# Mutual Exclusion & Election

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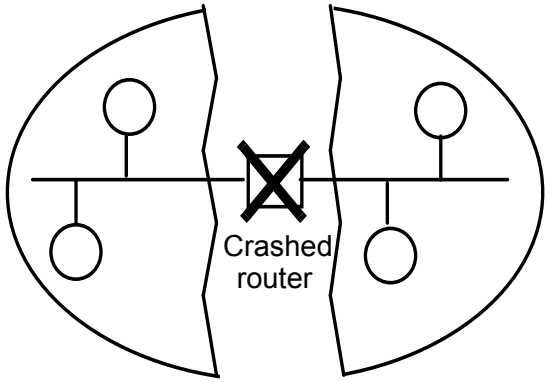
# Failure Assumptions

- Reliable channels
  - Guaranteed delivery ***eventually*** in asynchronous systems
  - Guaranteed  delivery within bound D)
  - $\Rightarrow$ network partitions/paths eventually repaired
- Independent processes $P_1 \ldots P_n$

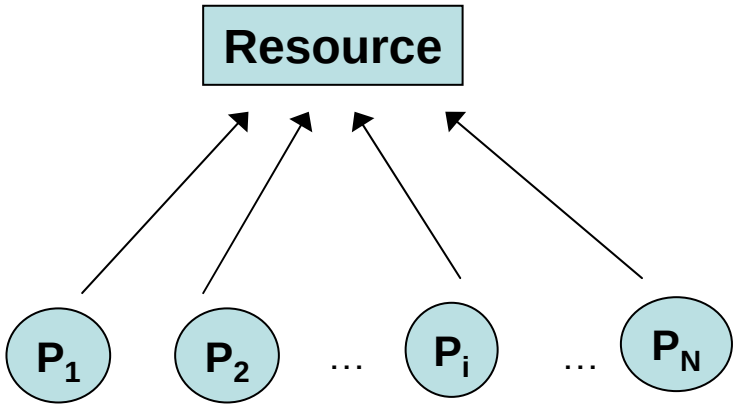
Network Partitioning




- Crash failures
  - ***Cannot*** be detected ***reliably*** in an asyncronous system by timeout
  - Heartbeats or probing in synchronous systems

# Distributed mutual exclusion

- A number of processes want to access some shared resource
- Prevent interference, maintain consistency; critical section.




Application-level protocol:

```
enter()           // block till free
resourceAccess()  // critical section
exit()            // free resource
```

General **requirements** for mutual exclusion

**ME1: safety**: at most one process may execute in the critical section at a time

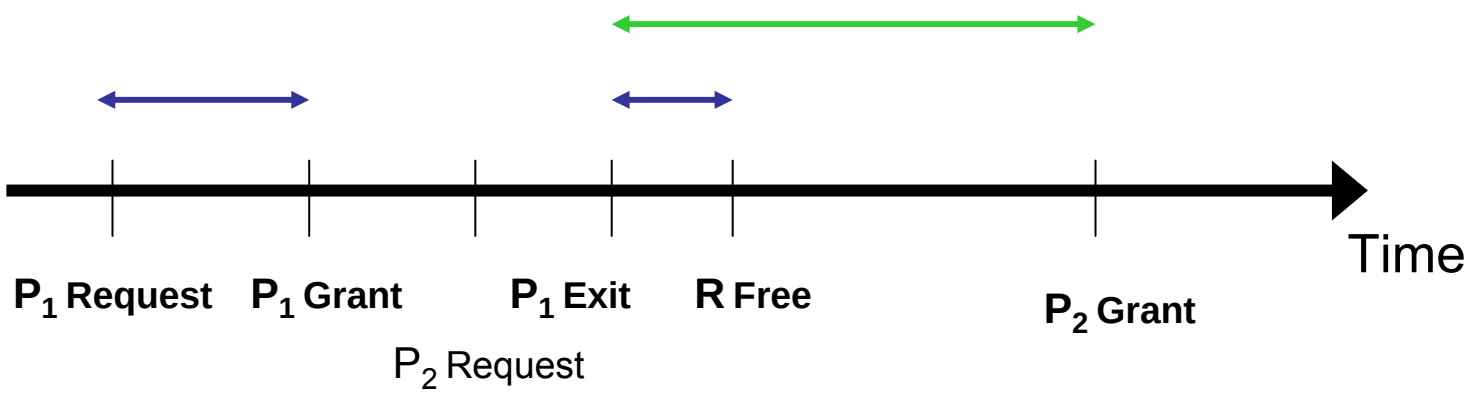
**ME2: liveness**: requests eventually succeed *(no deadlock, no starvation)*

**ME3: ordering**: if request A *happens-before* request B then grant A before grant B

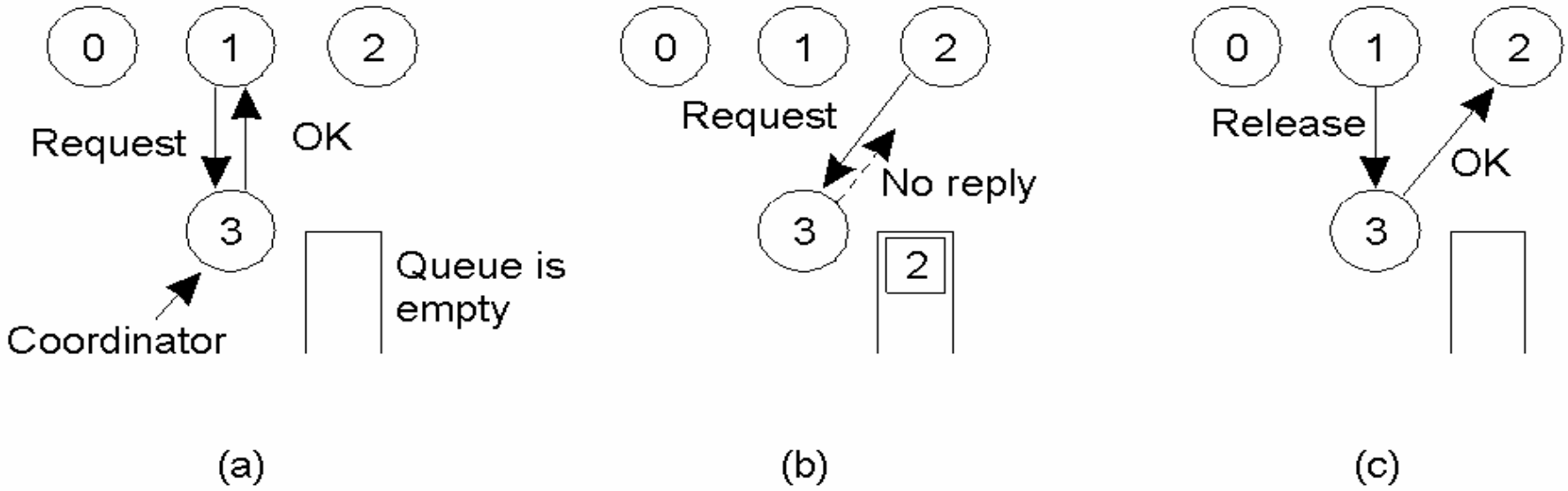
**Problems**: fault tolerance, performance

