ECEN 757
Elections

Chapter 15

Why Election?

- Example: Your Bank account details are replicated at a few servers, but one of these servers is responsible for receiving all reads and writes, i.e., it is the leader among the replicas
  - What if there are two leaders per customer?
  - What if servers disagree about who the leader is?
  - What if the leader crashes?

    Each of the above scenarios leads to Inconsistency

Leader Election Problem

- In a group of processes, elect a *Leader* to undertake special tasks
  - And *let everyone know* in the group about this Leader
- What happens when a leader fails (crashes)
  - Some process detects this (using a Failure Detector!)
  - Then what?
- Focus of this lecture: Election algorithm. Its goal:
  1. Elect one leader only among the non-faulty processes
  2. All non-faulty processes agree on who is the leader

System Model

- *N* processes.
- Each process has a unique id.
- Messages are eventually delivered.
- Failures may occur during the election protocol.
- Failed processes don't do anything
  - Ex. It does not send heartbeat messages
- (In contrast: Byzantine failure: failed processes can do anything inconsistent with the protocol)

How to Detect Failure?

- Each process p sends a heartbeat message to another process q every T seconds
- Process q determines that p has failed if it has not received a heartbeat message in T+D seconds
- Reliable failure detection for synchronous systems
- How about asynchronous systems?
  - Can be inaccurate: false alarm
  - Can be incomplete: miss

Calling for an Election

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

Election Problem, Formally

- A run of the election algorithm must always guarantee at the end:
  - **Safety**: For all non-faulty processes p: (p' s elected = (q: a particular non-faulty process with the best attribute value) or Null)
  - **Liveness**: All processes will eventually set its elected or crash
- At the end of the election protocol, the non-faulty process with the best (highest) election attribute value is elected.
  - Common attribute : leader has highest id
  - Other attribute examples: leader has highest IP address, or fastest cpu, or most disk space, or most number of files, etc.

Trivial Solution

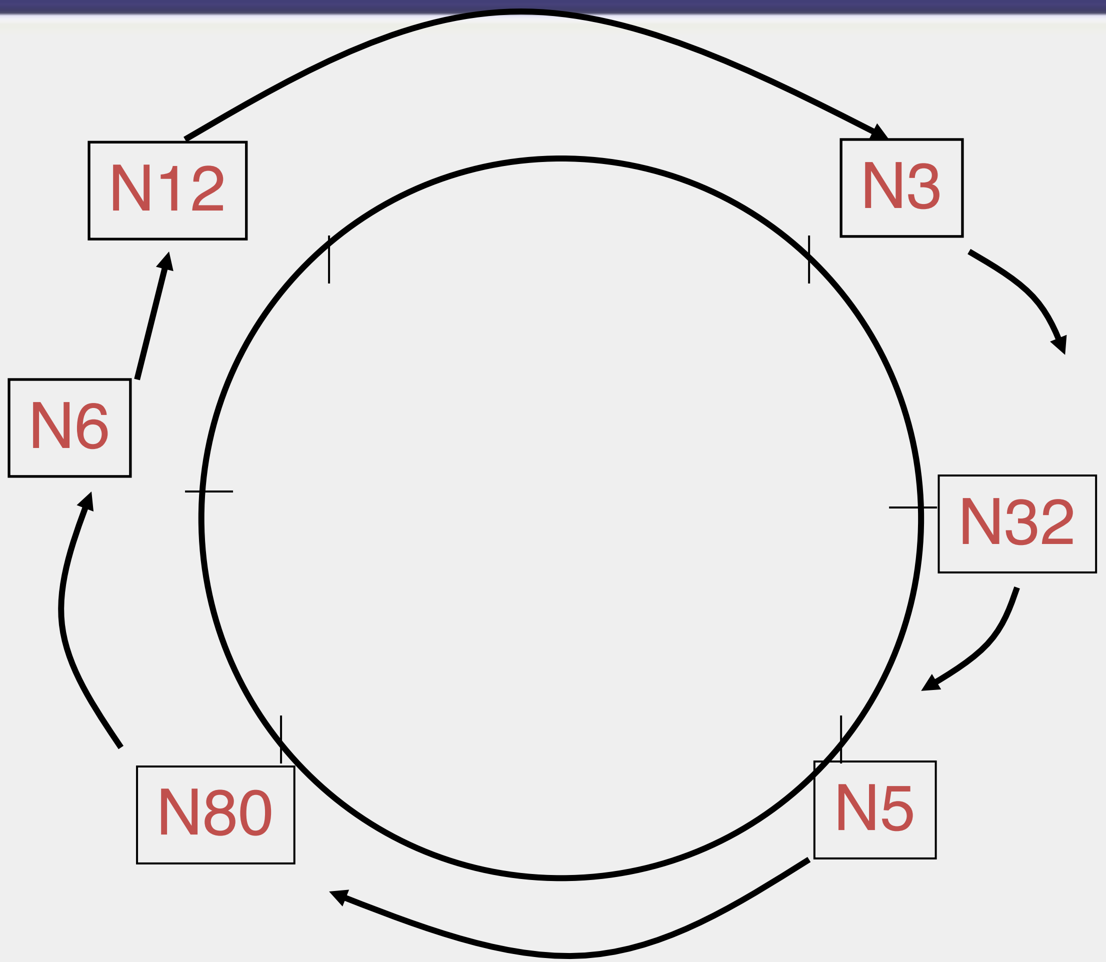
- When a process starts an election, it broadcasts a message to every other process
- Upon receiving this message, every process broadcast its ID to every other process
- After receiving all IDs, each process decides the process with the largest ID is the leader

- What are the potential problems?

First Classical Algorithm: Ring Election

- N processes are organized in a logical ring
  - i-th process p_i has a communication channel to $p_{(i+1) \bmod N}$
  - All messages are sent clockwise around the ring.

The Ring



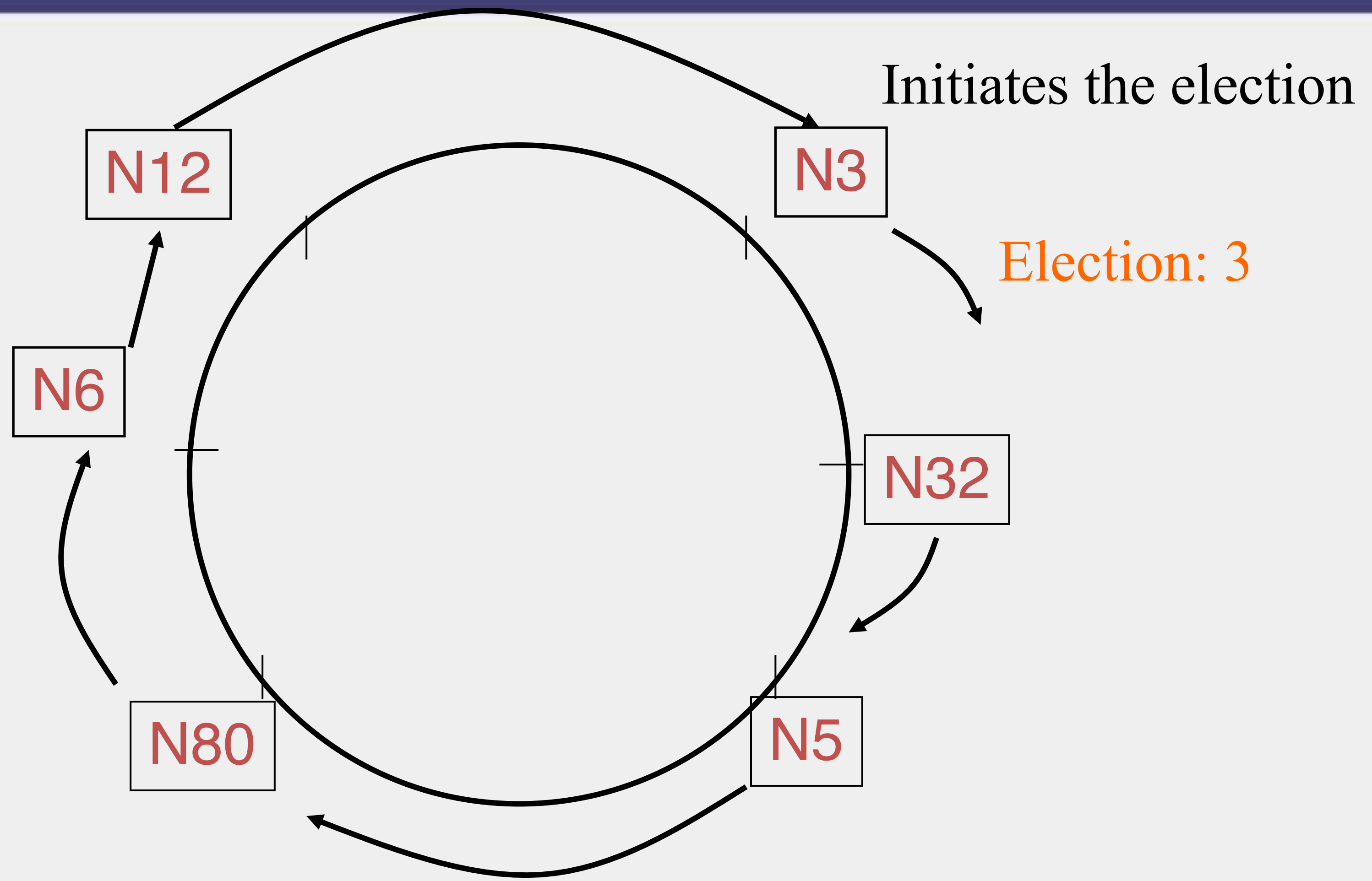
The Ring Election Protocol

- Any process p_i that discovers the old coordinator has failed initiates an "Election" message that contains p_i's own id:attr. This is the *initiator* of the election.
- When a process p_i receives an "Election" message, it compares the attr in the message with its own attr.
  - If the arrived attr is greater, p_i forwards the message.
  - If the arrived attr is smaller and p_i has not forwarded an election message earlier, it overwrites the message with its own id:attr, and forwards it.
  - If the arrived id:attr matches that of p_i, then p_i's attr must be the greatest (why?), and it becomes the new coordinator. This process then sends an "Elected" message to its neighbor with its id, announcing the election result.

