CS 455: Introduction To Distributed Systems [Election Algorithms]

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Frequently asked questions from the previous class survey

- Does a process always say "yes" to itself?
- What is the initial process state before any requests to enter the critical section have been made? Released?
- Approximate voting is $\sim 2\sqrt{N}$ in the matrix approximation?
- What happens if multiple processes initiate an election for the same event, but at different times? What ensures that they are part of the same round?
- Other interesting CS chairs?

Topics covered in this lecture

- Election algorithms
  - Ring based algorithm
- Failure detectors

Election Algorithms

Managing the identity of the elected process

- Each process p_i $(i=1, 2, \ldots, N)$ has a variable $elected_i$
  - Contains identifier of the elected process
- When a process first becomes a participant in an election
  - Set this variable to $\perp$ indicating that it is undefined

Requirements for the election algorithm

- **E1** (safety)
  - Participant process has $elected_i = \perp$ or $elected_i = P$
    - P is a non-crashed process at the end of run with the largest identifier
- **E2** (liveness)
  - **All** processes p_i participate and eventually either set $elected_i \neq \perp$ or crash

Measuring performance of election algorithms

- Network **bandwidth utilization**
  - How many messages are sent?
- **Turnaround time** for the algorithm
  - Number of message transmissions between the initiation and termination of a run

RING-BASED ELECTION ALGORITHM

Ring-based elections

- Each process p_i has a communication channel to the next process ($p_{(i+1) \bmod N}$) in the next ring
- All messages are sent **clockwise** around the ring

Conducting elections

- Any process can begin an election
- Process marks itself as a participant and:
  1. Places its identifier in the election message
  2. Sends it to its clockwise neighbor
- *On forwarding* an `election` message
  - Process marks itself as a **participant**

When a process receives an election message it compares identifier with its own

- If the arrived identifier is **greater**
  - *Forward* message to its neighbor
- If the arrived identifier is **smaller**
  - If the process is not a participant
    - *Substitute* with own identifier and forward the message
  - If the process is already a participant
    - *Do not forward* the message

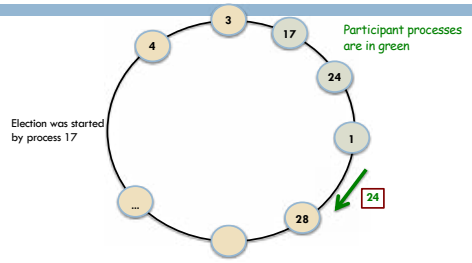
Selecting the coordinator

- If the received identifier is that of the receiver itself?
  - That process' identifier must be the greatest
  - Becomes the **coordinator**
- Coordinator marks itself as a non-participant
  - Sends an **elected** message to its neighbor

When a process p_i receives an elected message

- Marks itself as a **non-participant**
- Sets $elected_i$ to the identifier in the message
- Unless it is the coordinator, it forwards message to its neighbor

Ring based elections



Satisfying the requirements: Safety

- All identifiers are compared
  - A process must receive its own identifier back before sending an elected message
- For any two processes, the one with the **larger** identifier *will not pass* the other's identifier
  - Impossible that 2 processes will receive their own identifier back

Satisfying the requirements: Liveness

- Message traversals are guaranteed around the ring
  - The basic algorithm assumes no failures
- Duplicate messages arising when 2 processes start election at the same time?
  - Participant and non-participant states *extinguish* this ASAP and …
  - *Always before* winning election result has been announced

Performance analysis

- If only a single process starts an election
  - Worst case is when **anti-clockwise neighbor** has the highest identifier
    - Total of N-1 messages to reach this neighbor
    - Will not announce election till its identifier completes another circuit … N messages
    - Elected message is sent N times
    - Total of **3N-1** messages
  - Turnaround time also is 3N-1 in the worst case
    - Messages are sent *sequentially*

FAILURE DETECTORS

Failure detection

- In order to properly **mask** failures …
  - We generally need to detect them well
- Failure detection is one of the cornerstones of fault tolerance in distributed systems

What it all boils down to …

- For a group of processes, non-faulty members must be able to decide:
  - Who is *still* a member and who is *not*
- We need to be able to detect when a member has failed

The two mechanisms for detecting failures

- Processes actively send "*are you alive?*" messages to each other
  - For which they obviously expect an answer
- Passively wait until heartbeats ("*I am alive!*") come in from different processes
  - In practice, active pinging occurs often as well

Huge body of theoretical work on failure detectors

- **Timeout** mechanisms are used to check whether a process has failed
- In real settings:
  - Due to unreliable networks, just because a process does not respond to a ping that does not mean it failed
  - So … false positives can occur quite easily
    - A healthy process may be removed from the membership

Disambiguating network failures from node failures

- Multiple nodes participate in failure detection
- When a node notices a timeout on a ping message
  - The node contacts other nodes to see if they can reach the **presumed** failing node

Communication styles

- Asynchronous communications
  - No timing assumptions
- Synchronous communications have bounds on
  - Maximum message transmission delay
  - Time to execute each step of a process
  - Clock drift rates

Allow us to use timeouts to detect process crashes

Failure assumptions & failure detectors

- Processes use reliable channels to communicate
  - Underlying protocol handles corruptions and retransmissions
- Failures of processes are independent

Failure assumptions & failure detectors

- **Network partitions** are possible between the set of communicating processes
- Over the internet with complex topologies and independent routing choices
  - Connectivity may be **asymmetric**
    - Communication from p to q is possible, but not vice versa
  - Connectivity may be **intransitive**
    - Communication is possible from p to q to r, but p cannot communicate directly with r