# Performance Measures

- Bandwidth: number of messages required for entry and exit
- Client delay (entry and exit)
- Throughput (Synchronization delay)



# Mutual Exclusion: A Centralized Algorithm




a) Process 1 asks the coordinator for permission to enter a critical region. Permission is granted

b) Process 2 then asks permission to enter the same critical region. The coordinator does not reply.

c) When process 1 exits the critical region, it tells the coordinator, which then replies to 2

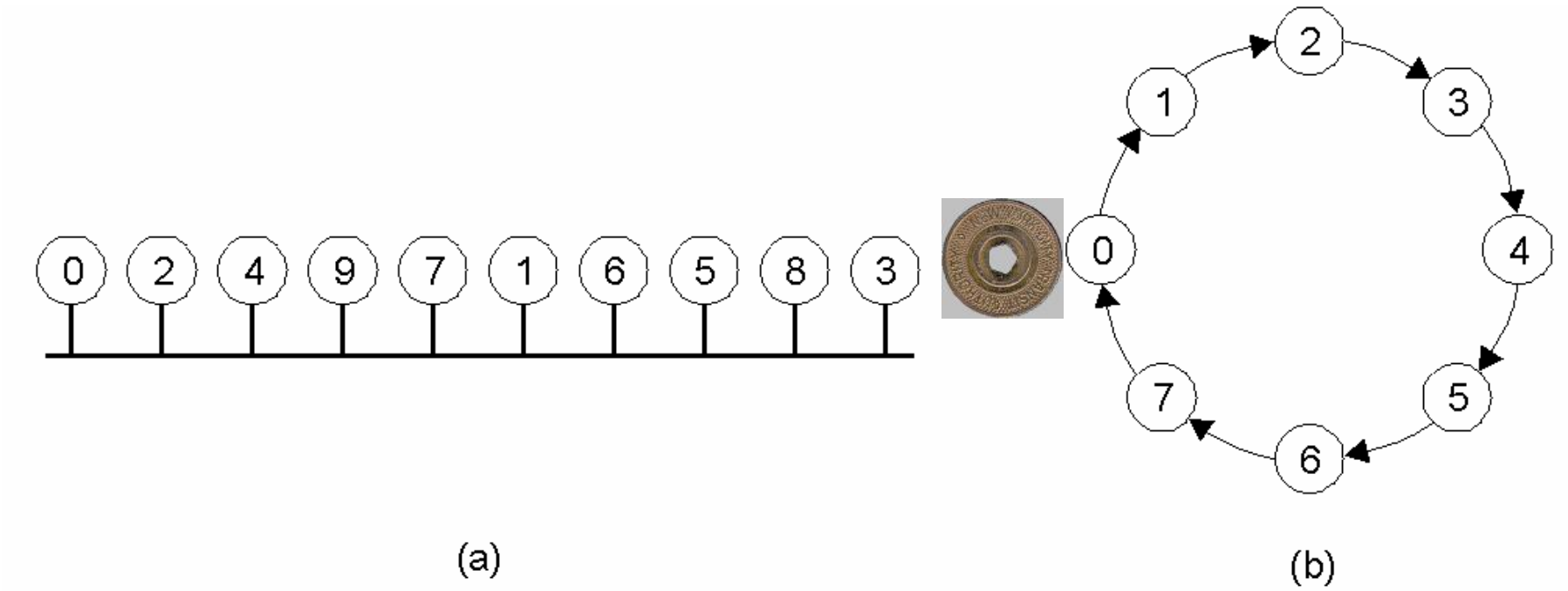
# Mutual Exclusion: A Centralized Algorithm

- Shortcomings
  - The coordinator is a single point of failure, so if it crashes, the entire system may go down.
    - Wait; why not just elect another coordinator?
    - You can. The only concern is figuring out who has access to the critical section.
    - How do you tell the difference between a dead coordinator and “permission denied”?
  - In a large system a single coordinator may become a performance bottleneck.
- Advantages:
  - Simple
  - Reasonable efficient

# Mutual Exclusion: A Centralized Algorithm

- Bandwidth
  - 3 messages to enter and leave a critical region: A request, a grant to enter and a release to exit
- Client Delay:
  - Entry: 2 messages: request + grant
  - Exit: 0 (asynchronous sending of release)
- Synchronization Delay: release + grant

# A Token Ring Algorithm




a) An unordered group of processes on a network.
b) A logical ring constructed in software.
c) Token holder may enter CS