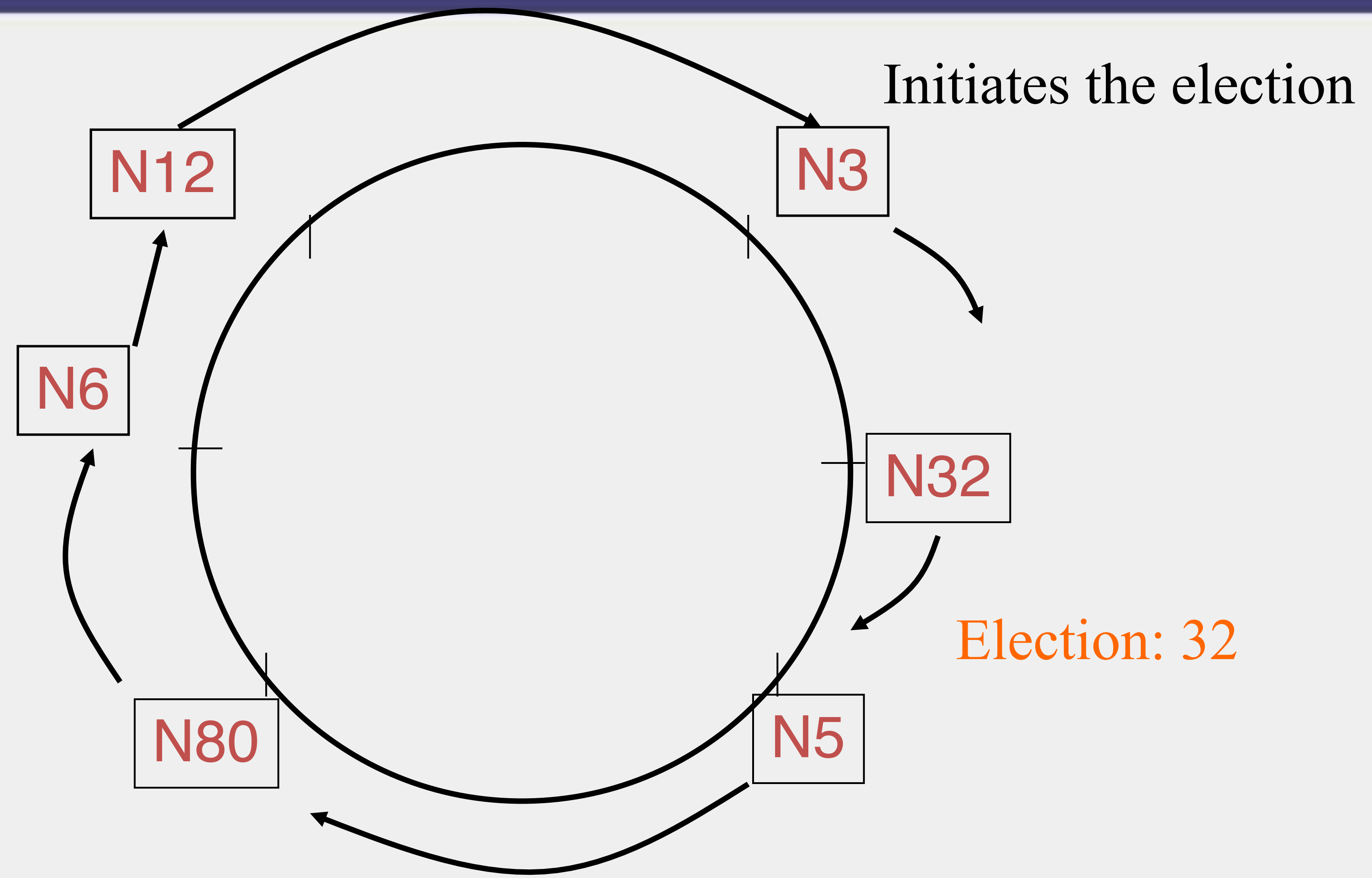
The Ring Election Protocol (2)

- When a process p_i receives an "Elected" message, it
  - sets its variable $elected_i \leftarrow$ id of the message.
  - forwards the message unless it is the new coordinator.