Failure detectors

- **Service** that processes queries about whether a process failed
- Often implemented as an object *local to each process*
  - Runs a failure detection algorithm in conjunction with counterparts at other processes
- Not necessarily accurate
  - Only as good as the information available at that process

Unreliable failure detectors

- Produces one of two values when given the identity of a process
  - Suspected or Unsuspected
  - These values are just *hints* and may not accurately reflect if a process has failed
- **Unsuspected**
  - Detector recently received evidence suggesting process has not failed
- **Suspected**
  - Detector has some indication that process probably failed
    - Message not received for more than the nominal silence interval

Unreliable failure detectors

- Suspicions may be **misplaced**
  - Process may be functioning, but on the other side of a network partition
  - Process runs slower than expected

Reliable failure detectors

- Answers liveness queries with
  - Unsuspected
  - Failed

BUILDING FAILURE DETECTORS

Implementing an unreliable failure detector

- Each process p, sends a **heartbeat** every T seconds
- Failure detector uses estimate of *maximum message transmission delay* of D seconds
- If failure detector at q does not receive heartbeat from p within T + D seconds of the last one?
  - Detector reports to q that p is Suspected
- If heartbeat is received within T + D then detector at q deems p to be OK

Choosing values for T and D

- If we choose **small values** for T and D?
  - Failure detector is likely to *suspect non-crashed* processes many times
  - Bandwidth will be consumed by heartbeat messages
- If we choose a large D?
  - *Crashed processes* will often be reported as Unsuspected

Practical solution to the problem

- Use timeout values that reflect *observed network delay* conditions
- If failure detector at q receives heartbeats from p every 20 seconds instead of 10 seconds?
  - Reset timeout for p to 20 seconds
- Failure detector would still be unreliable
  - But **probability of accuracy** increases

Building reliable failure detectors

- Possible **only in synchronous systems**
- D in this case is not an estimate, but an *absolute bound*
  - Absence of heartbeat from p within T+D seconds entitles detector at q to *conclude* that p has failed

Contrasting reliable and unreliable failure detectors

- Unreliable failure detectors can be
  - *Inaccurate*
    - Suspects process that has not failed
  - *Incomplete*
    - May not suspect a process that has failed
- Reliable failure detectors require a system that is synchronous
  - Few practical systems are

So why did we look at failure detectors?

- They help us think about failures in distributed systems
- Any practical system designed to cope with failures, must detect them
  - However imperfectly!
- Unreliable failure detectors with well-defined properties help us to provide practical solutions for coordinating processes

The Bully Algorithm

Bully algorithm (Garcia-Molina): Key features

- Allows processes to crash during an election
- Assumptions:
  - Message delivery between processes is reliable
  - Synchronous system
    - Uses **timeouts** to *detect a failure*
  - Each process **knows processes that have higher identifiers**
    - Can communicate with them

Message types

- `Election`
  - Sent to announce an election
- `Answer`
  - Sent in response to an `election` message
- `Coordinator`
  - Sent to announce the identity of the elected process

Initiating elections

- A process begins this when it notices that the coordinator has failed
- Several processes may discover this concurrently

Reliable failure detectors are possible because the system is synchronous

- T_{trans}: Maximum transmission delay
- $T_{process}$: Maximum delay for processing a message
- Upper bound on elapsed time between sending a message to a process & receiving a response
  - $\mathbf{T} = 2T_{trans} + T_{process}$
  - If no response arrives within $\mathbf{T}$, local failure detector tags intended recipient as having failed

In the case of a failure

- Process that knows it has the highest identifier can elect itself as the coordinator
  - Simply send a `coordinator` message to processes with lower identifiers

When a process with a lower identifier detects coordinator failure it initiates an election

- Send an `election` message to processes with higher identifiers
  - Await `answer` messages in response
- If no response within time T, process considers itself the coordinator
- If an answer does arrive, wait for additional time T' for `coordinator` message to arrive
  - If this does not arrive … start another election

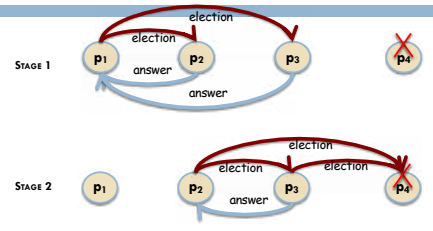
How a process responds to messages that it receives

- If a process p_i receives a `coordinator` message, it sets its variable $elected_i$ to the coordinator ID
- If a process receives an `election` message
  1. Sends back an answer message and …
  2. **Begins another election**
     - Unless it has started one already

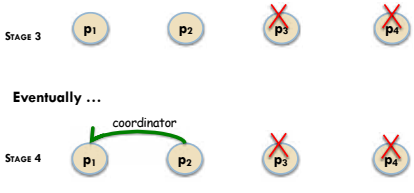
But why is this called the bully algorithm?

- When a process is started to replace a crashed process … it starts an election
- If this new process has the highest identifier?
  - It decides that it is the new coordinator and announces this
- The new process becomes the coordinator ***even though*** the current coordinator is functioning

Election of a coordinator after the failure of p4



Election of a coordinator after the failure of p4 and then p3



The contents of this slide set are based on the following references

- *Distributed Systems: Concepts and Design*. George Coulouris, Jean Dollimore, Tim Kindberg, Gordon Blair. 5th Edition. Addison Wesley. ISBN: 978-0132143011 [Chapter 15]
- *Distributed Systems: Principles and Paradigms. Andrew S. Tanenbaum and Maarten Van Steen. 2nd Edition. Prentice Hall. ISBN: 0132392275/978-0132392273 [Chapter 6, 8]*