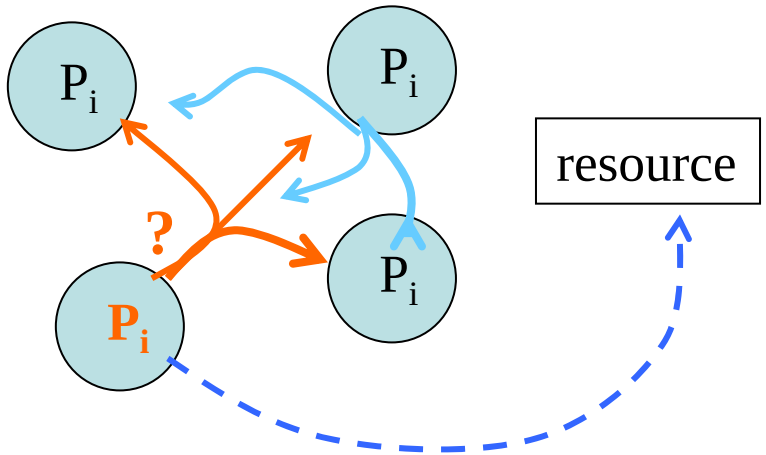
# Token Ring

- Client Delay
  - Entry: Wait: 0…N hops (N/2 in average)
  - Exit: send 1 msg (asynchronously)
- Synchronization Delay
  - 0…N hops (N/2 in average)
- Bandwidth
  - Always uses bandwidth to circulate token, used or not.

# Ricart and Agrawala's Algorithm [`81]

- Fully Distributed
- Optimized version of Lamports '78 algorithm
- Send "request" to N–1 other processes.
- Execute CS when "reply OK" permission is received from all other processes.
- $P_i$ maintains Lamport Clock
  - I.e., adjust counter $C_i$ on every internal event, and send and receive
- Break ties with Lamport time-stamp.

# Ricart and Agrawala




- The general idea:
  - ask everybody
  - wait for permission from everybody

The problem:

- several simultaneous requests (e.g., $P_i$ and $P_j$)
- all members have to agree (*everybody*: "first $P_i$ then $P_j$")

# Ricart – Agrawal's Algorithm

***On initialization***

*state* := RELEASED;

***To enter the section***

*state* := WANTED;
*T* := request's timestamp;
Multicast *request* to all processes;
*Wait until* (number of replies received = (*N-1)* );
*state* := HELD;

request processing deferred here

***On receipt of a request $<T_i, p_i>$ at $p_j$ ($i \neq j$)***

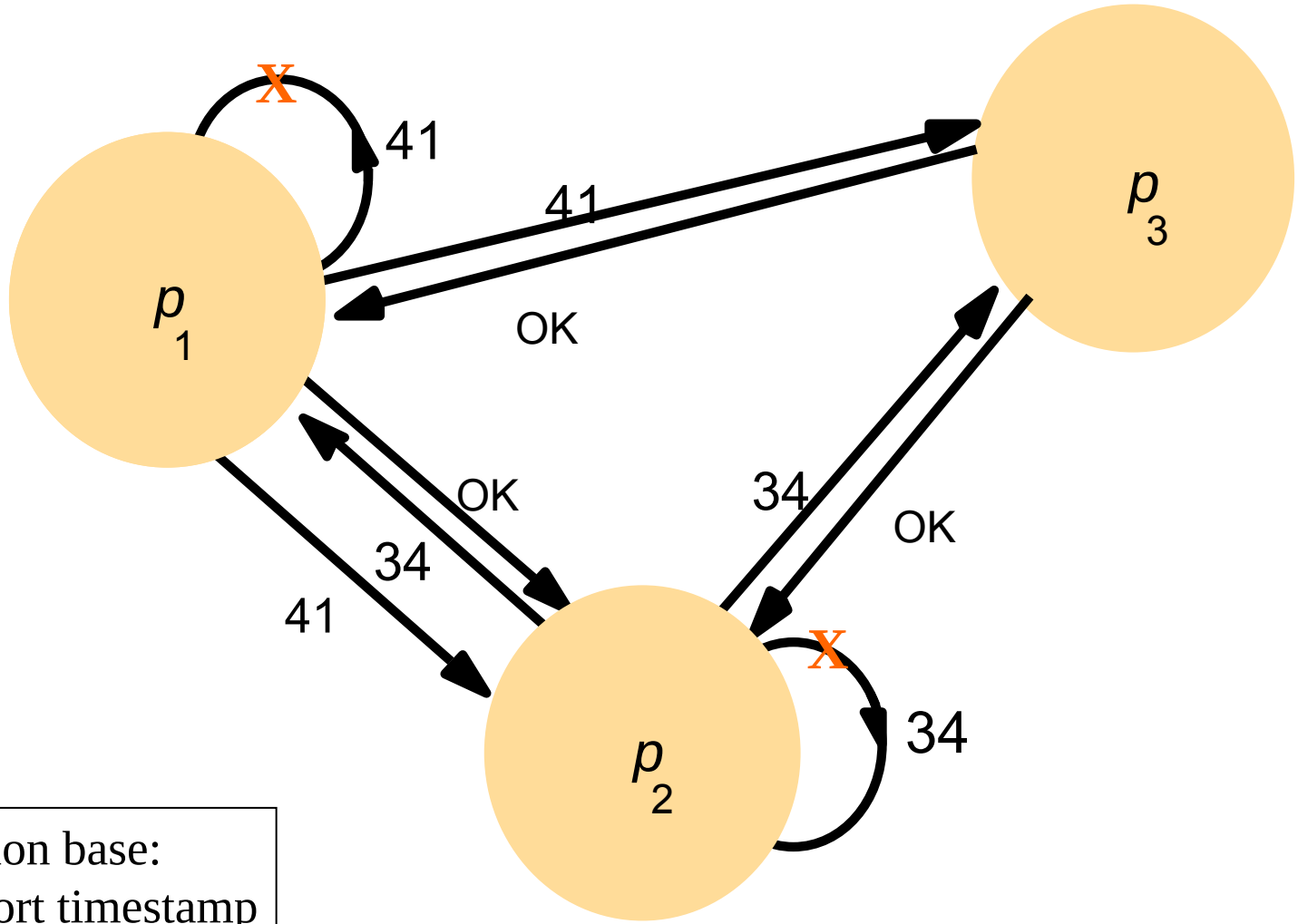
*if* (*state* = HELD or (*state* = WANTED *and* $(T, p_j) < (T_i, p_i)$))
*then*
    queue *request* from $p_i$ without replying;
*else*
    reply OK immediately to $p_i$;
*end if;*