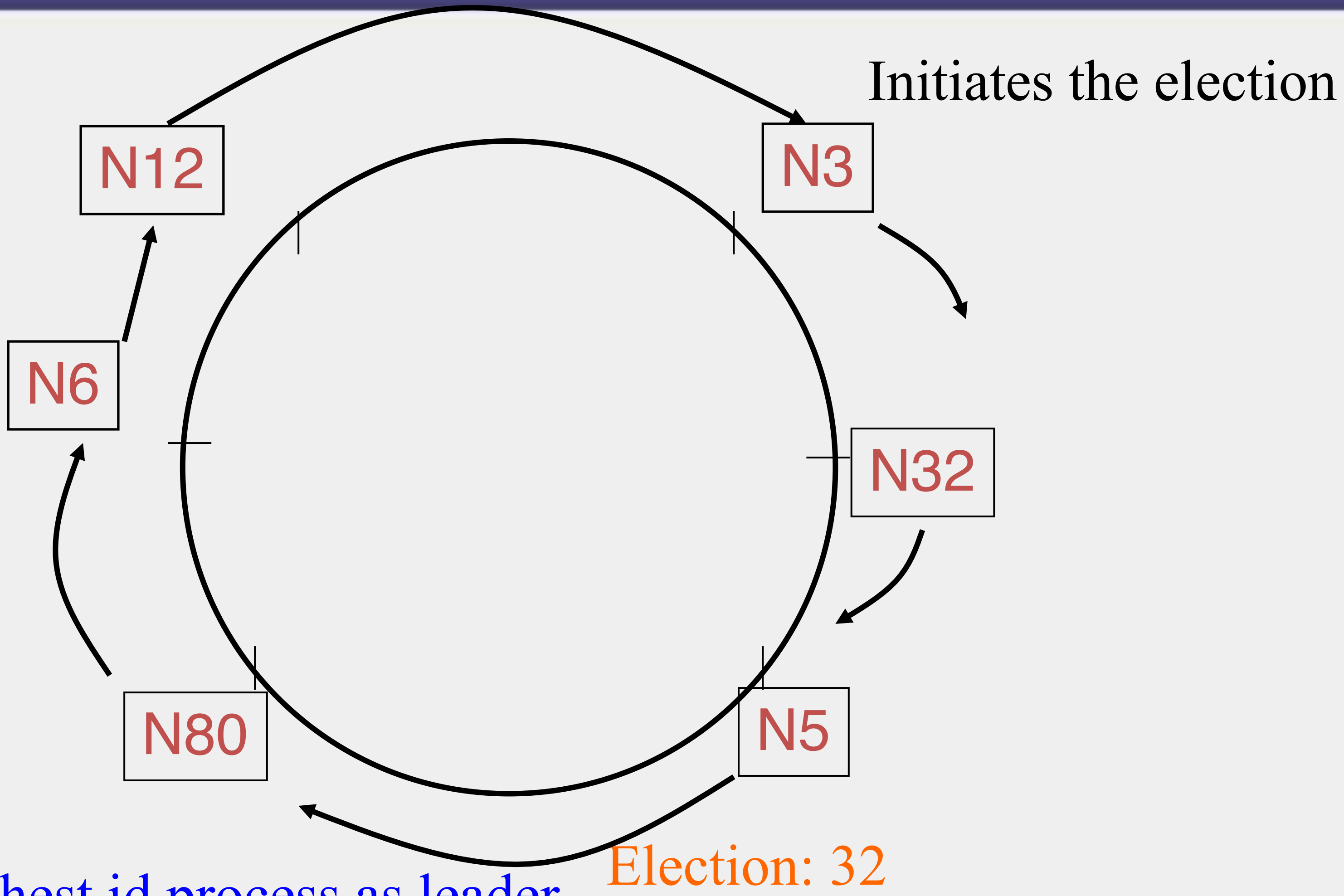
Ring Election: Example



Goal: Elect highest id process as leader

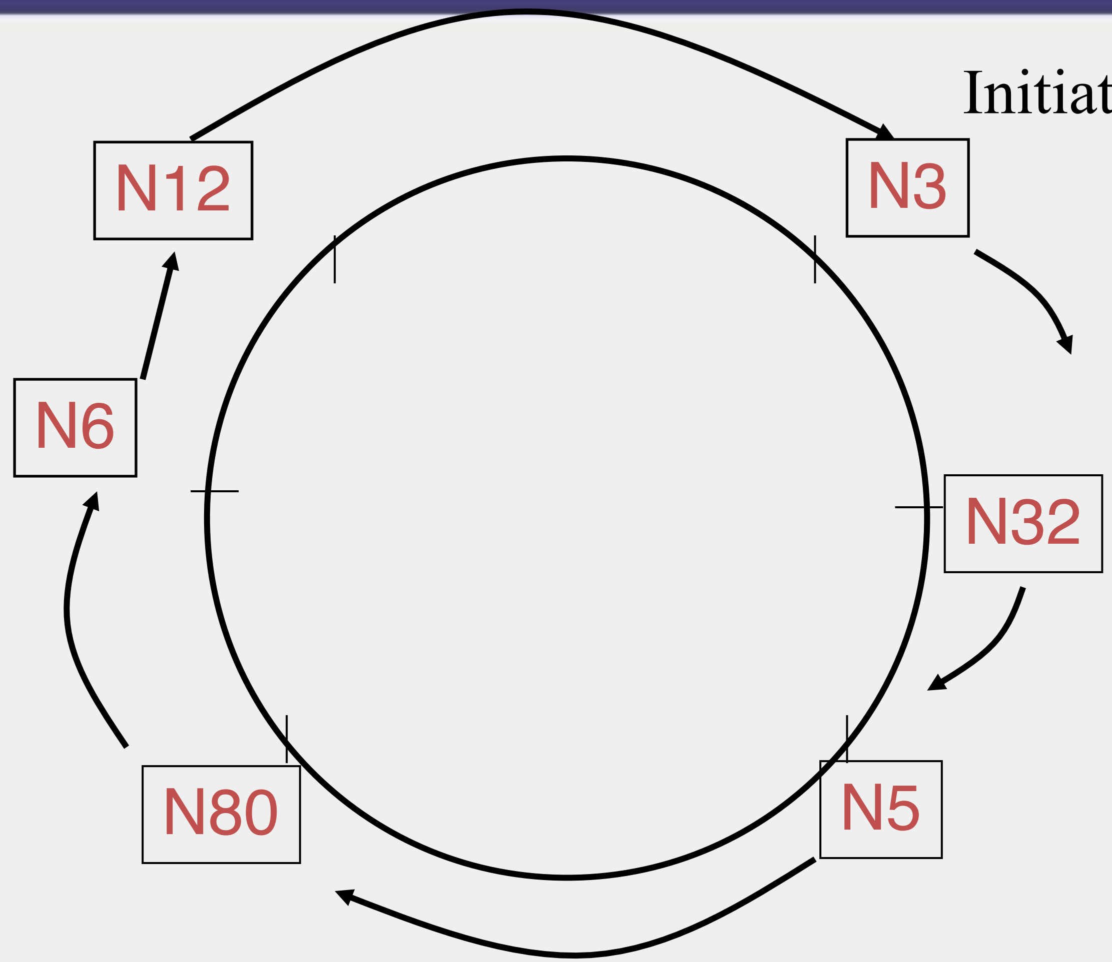


Goal: Elect highest id process as leader



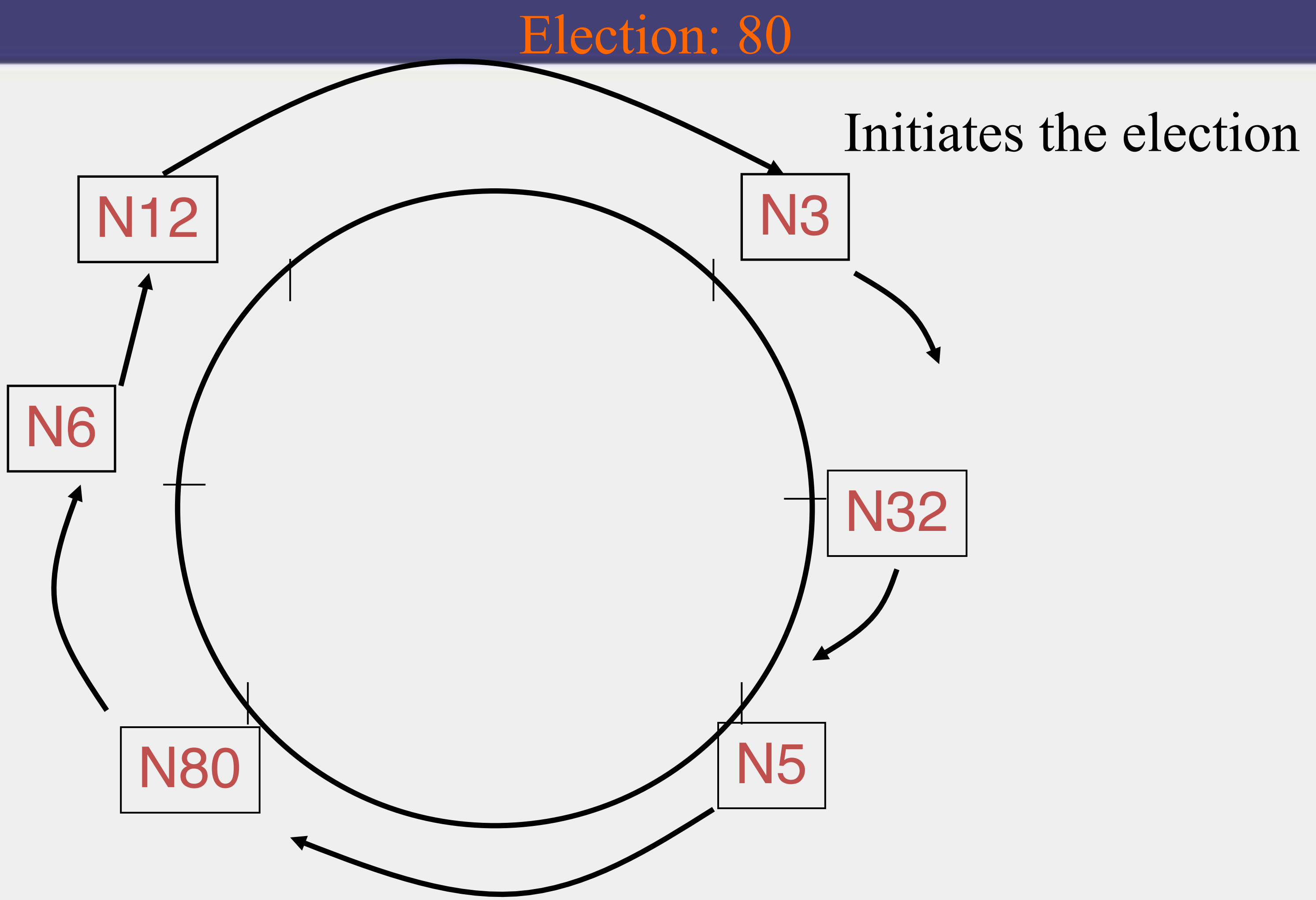
Goal: Elect highest id process as leader

Initiates the election

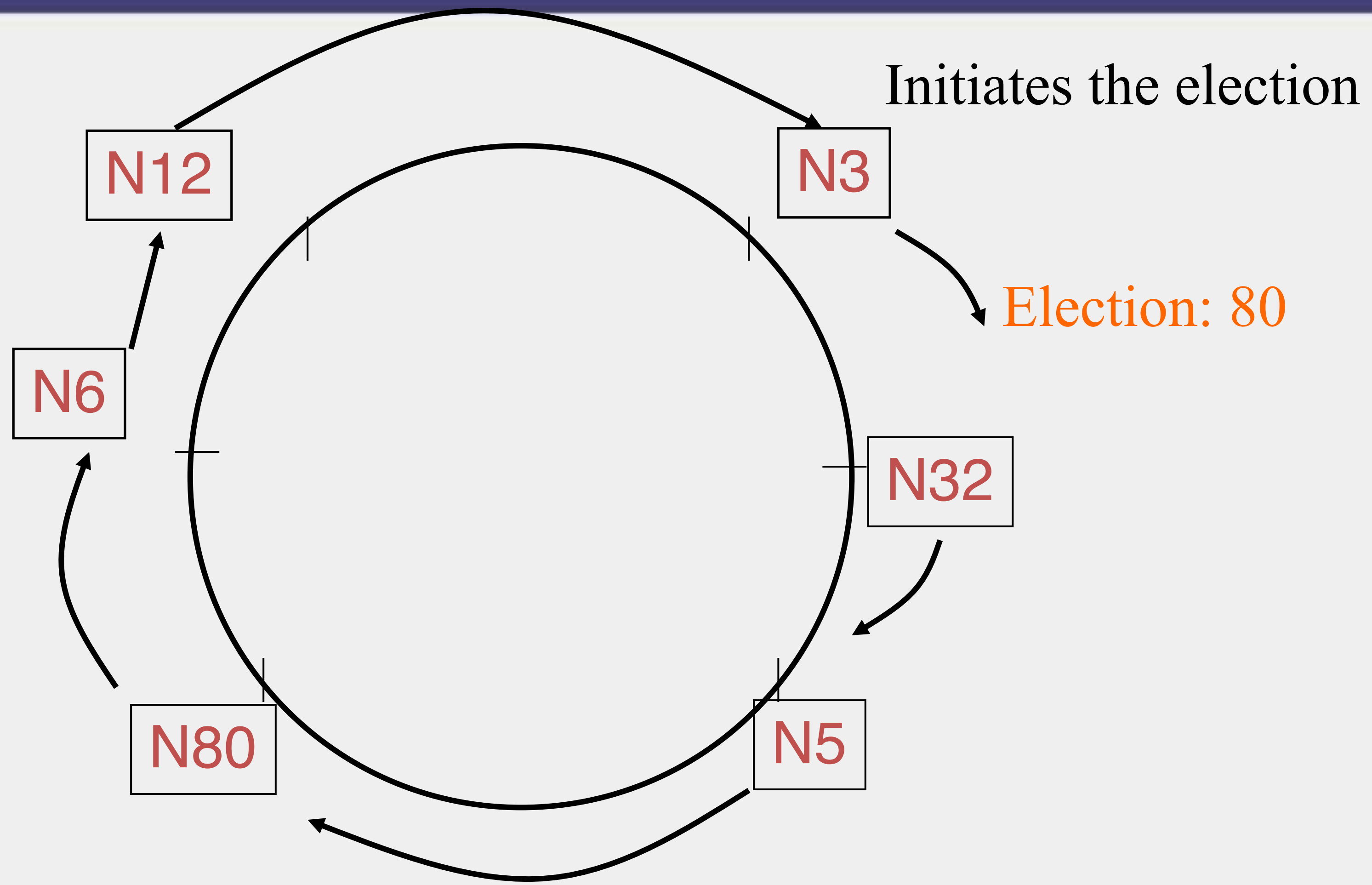


Election: 80

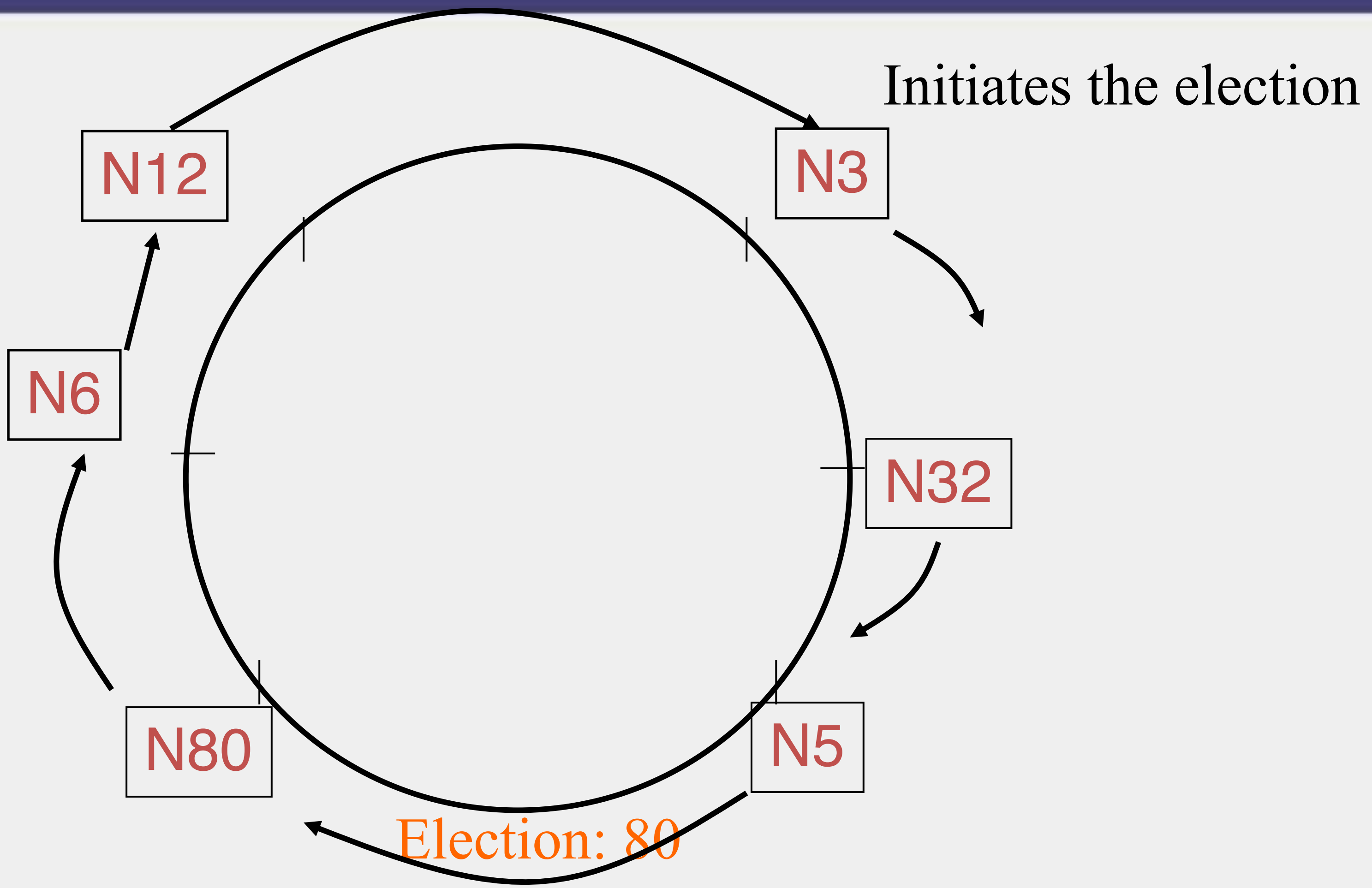
Goal: Elect highest id process as leader



