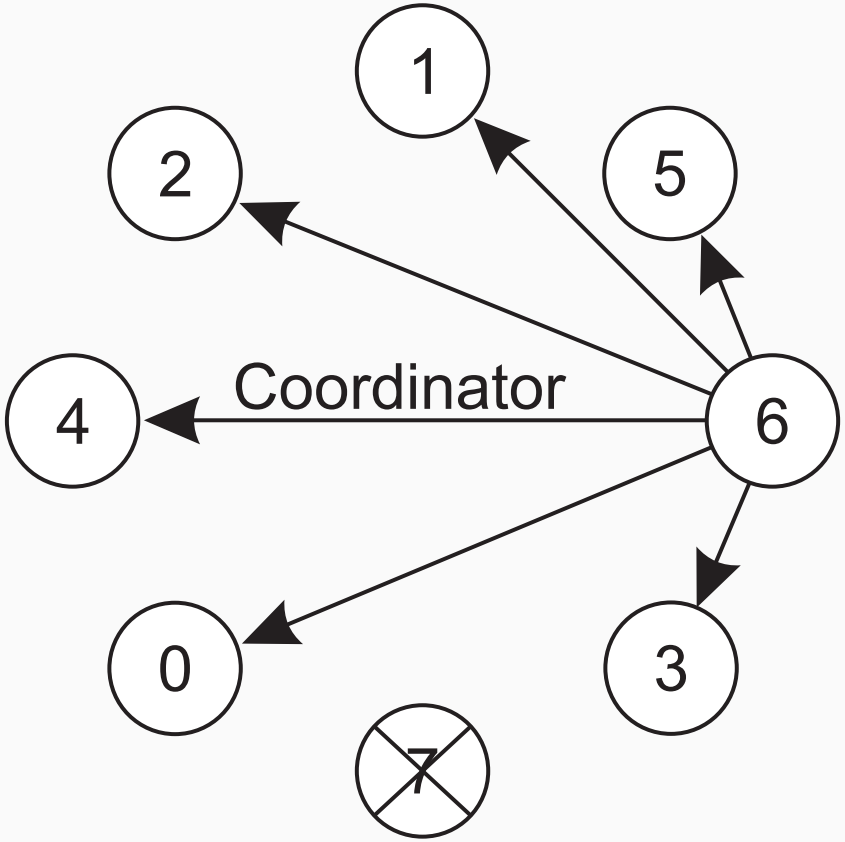
Any process p_i can initiate an election at any time:

- Send ELECTION message to all processes p_k such that $k > i$
- Wait for OK replies
- If no replies (within a timeout), process p_i has won and announces win using COORDINATOR

On receiving an ELECTION message:

- Send OK to sender
  - Sender cannot become a coordinator
- Initiate election if any higher processes known to exist
  - if not, process is new coordinator, send COORDINATOR

What happens when 7 comes back online?



Interesting Extensions

- Wireless networks
  - Small, dynamic, no fixed topology
- P2P networks
  - Large, dynamic, may need multiple coordinators
- See textbook for details
  - Will revisit some of these topics on a P2P lecture

Acknowledgements

All figures from van Steen and Tanenbaum, 3rd Edition.