***To exit the critical section***

*state* := RELEASED;
reply OK to all queued requests;

# Ricart – Agrawala EX.

P1 and P2 requests access concurrently at time 41 and 34




Decision base:
Lamport timestamp

X: i=j

# Performance

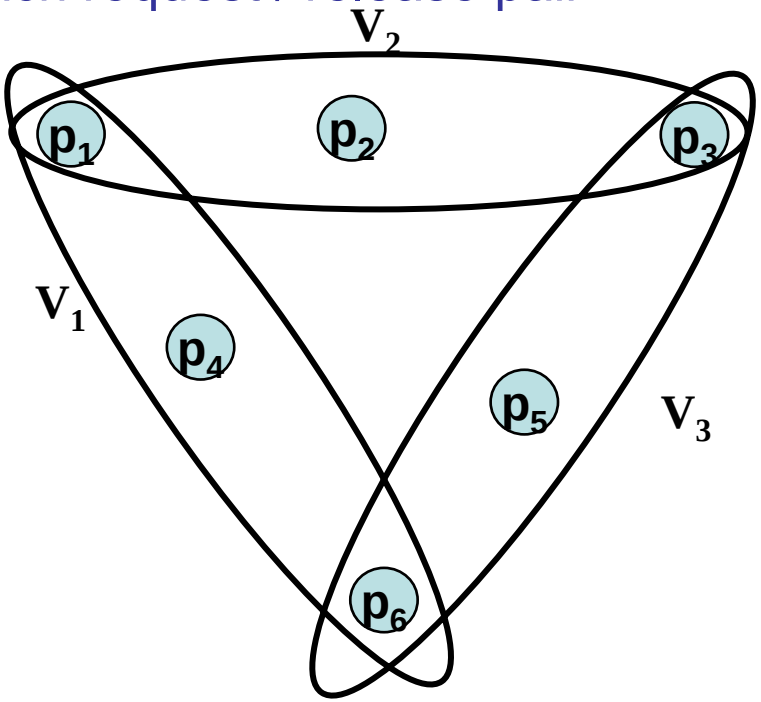
- Gaining entry:  2(n-1) messages per request without HW-multicast
  - N-1 to multicast request
  - N-1 replies
- Client Entry Delay: 1 round-trip time (multicasting is counted as 1 step)
- Client Exit Delay: 1 message
- Synchronization delay is one message
- N-points of failure

# Maekawa's Algorithm [1981]

- **Idea:** Get permission from only a subset of processes.
  - **quorum:**
    - "The minimal number of officers and members of a committee or organization, usually a majority, who must be present for valid transaction of business."

# Voting

- To enter its CS, a process gets permission from all members of its group
  - A process may grant permission to only one process at a time (between each request / release pair




- Complexity depends on group size
  - Want to minimize group size

# Voting-Sets

**Voting-set $V_i$ for $P_i$**

1. $\forall i,j$: $V_i \cap V \neq \emptyset$
   - Safety: at least one common member of any two voting-sets
2. $V_i$ contains process $p_i$
   - Saves a message
3. $|V_1| = |V_2| = \ldots = |V_N| = K$
   - *Fairness: every process has a voting set of the same size*
4. Each process is in $M$ of the voting sets $V_i$'s
   - Each processor has the same responsibility

- Minimal $K$ satisfying 1..4 is $c\sqrt{N}$.
- Heuristic algorithms exist

# Maekawa's algorithm – part 1

***On initialization***

*state* := RELEASED;
*voted* := FALSE;

***For $p_i$ to enter the critical section***

*state* := WANTED;
Multicast *request* to all processes in $V_i - \{p_i\}$;
*Wait until* (number of replies received = $(K - 1)$);
*state* := HELD;

***On receipt of a request from $p_i$ at $p_j$ ($i \neq j$)***

*if* (*state* = HELD *or voted* = TRUE)
*then*
    queue *request* from $p_i$ without replying;
*else*
    send *reply* to $p_i$;
    *voted* := TRUE;
*end if*

# Maekawa's algorithm – part 2

***For $p_i$ to exit the critical section***

*state* := RELEASED;

Multicast *release* to all processes in $V_i - \{p_i\}$;

***On receipt of a release from $p_i$ at $p_j$ ($i \neq j$)***

*if* (queue of requests is non-empty)

*then*

remove head of queue – from $p_k$, say;

send *reply* to $p_k$;