Goal: Elect highest id process as leader

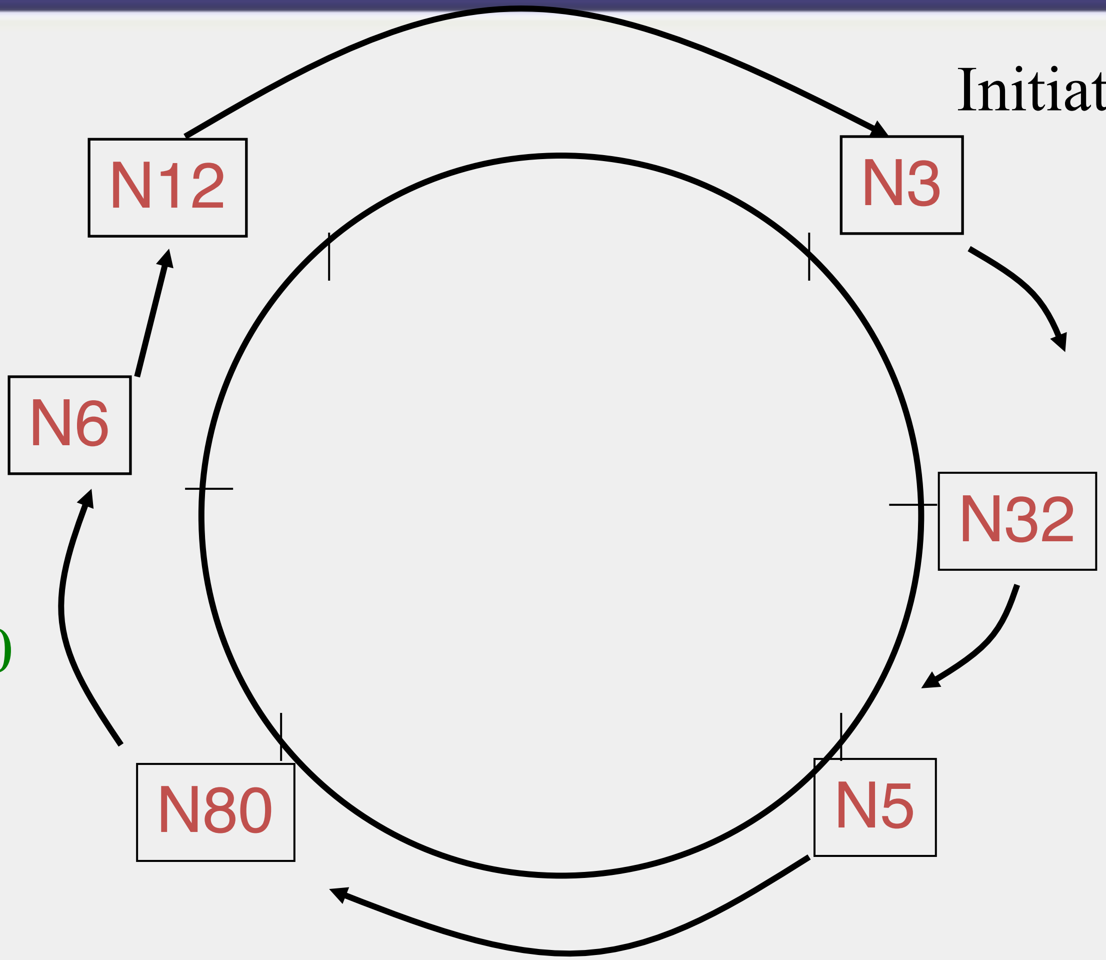


Goal: Elect highest id process as leader



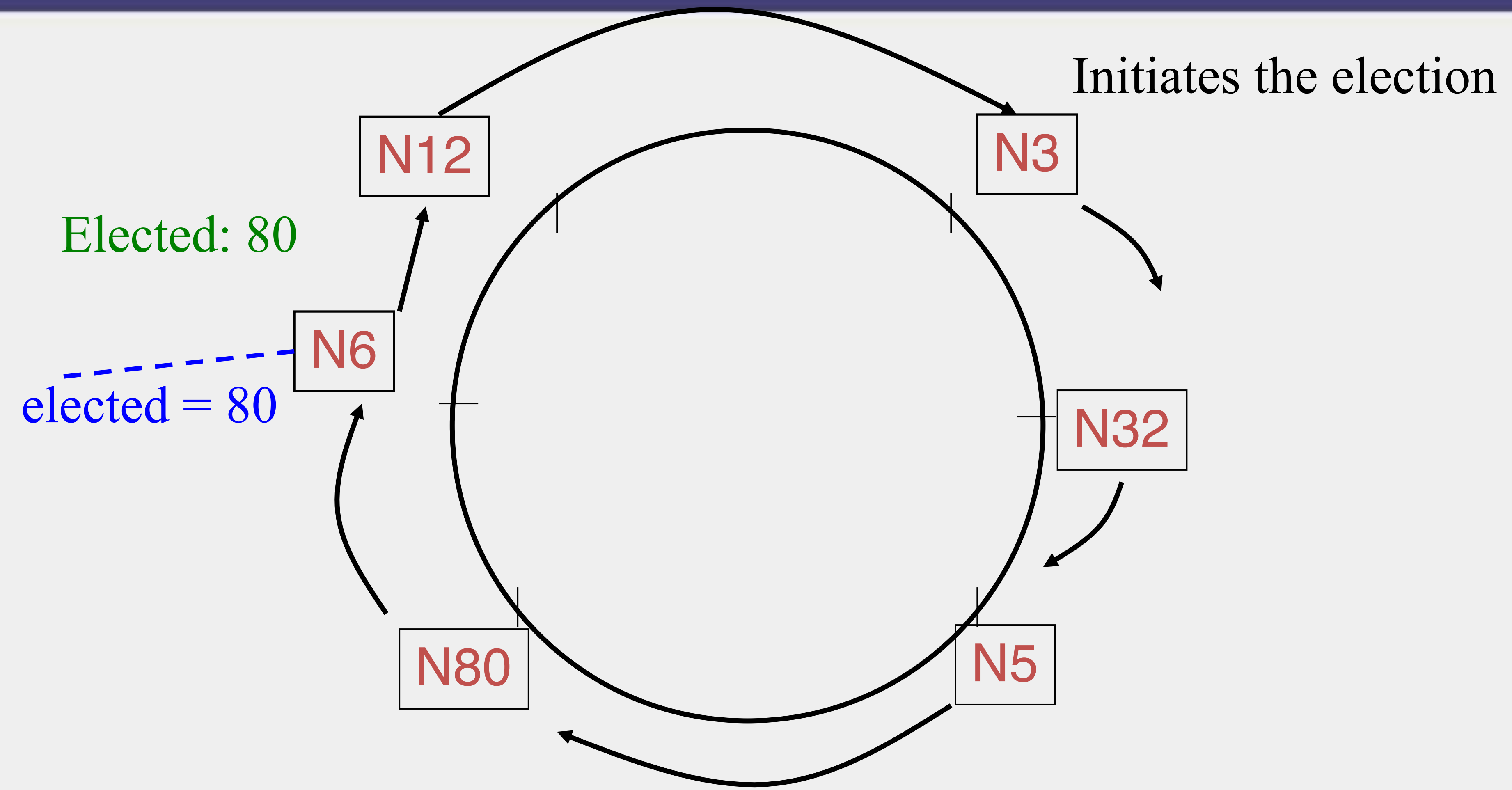
Goal: Elect highest id process as leader

