Last Class: Clock Synchronization

- Physical clocks
- Clock synchronization algorithms
  - Cristian’s algorithm
  - Berkeley algorithm
- Logical clocks
Today: More Canonical Problems

• Causality
  – Vector timestamps

• Global state and termination detection

• Election algorithms
Causality

- Lamport’s logical clocks
  - If $A \rightarrow B$ then $C(A) < C(B)$
  - Reverse is not true!!
    - Nothing can be said about events by comparing time-stamps!
    - If $C(A) < C(B)$, then ??

- Need to maintain causality
  - Causal delivery: If send(m) -> send(n) => deliver(m) -> deliver(n)
  - Capture causal relationships between groups of processes
  - Need a time-stamping mechanism such that:
    - If $T(A) < T(B)$ then $A$ should have causally preceded $B$
Vector Clocks

- Each process $i$ maintains a vector $V_i$
  - $V_i[i]$ : number of events that have occurred at $i$
  - $V_i[j]$ : number of events I knows have occurred at process $j$

- Update vector clocks as follows
  - Local event: increment $V_i[I]$
  - Send a message: piggyback entire vector $V$
  - Receipt of a message: $V_j[k] = \max(V_j[k], V_i[k])$
    - Receiver is told about how many events the sender knows occurred at another process $k$
    - Also $V_j[i] = V_j[i]+1$

- Homework: convince yourself that if $V(A) < V(B)$, then $A$ causally precedes $B$
Global State

- Global state of a distributed system
  - Local state of each process
  - Messages sent but not received (state of the queues)
- Many applications need to know the state of the system
  - Failure recovery, distributed deadlock detection
- Problem: how can you figure out the state of a distributed system?
  - Each process is independent
  - No global clock or synchronization
- Distributed snapshot: a consistent global state
Global State (1)

(a) A consistent cut
(b) An inconsistent cut

Sender of m2 cannot be identified with this cut
Distributed Snapshot Algorithm

• Assume each process communicates with another process using unidirectional point-to-point channels (e.g., TCP connections)

• Any process can initiate the algorithm
  – Checkpoint local state
  – Send marker on every outgoing channel

• On receiving a marker
  – Checkpoint state if first marker and send marker on outgoing channels, save messages on all other channels until:
  – Subsequent marker on a channel: stop saving state for that channel
Distributed Snapshot

• A process finishes when
  – It receives a marker on each incoming channel and processes them all
  – State: local state plus state of all channels
  – Send state to initiator

• Any process can initiate snapshot
  – Multiple snapshots may be in progress
    • Each is separate, and each is distinguished by tagging the marker with the initiator ID (and sequence number)
a) Organization of a process and channels for a distributed snapshot
b) Process Q receives a marker for the first time and records its local state

c) Q records all incoming message

d) Q receives a marker for its incoming channel and finishes recording the state of the incoming channel
Termination Detection

- Detecting the end of a distributed computation
- Notation: let sender be \textit{predecessor}, receiver be \textit{successor}
- Two types of markers: Done and Continue
- After finishing its part of the snapshot, process $Q$ sends a Done or a Continue to its predecessor
- Send a Done only when
  - All of $Q$’s successors send a Done
  - $Q$ has not received any message since it check-pointed its local state and received a marker on all incoming channels
  - Else send a Continue
- Computation has terminated if the initiator receives Done messages from everyone
Election Algorithms

• Many distributed algorithms need one process to act as coordinator
  – Doesn’t matter which process does the job, just need to pick one
• Election algorithms: technique to pick a unique coordinator (aka leader election)
• Examples: take over the role of a failed process, pick a master in Berkeley clock synchronization algorithm
• Types of election algorithms: Bully and Ring algorithms
Bully Algorithm

- Each process has a unique numerical ID
- Processes know the IDs and address of every other process
- Communication is assumed reliable
- **Key Idea**: select process with highest ID
- Process initiates election if it just recovered from failure or if coordinator failed
- 3 message types: *election, OK, I won*
- Several processes can initiate an election simultaneously
  - Need consistent result
- $O(n^2)$ messages required with $n$ processes
Bully Algorithm Details

- Any process $P$ can initiate an election
- $P$ sends *Election* messages to all processes with higher IDs and awaits *OK* messages
- If no *OK* messages, $P$ becomes the coordinator and sends *I won* messages to all processes with lower IDs
- If it receives an *OK*, it drops out and waits for an *I won*
- If a process receives an *Election* msg, it returns an *OK* and starts an election
- If a process receives a *I won*, it treats the sender as a coordinator
Bully Algorithm Example

- The bully election algorithm
- Process 4 holds an election
- Process 5 and 6 respond, telling 4 to stop
- Now 5 and 6 each hold an election
Bully Algorithm Example

d) Process 6 tells 5 to stop

e) Process 6 wins and tells everyone