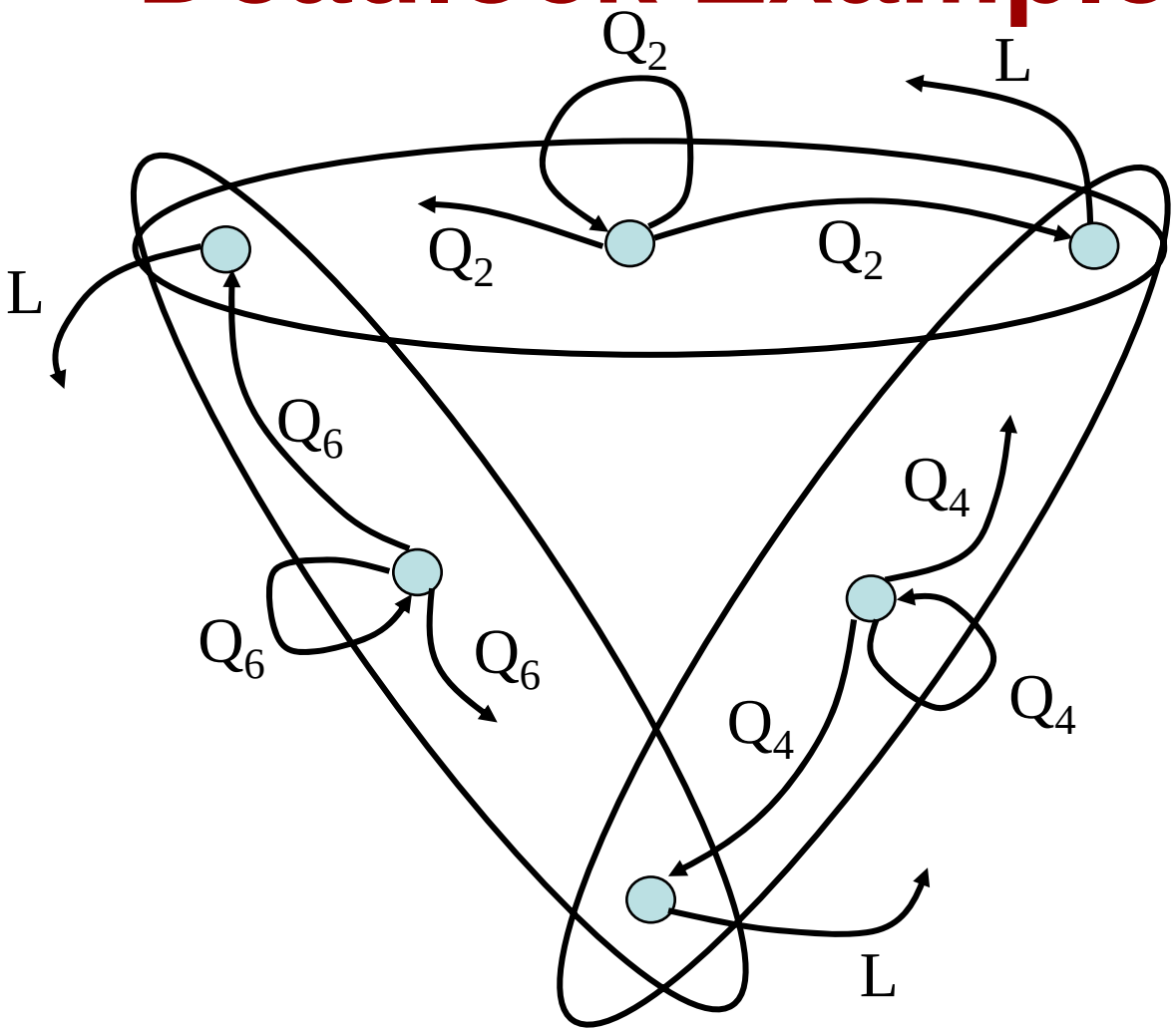
*voted* := TRUE;

*else*

*voted* := FALSE;

*end if*

# Deadlock Example




Concurrent request ⇒ common processes votes to left most quorum ⇒
Circular wait possible ⇒ deadlock possible

# Comparison

| Algorithm | Messages per entry/exit | Synchronization Delay (seq. msgs) | Problems |
|---|---|---|---|
| Centralized | 3 | 2 | Coordinator crash |
| Token ring | 1 … ∞ | 0..n-1 (Avg: n/2) | Lost token, process crash |
| Ricart & Agrawali | 2 ( n – 1 ) | 1 | Crash of **any** process |
| Maekava voting | 3√N | 2 | Crash of process in voting set |

A comparison of mutual exclusion algorithms.

**Notice**: the system may contain a remarkable amount of sharable resources!

# Summary

- All distributed algorithms suffer badly in event of crashes.
- Special measures and additional complexity must be introduced to avoid having a crash bring down the entire system.