Initiates the election

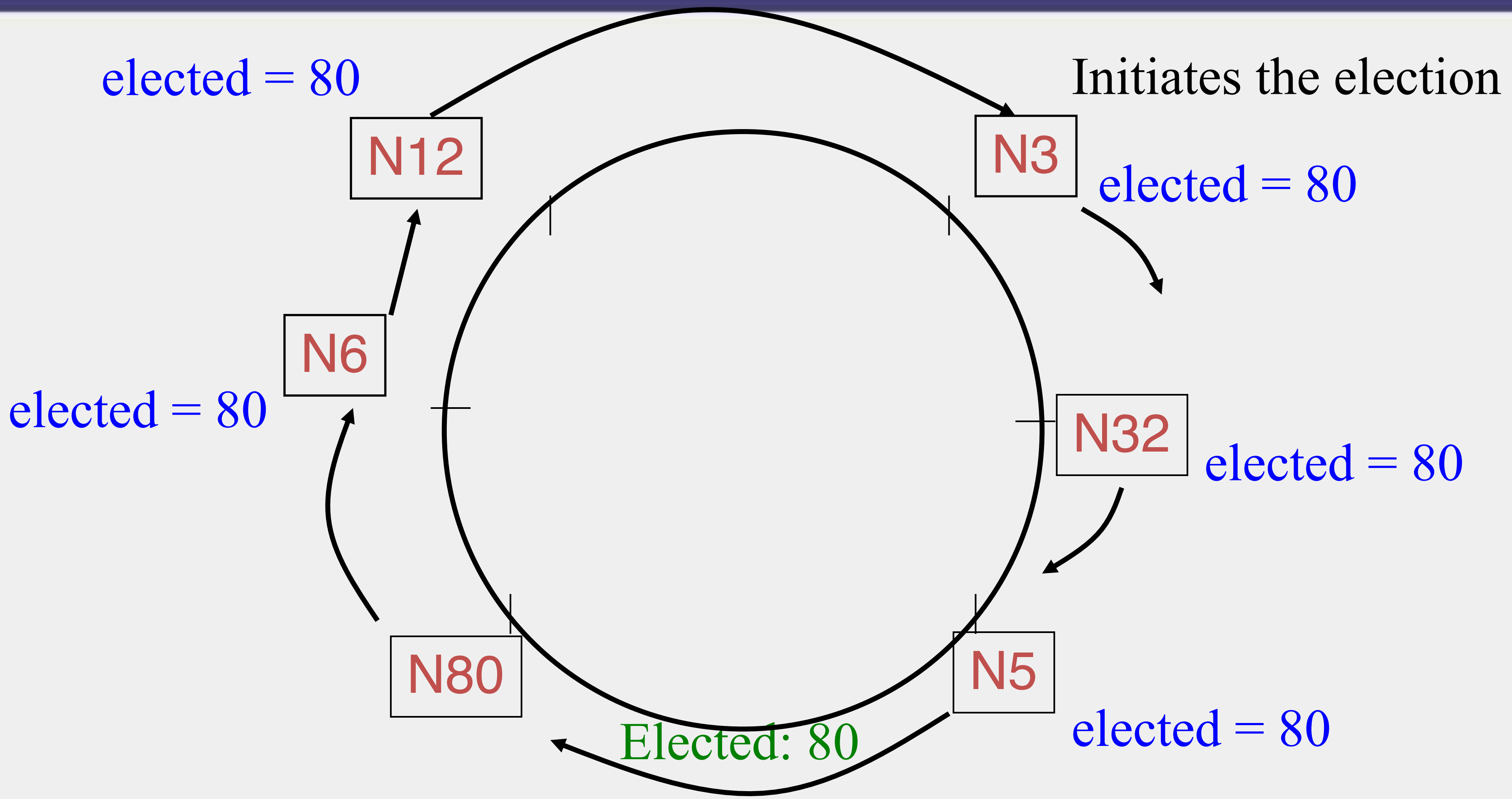


Elected: 80

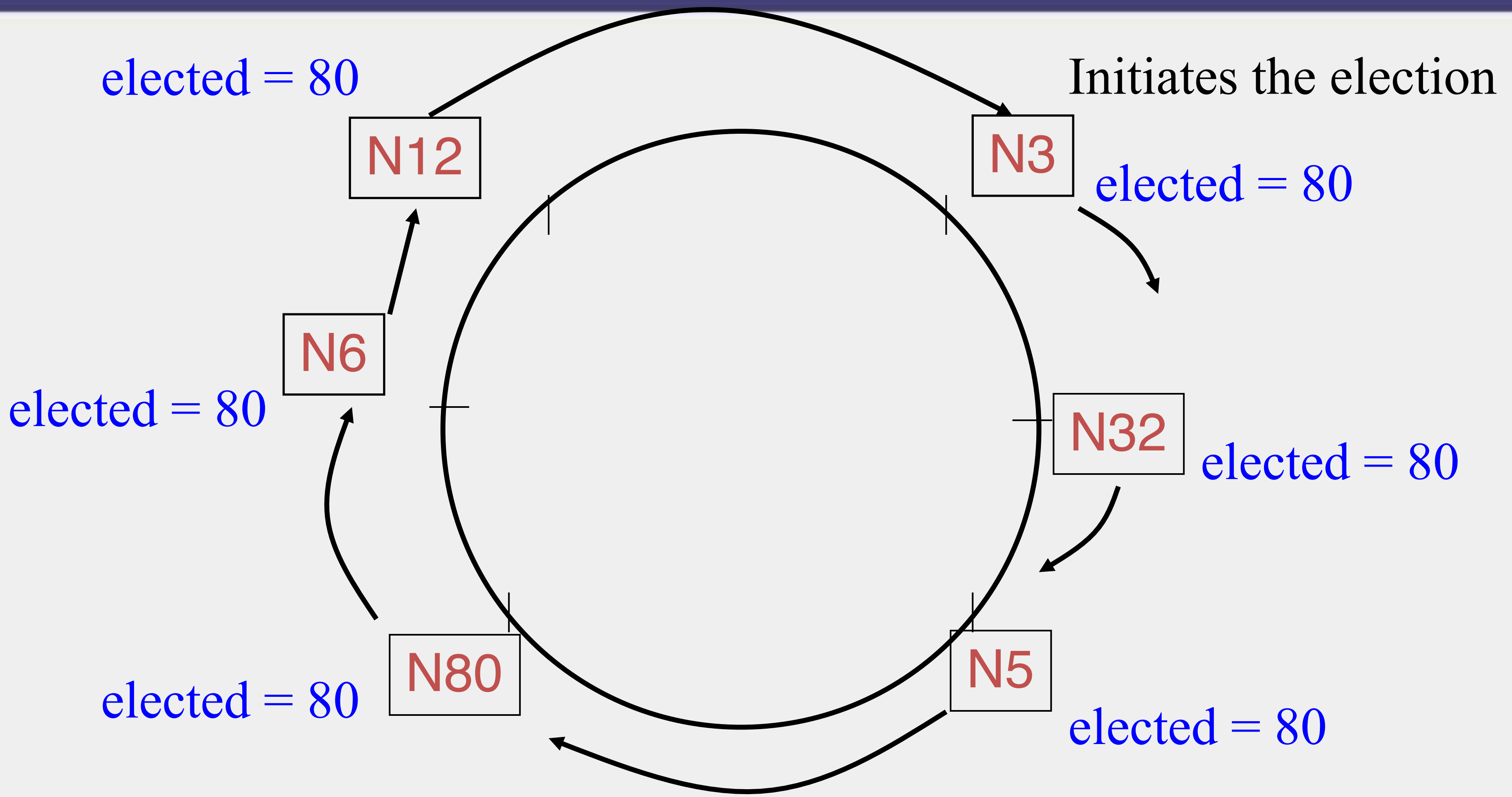
Goal: Elect highest id process as leader



Goal: Elect highest id process as leader



Goal: Elect highest id process as leader



Goal: Elect highest id process as leader

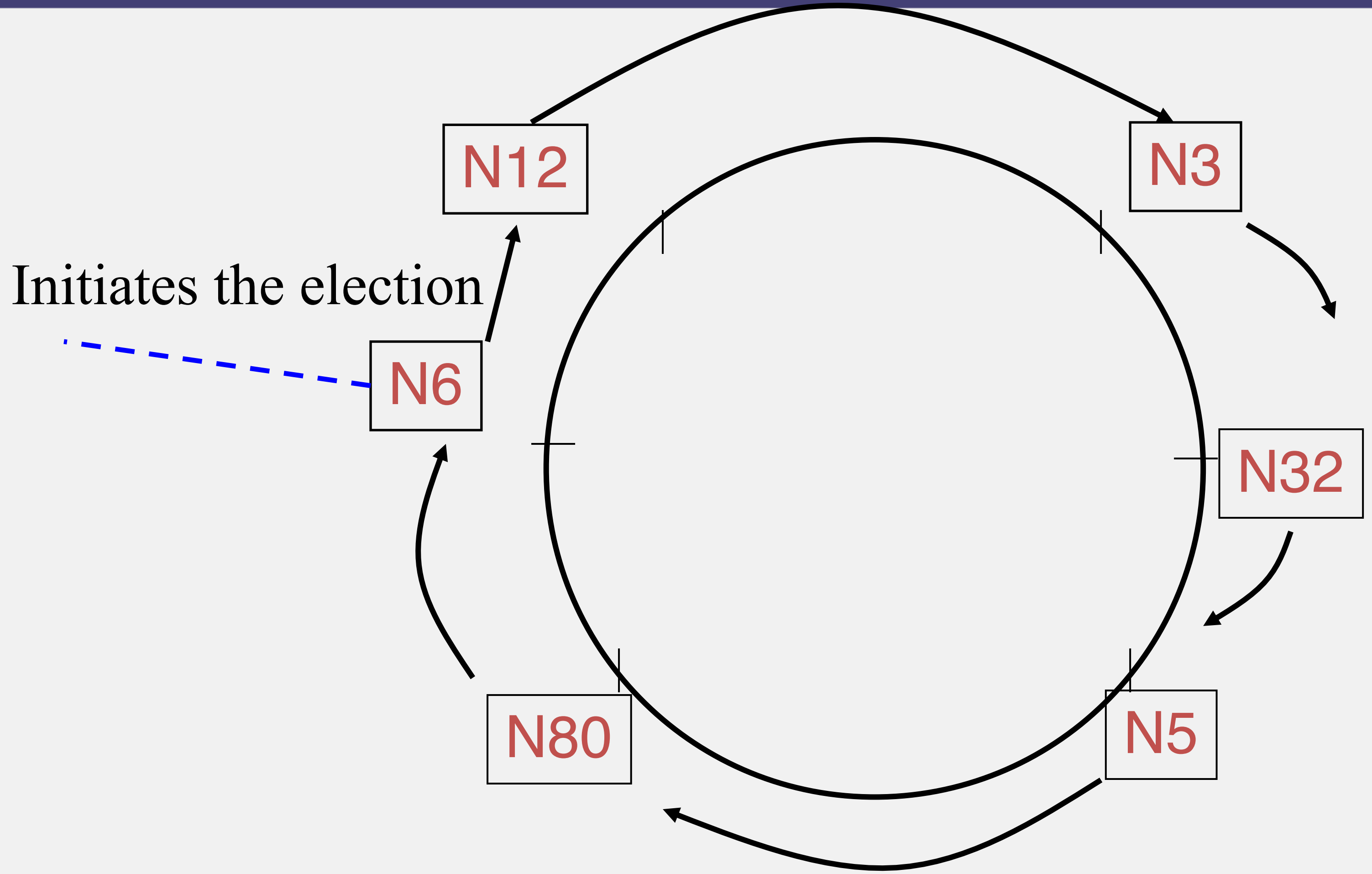
Analysis

- Let’s assume no failures occur during the election protocol itself, and there are N processes

- How many messages?

- Worst case occurs when the initiator is the ring successor of the would-be leader

Worst-case



Goal: Elect highest id process as leader

Worst-case Analysis

- (N-1) messages for Election message to get from Initiator (N6) to would-be coordinator (N80)
- N messages for Election message to circulate around ring without message being changed
- N messages for Elected message to circulate around the ring
- Message complexity: ($3N$-1) messages
- Completion time: ($3N$-1) message transmission times
- Thus, if there are no failures, election terminates (liveness) and everyone knows about highest-attribute process as leader (safety)

