Distributed Systems

Global states and snapshots

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Distributed snapshots

• Take a “snapshot” of a system
• E.g. for backup: If system fails, it can start up from a meaningful state

• Problem:
  – Imagine a sky filled with birds. The sky is too large to cover in a single picture.
  – We want to take multiple pictures that are consistent in a suitable sense
    • Eg. We can correctly count the number of birds from the snapshot
Events and states

- Every process goes through alternate sequence of states and events
- It is enough to count the states for correct clock sequence
Events and states

• Happened before and concurrent relations for states are defined similarly
Distributed snapshots

• Global state:
  – State of all processes
  – And state of all communication channels
    • What message it is carrying

• Consistent cuts:
  – A set of states of all processes is a consistent cut if:
  – For any states s, t in the cut, s || t

• If a → b, then the following is not allowed:
  – b is before the cut, a is after the cut
Consistent cut
Distributed snapshot algorithm

• Find a set of states: one for each process
  – Ask each process to record its state
• The set of states must be a consistent cut

• Assumptions:
  – Communication channels are FIFO
  – Processes communicate only with neighbors
  – (We assume for now that everyone is neighbor of everyone)
  – Processes do not fail
Global snapshot: Chandy and Lamport algorithm

• One process initiates snapshot and sends a marker

• Marker is the boundary between “before” and “after” the snapshot
Global snapshot: Chandy and Lamport algorithm

- Marker send rule (Process i)
  - Process i records its state
  - On every outgoing channel where a marker has not been sent:
    - i sends a marker on the channel
    - before sending any other message

- Marker receive rule (Process j receives marker on channel C)
  - If j has not received the marker before
    - Record state of j
    - Record state of C as empty
    - Follow marker send rule
  - Else:
    - Record the state of C as the set of messages received on C since recording j’s state and before receiving marker on C

- Algorithm stops when all processes have received marker on all incoming channels
Complexity

• Message?
Property

• If $s_1$ (in $p_1$) $\rightarrow$ $s_2$ (in $p_2$)
  – Then $s_2$ is before the cut $\Rightarrow$ $s_1$ is before the cut
  – Suppose not & $s_1$ is after the cut.
    • Then $p_1$ recorded its state before $s_1$
    • Consider the message $m$ from $p_1$ to $p_2$
      – This causes the relation $s_1 \rightarrow s_2$ to be true
    • $p_1$ must have recorded its state before sending $m$
    • $p_1$ must have sent marker to $p_2$ before sending $m$
      – By marker sending rule
    • $p_2$ must have received marker before $m$ and before $s_2$
    • $s_2$ must be after the cut – contradiction.
Application of snapshots:
Detection of stable predicates

• Stable predicate:
  – A property that once it becomes true, stays true (until detection and intervention)
  – Eg:
    • Deadlocked: every process in some subset is waiting for another
    • Terminated: once ended, computation remains stopped
    • Loss of token: in mutual exclusion, process with token can access a resource. If token gets lost due to failure, it stays lost.
    • Garbage: If no-one has a reference to a file, that file can be deleted
  – So, if such a property was true before the snapshot, it is true in the snapshot, and can be detected by checking the snapshot
Where snapshots are not useful: non-stable predicates

• E.g.
  – Was this file opened at some time?
  – Was $x_1 - x_2 < \delta$ ever?

  – Non-stable predicates may have happened, but then system state changes..
Types of non-stable predicates

• Possibly B:
  – B could have happened

• Definitely B:
  – B definitely happened

• How can we check for definitely B and possibly B?
Collecting global states

• Each process notes its every state & vector timestamp
  – Sends it to a server for recording
  – Note: we do not need to save every time a state changes: only when it affects the predicates to be checked
    • Assuming we know what predicates will be checked
• The server looks at these and tries to figure out if predicate B was possibly or definitely true
Possible states

• Server checks for possible states: consistent cuts for B: $x=y$
Note on difference with books

• We are using the following notation that may differ from books
  – The circles are ‘states’, and bars are ‘events’
  – We are concerned with which pairs of states form consistent cuts
  – An event’s occurrence changes the state of the process
  – We are following the convention that an event carries the label of the state in which it happened i.e. the label of the circle to the left of it.
    • You can see this in the vector clock label carried by the messages
  – Some books follow a different convention that the event (message) carries the label of the state after the event
  – Sometimes the representation of the states are merged with the events

• This does not change any of the fundamental ideas or properties of causality or snapshots
  – But labels in diagrams may look a little different

• In exam, you are allowed to use either convention if you are drawing a diagram. Mention which you are using.

• If a problem explicitly gives a diagram, it will use the convention in the slides, of separating states and events
Possible states

- Server checks for possible states: consistent cuts for $B: x=y$
Lattice of global states (consistent cuts)

- Any downward path from Initial state to final state is a valid execution
  - A possible sequence of states that could have existed
Lattice of global states (consistent cuts)

• Possibly B:
  – B occurs on at least one downward path

• Definitely B
  – B occurs on all downward paths
Lattice of global states (consistent cuts)

• How do you compute possibly and definitely B?
Lattice of global states (consistent cuts)

• Possibly B:
  – B occurs on at least one downward path

• Do a BFS from start state
  – If there is one state with B true, then possibly B is true
Lattice of global states (consistent cuts)

• Definitely B
  – B occurs on all downward paths

• Do a BFS from start state
  – Do not visit nodes with B: true
  – If BFS reaches final state and B is false in final state then Definitely B is false
  – Else Definitely B is true
What is the computational complexity?
What is the computational complexity?

• Possibly exponential in number of processes
• Problem is NP-complete

• Observation: more messages reduces complexity!