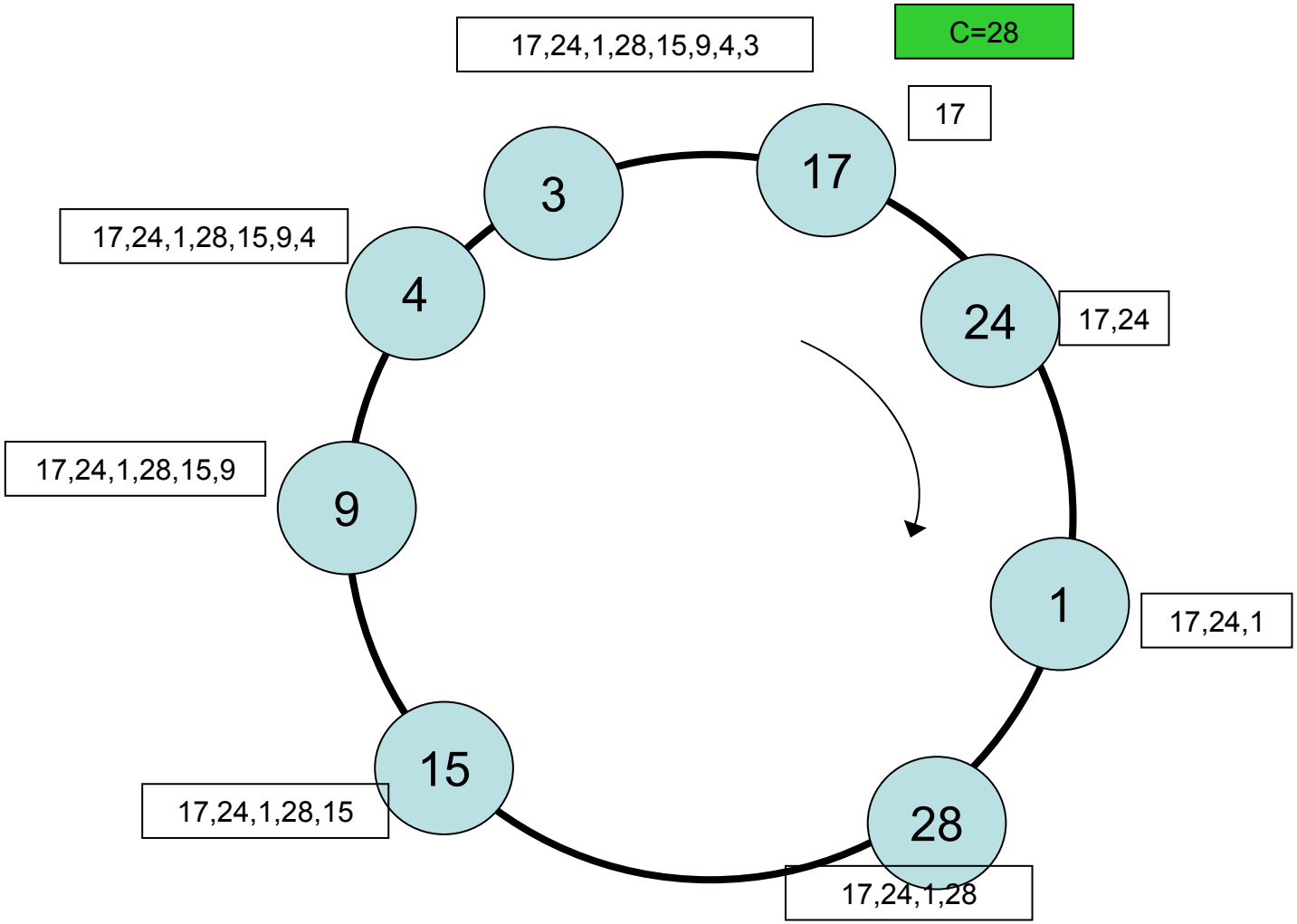
# Election Algorithms

- Need:
  - computation: a group of concurrent processes
  - algorithms based on the activity of a special role (coordinator, initiator)
  - election of a coordinator: initially or after some special event (e.g., the previous coordinator has disappeared)
- Premises:
  - each member of the group
    - knows the identities of all other members
    - does not know who is up and who is down
  - all electors use the same algorithm
  - election rule: the member with the highest process id

# Election Requirements

- **E1:** *(safety)* A participant process $p_i$ has either $elected_i = \perp$, or $elected_i = p$, where $p$ is the *non-crashed* process having the largest process identifier
- **E2:** *(liveness)* All processes $p_i$ participate and will at some point in time set their $elected_i$ variable to a value different from $\perp$ or crash
- $\perp$ = undefined

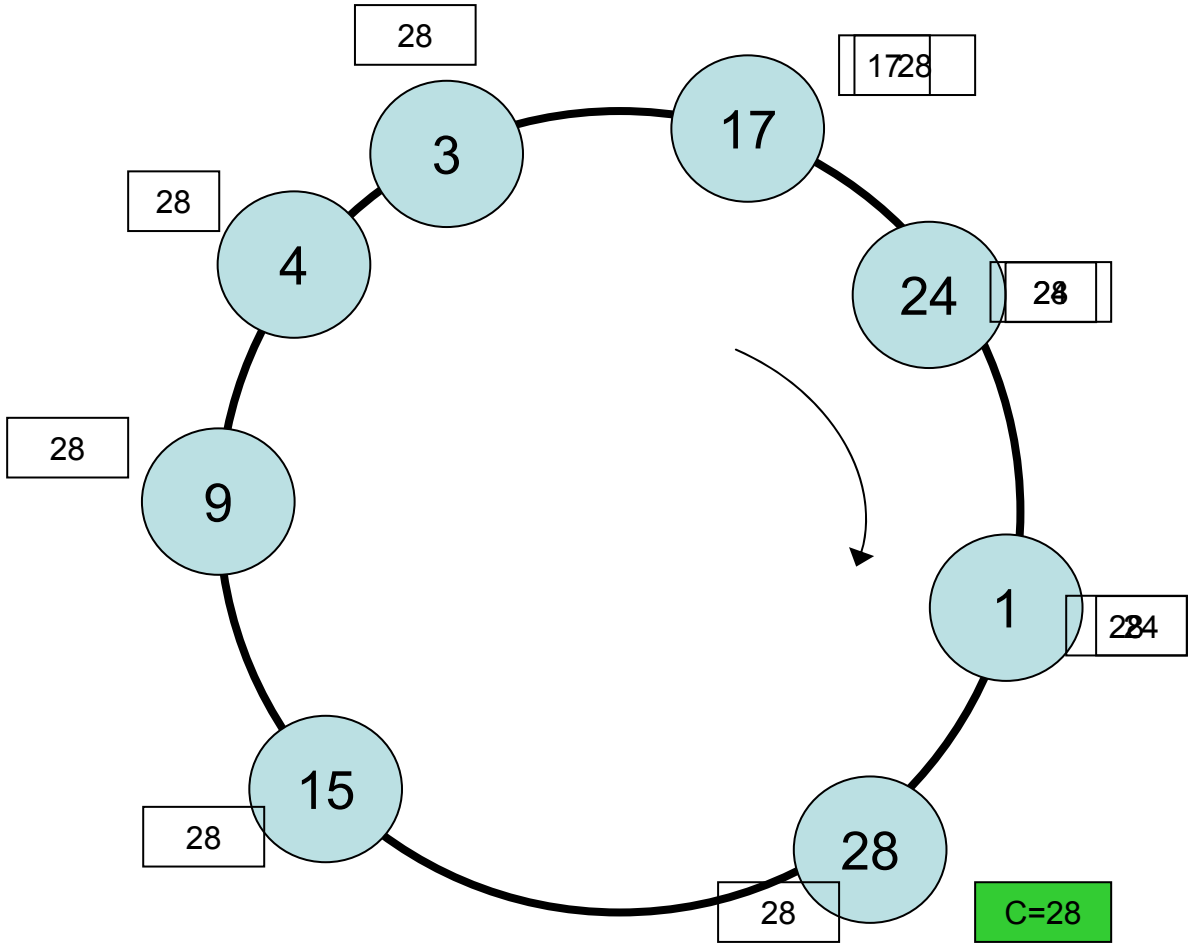
# A ring-based election 1



# Chang-Roberts

- Improvement Idea:
  - When a node receives a token with smaller id than itself, why should it keep forwarding it?
    - It is a waste, we know that that id will never win!
    - Lets drop tokens with smaller ids than ourselves!
  - Mark nodes that has already participated in an ongoing election to kill concurrent elections
  - A process declares itself elected when it receives its own ID back

