CSE 486/586 Distributed Systems
Global States

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Last Time

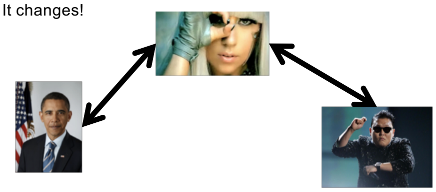
- Ordering of events
  - Many applications need it, e.g., collaborative editing, distributed storage, etc.
- Logical time
  - Lamport clock: single counter
  - Vector clock: one counter per process
  - Happens-before relation shows causality of events
- Today: An important algorithm related to the discussion of time

Today's Topic

- Global snapshots
- For distributed programming, it's important to be able to reason about your system's behavior in the abstract.
- Today's topic will further increase your understanding.

Today's Question

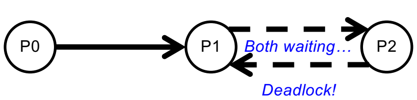
- Example question: who has the most friends on Facebook?
- Challenges to answering this question?
  - It changes!



- What do we need?
  - A snapshot of the social network graph at a particular time

Today's Question

- Distributed debugging

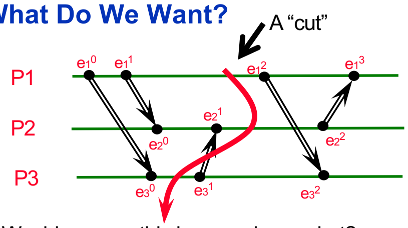


- How do you debug this?
  - Log in to one machine and see what happens
  - Collect logs and see what happens
  - Taking a global snapshot!

What is a Snapshot?

- Single process snapshot
  - Just a snapshot of the local state, e.g., memory dump, stack trace, etc.
  - For the sake of this lecture, let's say a log of events.
- Multi-process snapshot
  - Two things
  - Process snapshots: Snapshots of all process states
  - Network snapshot: All messages in the network

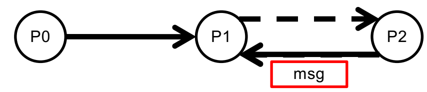
What Do We Want?



- Would you say this is a good snapshot?
  - "Good": we can explain all the causality, including messages
  - No because e_2^1 might have been caused by e_3^1.
- Three things we want.
  - Per-process state
  - Messages that are causally related to each and every local snapshot and in flight
  - All events that happened before each event in the snapshot

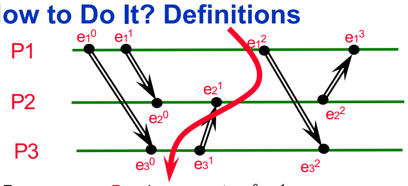
Obvious First Try

- Synchronize clocks of all processes
  - Ask all processes to record their states at known time *t*
- Problems?
  - Time synchronization possible only approximately
  - Another issue?



  - Does not record the state of messages in the channels
- Again: synchronization not required – causality is enough!
- What we need: logical global snapshot
  - The state of each process
  - Messages in transit in all communication channels

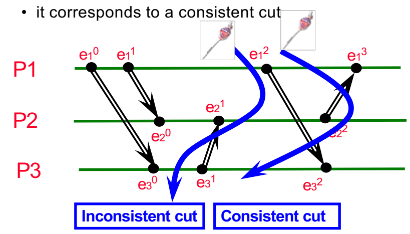
How to Do It? Definitions



- For a process P_i, where events $e_i^0, e_i^1, \ldots$ occur,
  - *history(P_i)* = $h_i = \langle e_i^0, e_i^1, \ldots \rangle$
  - *prefix history(P_i^k)* = $h_i^k = \langle e_i^0, e_i^1, \ldots, e_i^k \rangle$
  - S_i^k : P_i's state immediately after k^{th} event
- For a set of processes $P_1, \ldots, P_i, \ldots$:
  - Global history: $H = \cup (h_i)$
  - Global state: $S = \cup (S_i^{k_i})$
  - A cut $C \subseteq H = h_1^{c1} \cup h_2^{c2} \cup \ldots \cup h_n^{cn}$
  - The frontier of $C = \{e_i^{ci}, i = 1,2, \ldots n\}$

Consistent States

- A cut C is consistent if and only if
  - $\forall_{e \in C}$ (if $f \rightarrow e$ then $f \in C$)
- A global state S is consistent if and only if
  - it corresponds to a consistent cut



Why Consistent States?

- #1: For each event, you can trace back the causality.
- #2: The state machine view of a distributed system
  - The execution of a distributed system as a series of transitions between global states: S0 → S1 → S2 → …
  - …where each transition happens with one single action from a process (i.e., local process event, send, and receive)
  - Each state (S0, S1, S2, …) is a consistent state.

CSE 486/586 Administrivia

- PA2-A deadline: This Friday
- PA1: Will start grading from today
- Please come and ask questions during office hours.