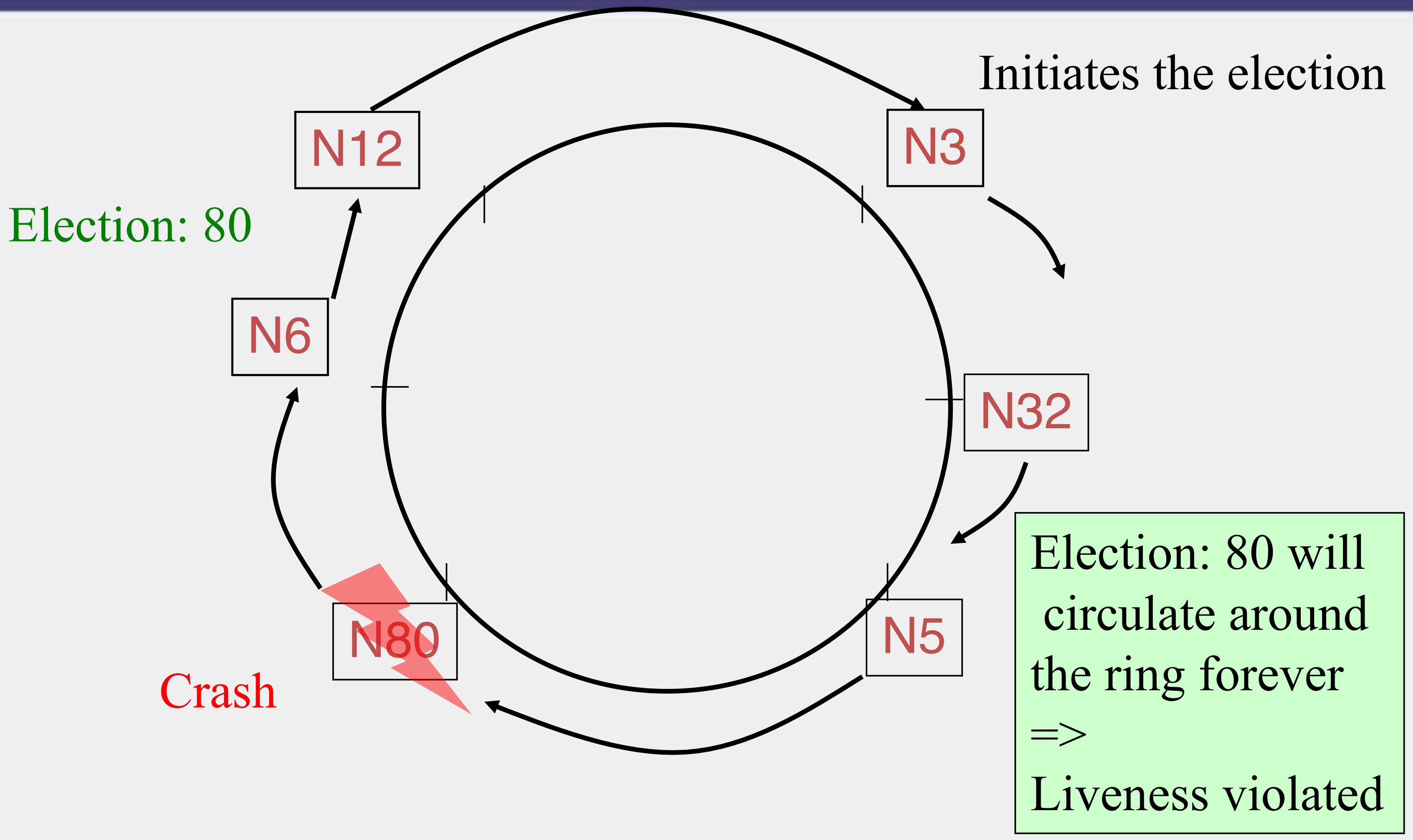
Best Case?

- Initiator is the would-be leader, i.e., N80 is the initiator
- Message complexity: $2N$ messages
- Completion time: $2N$ message transmission times

Multiple Initiators?

- Include initiator’s id with all messages
- Each process remembers in cache the initiator of each Election/Elected message it receives
- (All the time) Each process suppresses Election/Elected messages of any lower-id initiators
- Updates cache if receives higher-id initiator’s Election/Elected message
- Result is that only the highest-id initiator’s election run completes
- What about failures?

Effect of Failures



Fixing for failures

- One option: have predecessor (or successor) of would-be leader N80 detect failure and start a new election run
  - May re-initiate election if
    - Receives an Election message but times out waiting for an Elected message
    - Or after receiving the Elected:80 message
  - But what if predecessor also fails?
  - And its predecessor also fails? (and so on)

Fixing for failures (2)

- Second option: use the failure detector
- Any process, after receiving Election:80 message, can detect failure of N80 via its own local failure detector
  - If so, start a new run of leader election
- But failure detectors may not be both complete and accurate
  - Incompleteness in FD => N80's failure might be missed => Violation of Safety
  - Inaccuracy in FD => N80 mistakenly detected as failed
    - => new election runs initiated forever
    - => Violation of Liveness

Why is Election so Hard?

- Because it is related to the consensus problem!
- If we could solve election, then we could solve consensus!
  - Elect a process, use its id’s last bit as the consensus decision

- But since consensus is impossible in asynchronous systems, so is election!
  - More about this in next lecture

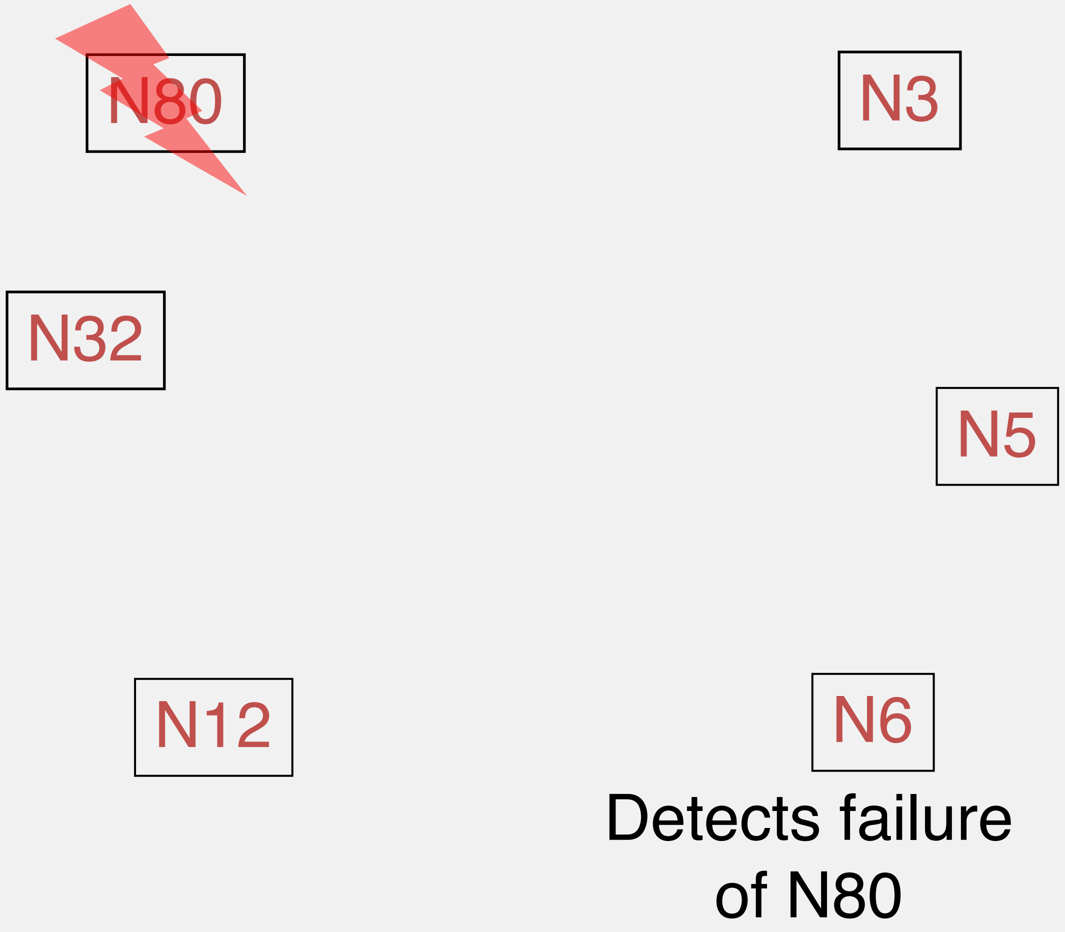
Another Classical Algorithm: Bully Algorithm

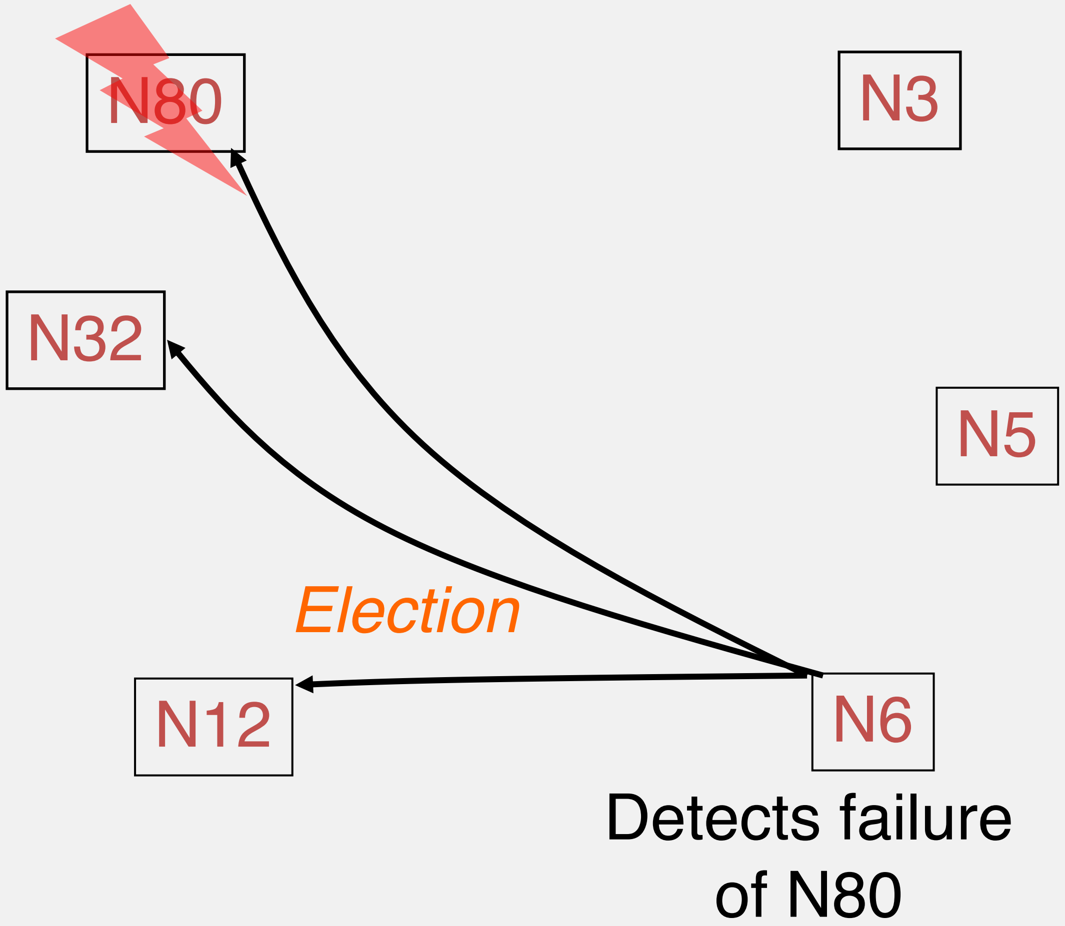
- All processes know other process' ids
- When a process finds the coordinator has failed (via the failure detector):
  - **if** it knows its id is the highest
    - it elects itself as coordinator, then sends a *Coordinator* message to all processes with lower identifiers. Election is completed.
  - **else**
    - it initiates an election by sending an *Election* message
    - (contd.)