# Chang-Roberts



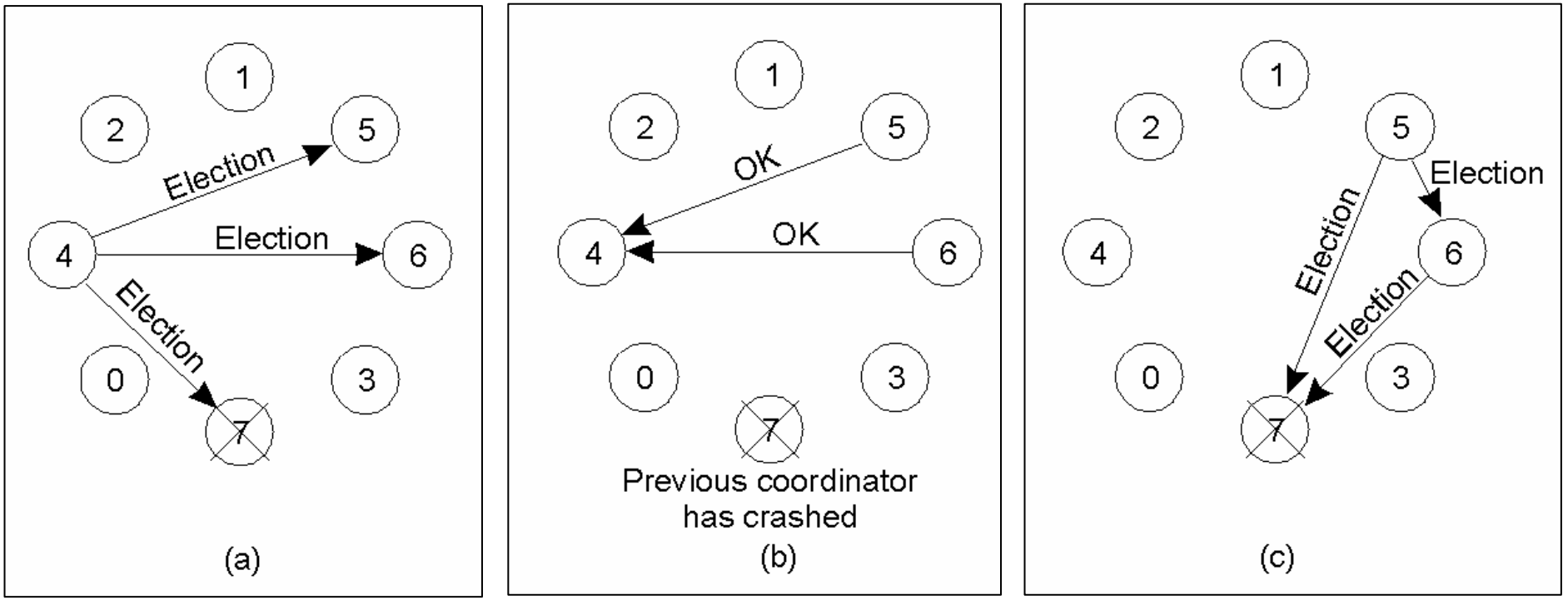
# Performance

- Bandwidth: 3N-1
  - N-1 in worst case to reach process with highest ID +
  - One round of N messages before node with highest ID can announce it is a winner +
  - One round of N messages to inform other nodes about coordinator
- Turnaround: an election takes sequential 3 rounds

# Bully Algorithm

- Bully
  - *A person who is habitually cruel, especially to smaller or weaker people*
- Processes may fail during election
- Uses timeout to detect failure ($\Rightarrow$assumes synchronous system)
- Each process knows processes with higher ID's
- 3 message types
  - A process sends *Election* to all processes with larger IDs to start an election
  - *Answer (OK):* to election message tells receiver that sender is alive and that receiver must shut-up
  - *Coordinator:* inform about new coordinator

# The Bully Algorithm (2)



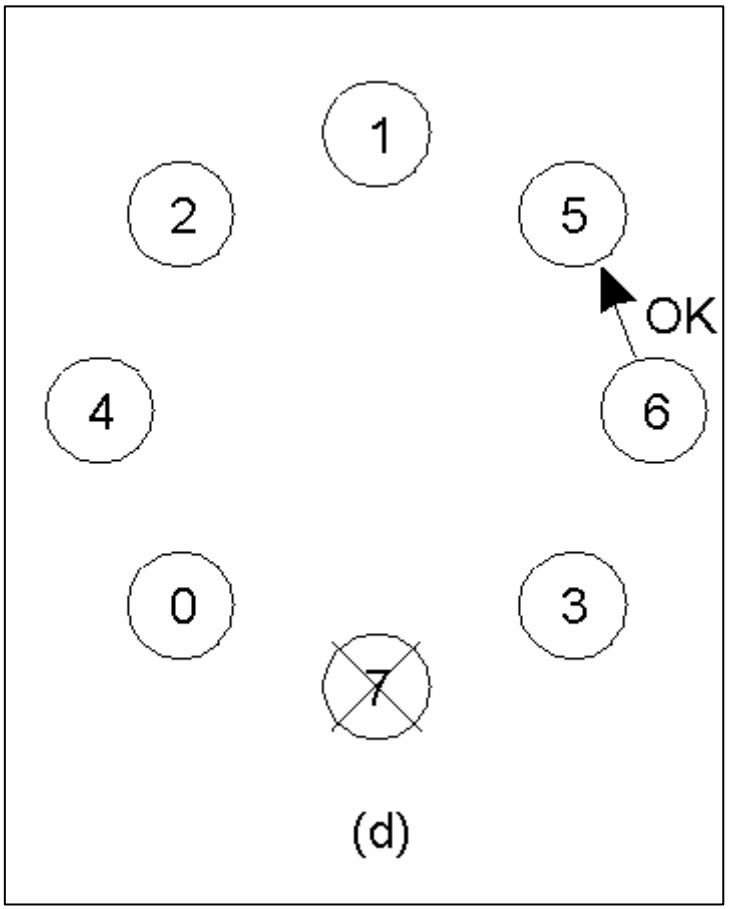

Coordinator id 7 is dead

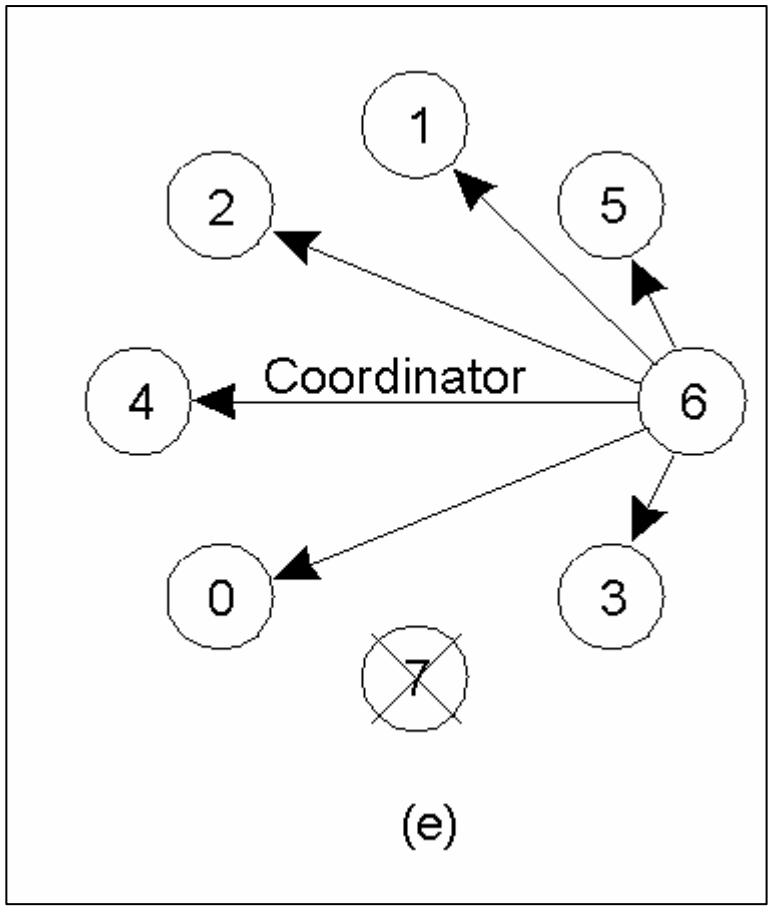
( a ) Process 4 holds an election

( b ) Process 5 and 6 respond, telling 4 to stop

( c ) Now 5 and 6 each hold an election

# The Bully Algorithm (3)



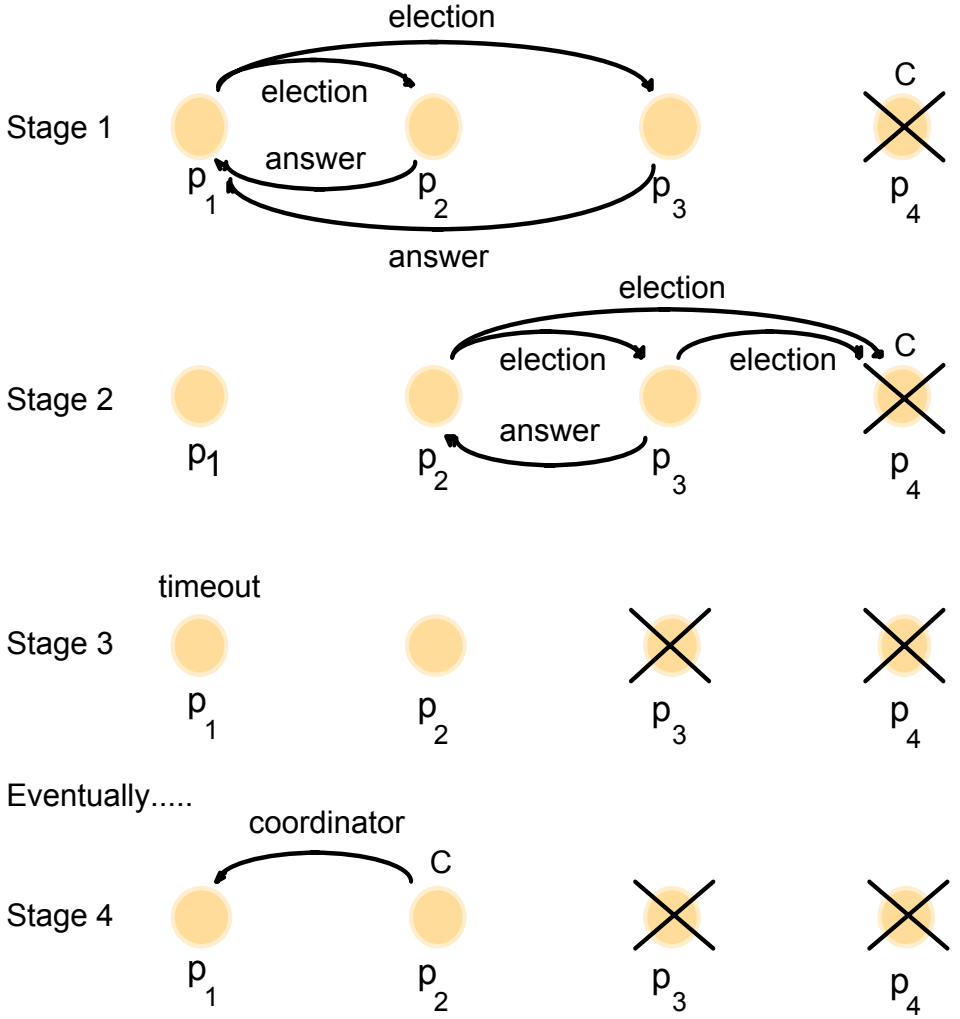




( d) Process 6 tells 5 to stop

( e) Process 6 wins and tells everyone

# The bully algorithm

- $P_1$ detects crash of coordinator $p_4$
- $P_1$ decides to hold an election
- $P_2$ and $p_3$ tells $P_1$ to shut up and hold their own (concurrent) elections
- $p_3$ tells $P_2$ to shut up
- $p_3$ times out waiting from answer from $P_4$ and declares itself the coordinator
- Alas, $P_3$ fails
- $P_1$ times out waiting for coordinator and decides to hold an election
- $P_2$ starts an election and realizes that it is largest living process and declares itself the coordinator $p_2$,



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