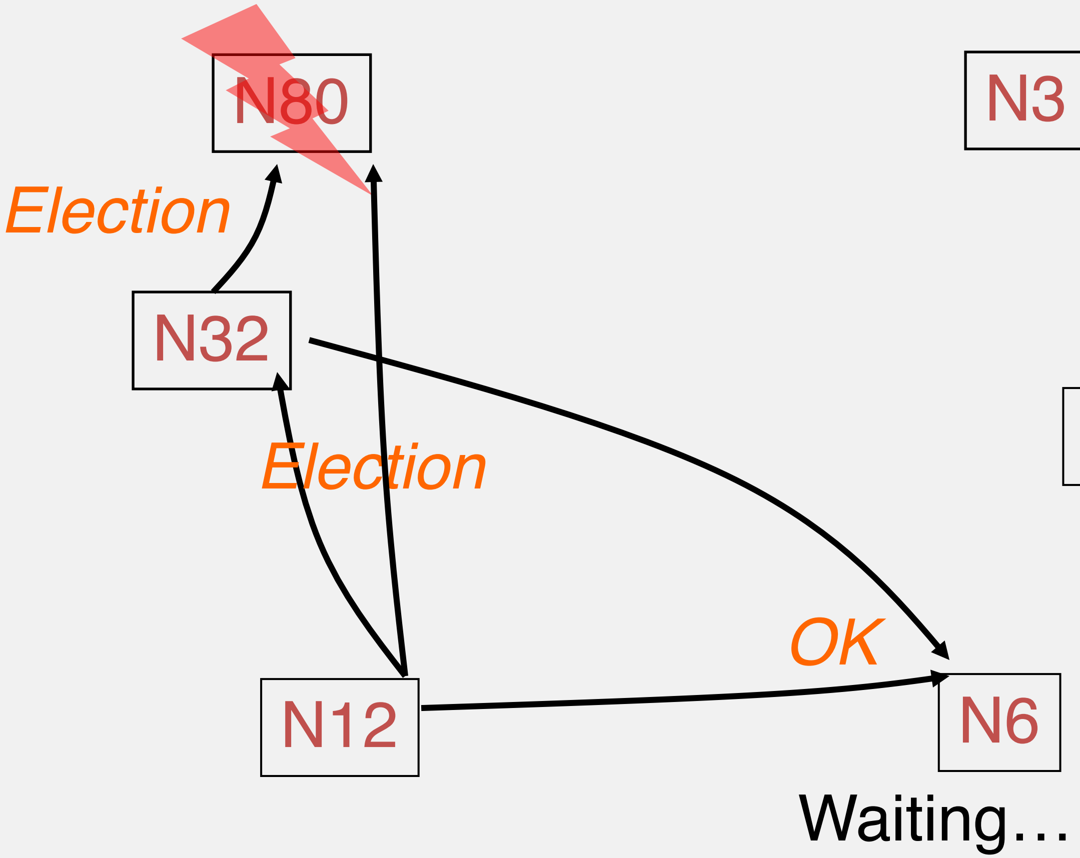
Bully Algorithm (2)

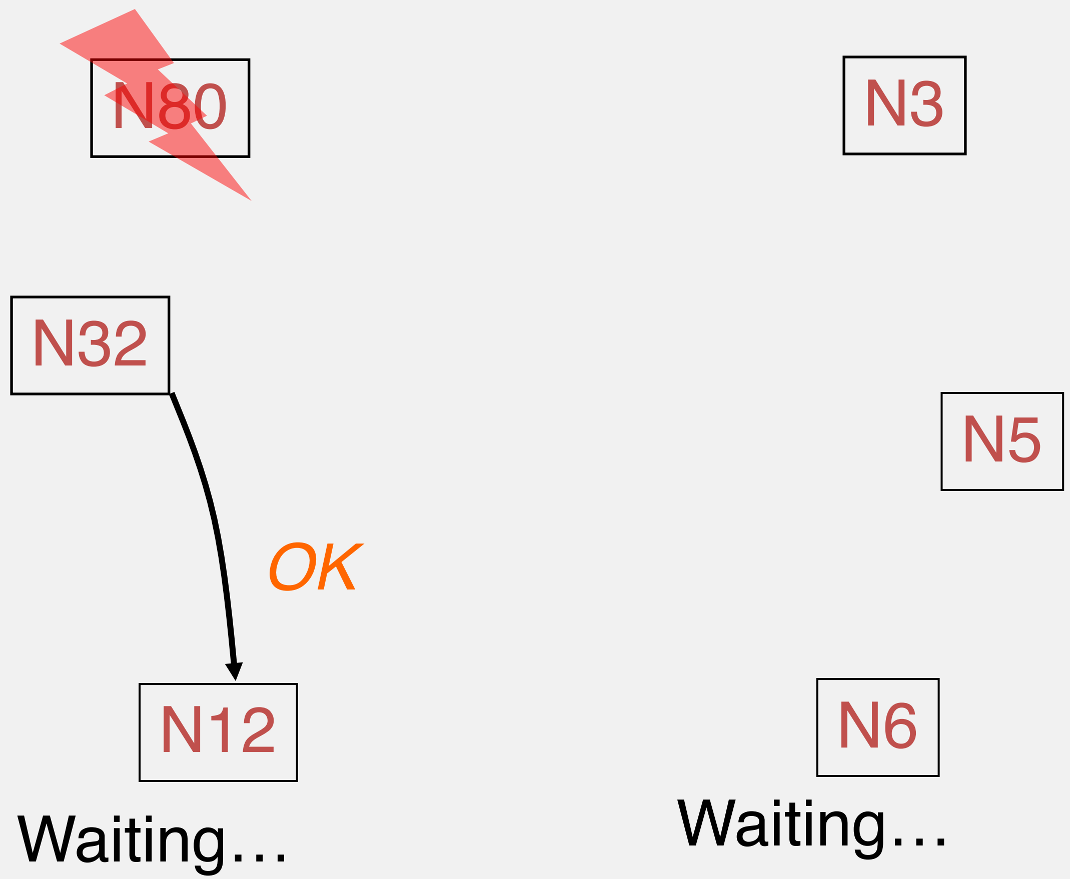
- **else** it initiates an election by sending an *Election* message
  - Sends it to only processes that have a *higher id than itself.*
  - **if** receives no answer within timeout, calls itself leader and sends *Coordinator* message to all lower id processes. Election completed.
  - **if** an answer received however, then there is some non-faulty higher process => so, wait for coordinator message. If none received after another timeout, start a new election run.
- A process that receives an *Election* message replies with *OK* message, and starts its own leader election protocol (unless it has already done so)

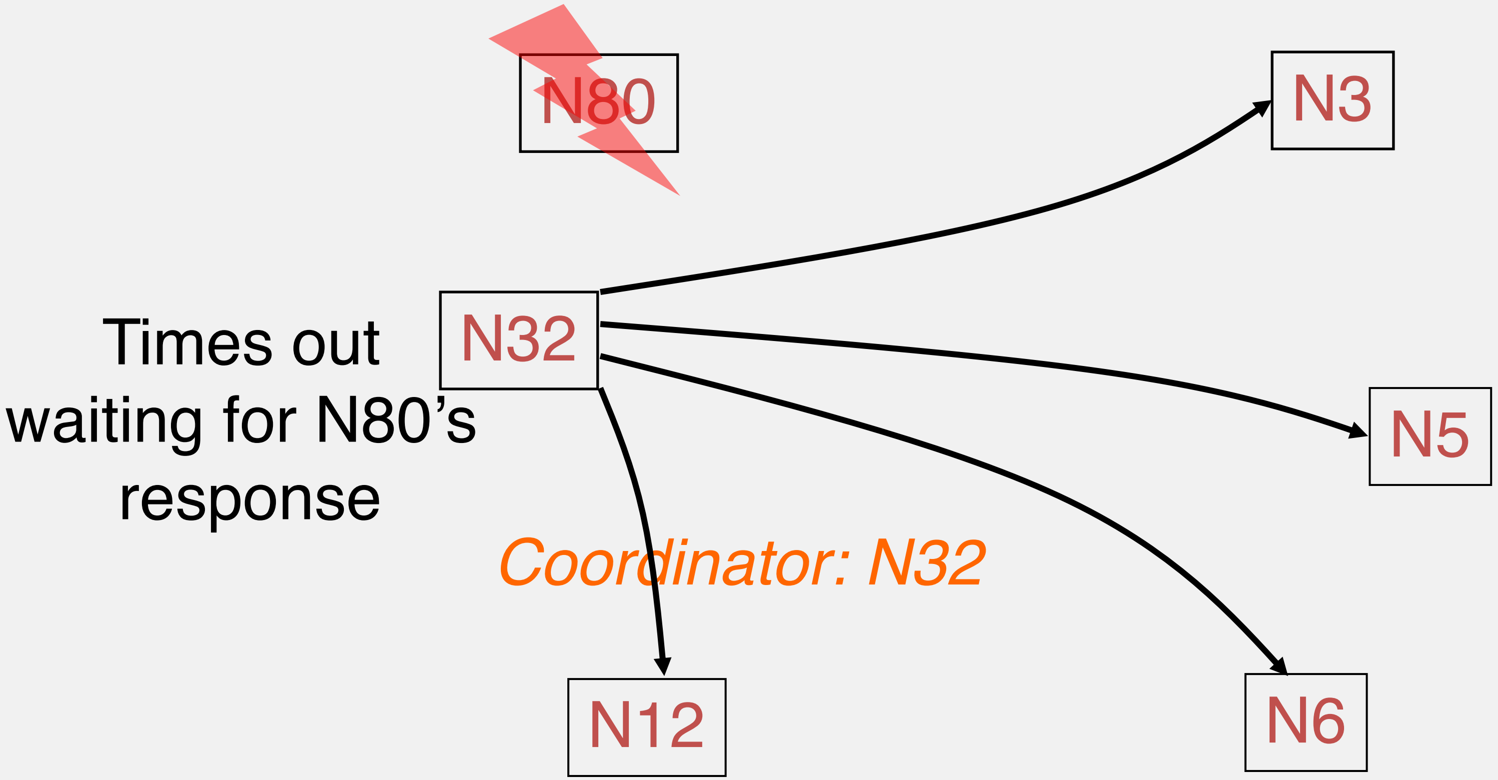
Bully Algorithm: Example




N80
N3
N32
N5
Election
N12
N6
Detects failure
of N80

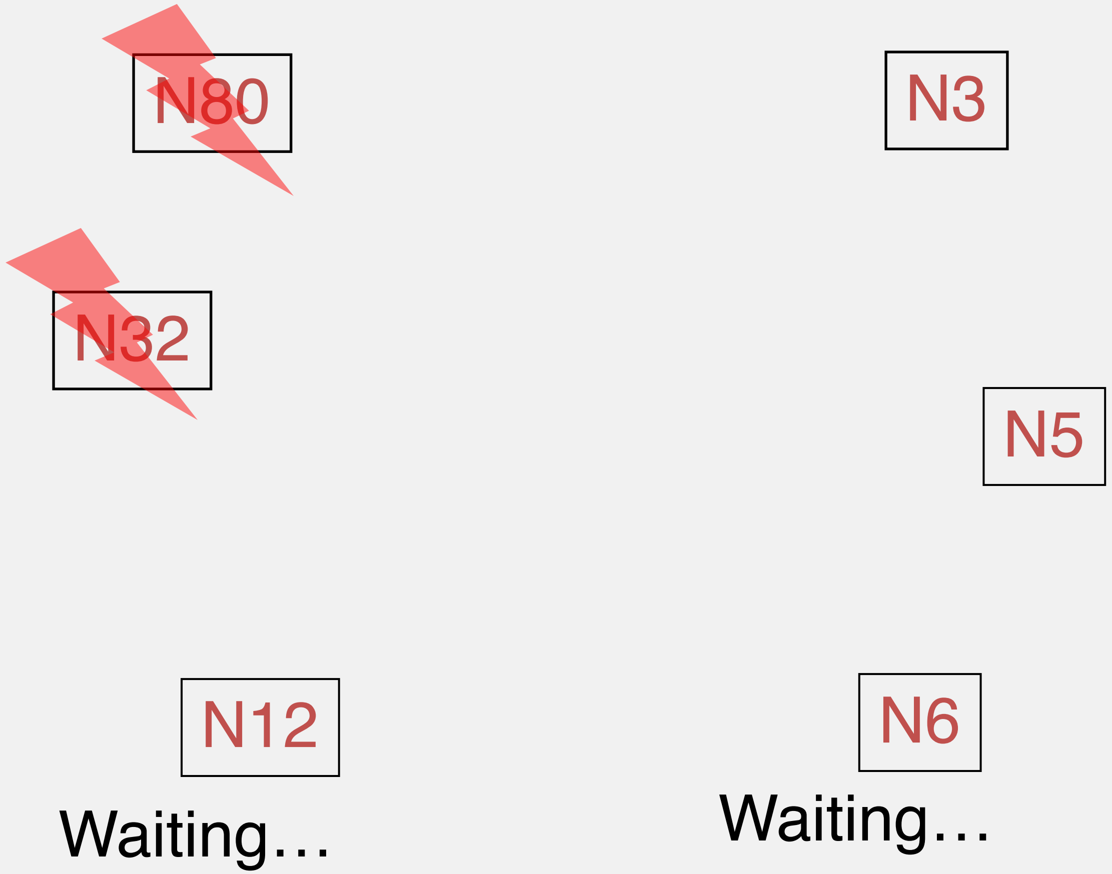

N80
N3
Election
N32
N5
Election
OK
N12
N6
Waiting…

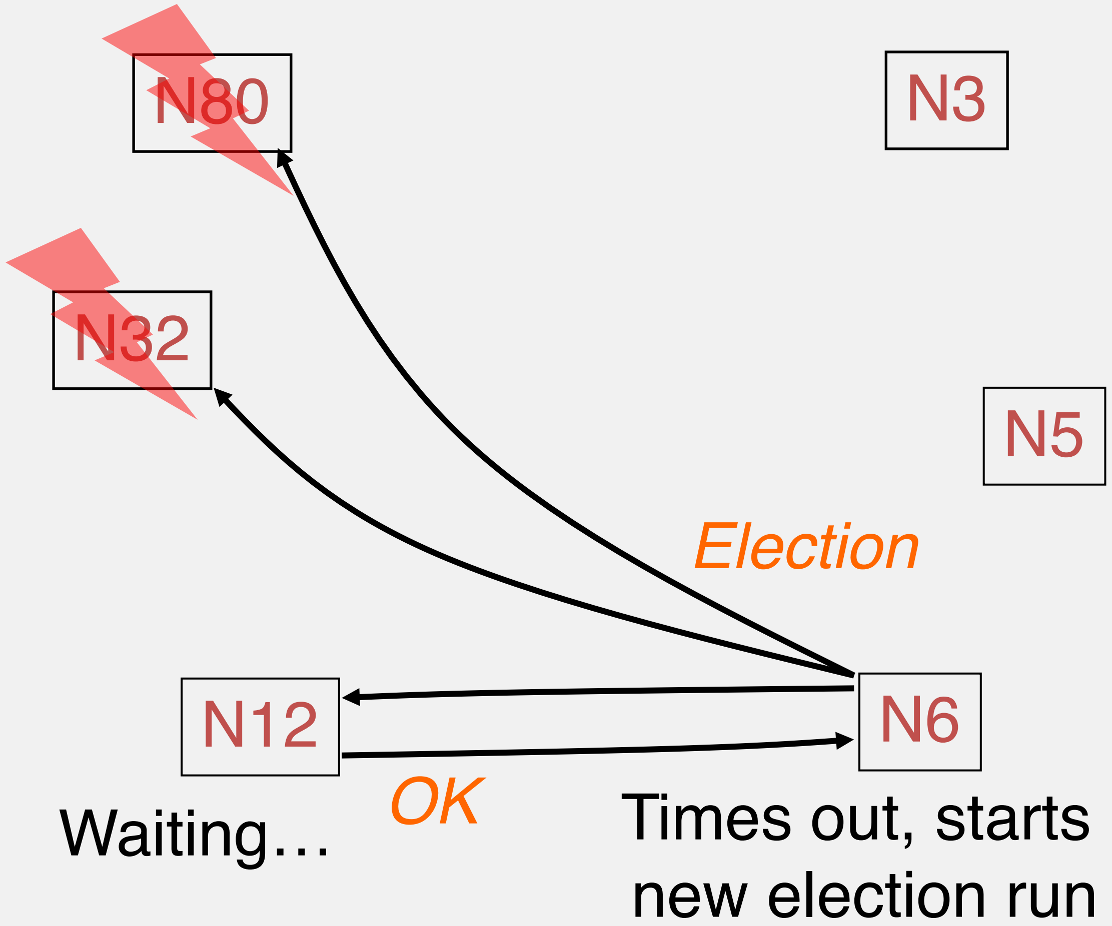

N80
N3
N32
N5
OK
N12
Waiting…
N6
Waiting…

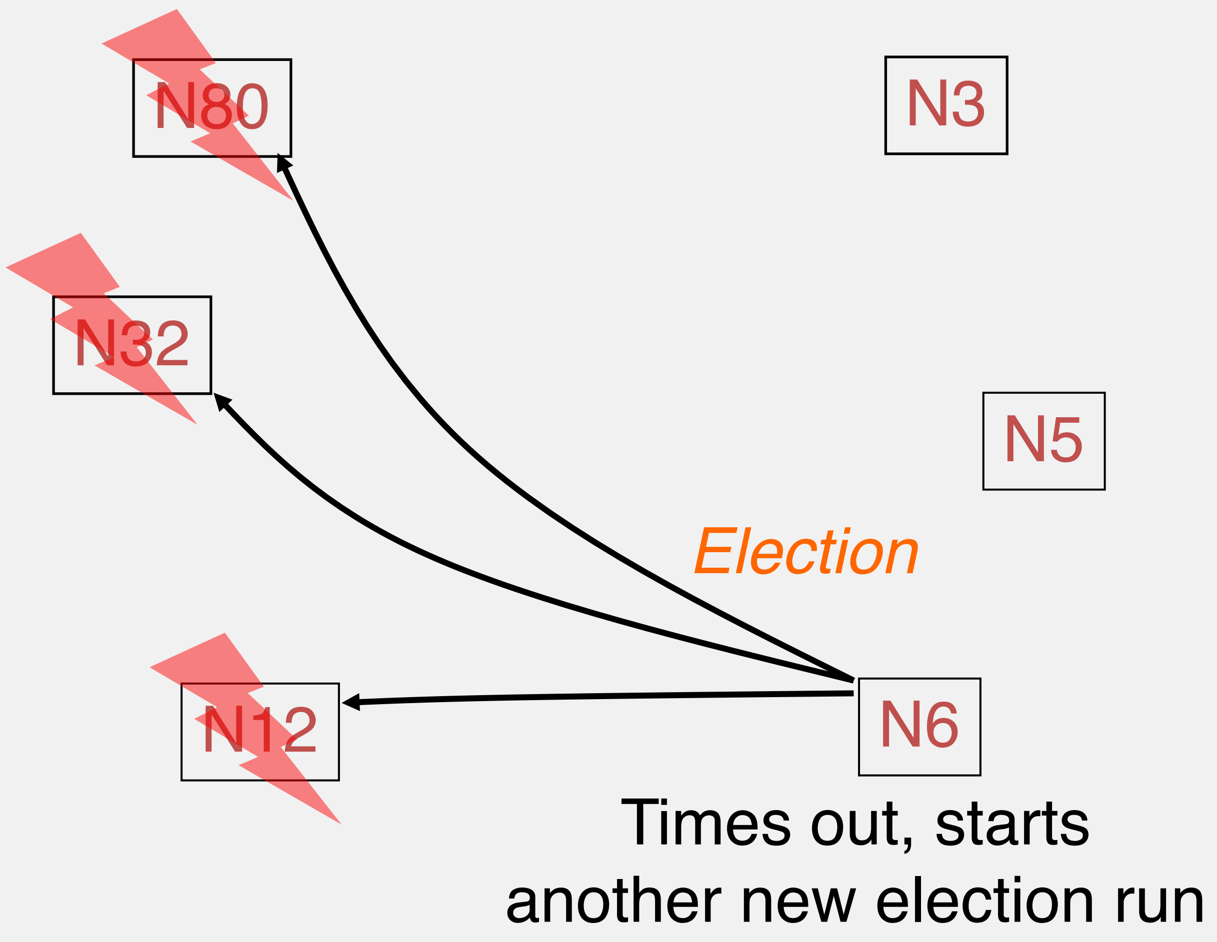


Election is completed

Failures during Election Run




N80
N3
N32
N5
Election
N12
N6
OK
Waiting…
Times out, starts
new election run


N80
N3
N32
N5
Election
N12
N6
Times out, starts
another new election run

Failures and Timeouts

- If failures stop, eventually will elect a leader
- How do you set the timeouts?
- Based on Worst-case time to complete election
  - 5 message transmission times if there are no failures during the run:
    1. Election from lowest id server in group
    2. Answer to lowest id server from 2nd highest id process
    3. Election from 2nd highest id server to highest id
    4. Timeout for answers @ 2nd highest id server
    5. Coordinator from 2nd highest id server

Analysis

- **Worst-case** completion time: 5 message transmission times
  - 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.
    - i-th highest id process sends (i-1) election messages
  - Number of Election messages
    $= N\text{-}1 + N\text{-}2 + \ldots + 1 = (N\text{-}1)*N/2 = O(N^2)$
- **Best-case**
  - Second-highest id detects leader failure
  - Sends (N-2) Coordinator messages
  - Completion time: 1 message transmission time

Impossibility?

- Since timeouts built into protocol, in asynchronous system model:
  - Protocol may never terminate => Liveness not guaranteed
- But satisfies liveness in synchronous system model where
  - Worst-case one-way latency can be calculated = worst-case processing time + worst-case message latency

Can use Consensus to solve Election

- One approach
  - Each process proposes a value
  - Everyone in group reaches consensus on some process P*i*'s value
  - That lucky P*i* is the new leader!