The Snapshot Algorithm: Assumptions

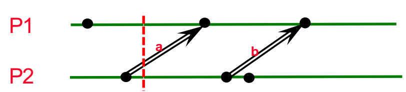
- There is a communication channel between each pair of processes (@each process: N-1 in and N-1 out)
- Communication channels are unidirectional and FIFO-ordered (important point)
- No failure, all messages arrive intact, exactly once
- Any process may initiate the snapshot
- Snapshot does not interfere with normal execution
- Each process is able to record its state and the state of its incoming channels (no central collection)

Single Process vs. Multiple Processes

- Single process snapshot
  - Just a snapshot of the local state, e.g., memory dump, stack trace, etc.
  - But for the sake of this lecture, let's say a log of all events
- Multi-process snapshot
  - Snapshots of all process states
  - Network snapshot: All messages in the network
- Two questions:
  - #1: When to take a local snapshot at each process so that the collection of them can form a consistent global state? (Process snapshot)
  - #2: How to capture messages in flight? (Network snapshot)

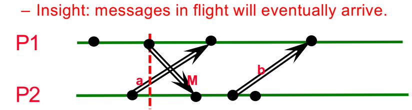
Reminder: Clock-Sync'd Snapshot

- Instantaneous snapshot
  - Process snapshots and network messages at time t
  - We can't quite do it due to (i) imperfect clock sync and (ii) no help from the network.



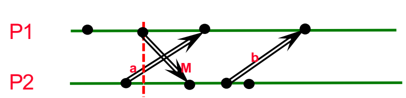
Chandy and Lamport's Snapshot: Basic Idea

- Goal: taking a consistent (not instantaneous) global snapshot
- Any process can initiate a snapshot-taking process by taking a local snapshot and sending a message called a marker.
- Upon receiving a marker, a process takes a local snapshot of its own. (The proc. snapshot part done)
  - Still need to take a network snapshot.
- How do we take a network snapshot?
  - Insight: messages in flight will eventually arrive.



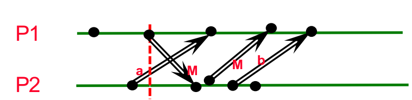
Chandy and Lamport's Snapshot: Basic Idea

- Each process that has taken a snapshot also starts recording incoming messages
  - Since those messages were in the network when the snapshot was being taken.
  - If every process does this, we will capture all messages in flight, recording messages destined to each process.
- Tricky part: the algorithm has a mechanism to stop recording incoming messages at some point.



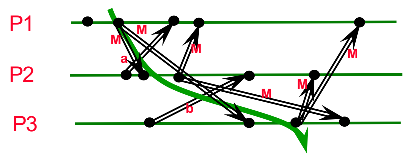
Chandy and Lamport's Snapshot: Basic Idea

- Reminder: which messages do we want to record?
  - Messages that were in the network at the time of taking a snapshot
- How do we record just those messages?
  - Insight: we can mark the end of relevant messages.
- After taking a local snapshot, each process sends a message saying that it's done sending all messages relevant to the snapshot.
  - In fact, we don't need a different message type, we use the same marker message.



Chandy and Lamport's Snapshot

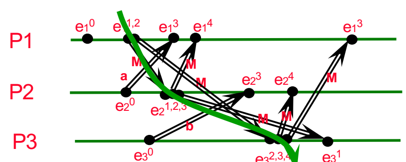
- Marker broadcast & recording
  - The initiator broadcasts a "marker" message to everyone else
  - If a process receives a marker for the first time, it takes a local snapshot, starts recording all incoming messages, and broadcasts a marker again to everyone else.
  - A process stops recording for each channel, when it receives a marker for that channel.



The Snapshot Algorithm

1. Marker sending rule for initiator process P_0
   - After P_0 has recorded its own state
     - for each outgoing channel C, send a marker message on C
2. Marker receiving rule for a process P_k
   on receipt of a marker over channel C
   - if P_k has not yet recorded its own state
     - record P_k's own state
     - record the state of C as "empty"
     - for each outgoing channel C, send a marker on C
     - turn on recording of messages over other incoming channels
   - else
     - record the state of C as all the messages received over C since P_k saved its own state; stop recording state of C

Exercise



1- P1 initiates snapshot: records its state (S1); sends Markers to P2 & P3; turns on recording for channels C21 and C31

2- P2 receives Marker over C12, records its state (S2), sets state(C12) = {} sends Marker to P1 & P3; turns on recording for channel C32

3- P1 receives Marker over C21, sets state(C21) = {a}

4- P3 receives Marker over C13, records its state (S3), sets state(C13) = {} sends Marker to P1 & P2; turns on recording for channel C23

5- P2 receives Marker over C32, sets state(C32) = {b}

6- P3 receives Marker over C23, sets state(C23) = {}

7- P1 receives Marker over C31, sets state(C31) = {}

One Provable Property

- The snapshot algorithm gives a consistent cut
- Meaning,
  - Suppose e_i is an event in P_i, and e_j is an event in P_j
  - If $e_i \rightarrow e_j$, and e_j is in the cut, then e_i is also in the cut.
- Proof sketch: proof by contradiction
  - Suppose e_j is in the cut, but e_i is not.
  - Since $e_i \rightarrow e_j$, there must be a sequence M of messages that leads to the relation.
  - Since e_i is not in the cut (our assumption), a marker should've been sent before e_i, and also before all of M.
  - Then P_j must've recorded a state before e_j, meaning, e_j is not in the cut. (Contradiction)

Summary

- Global states
  - A union of all process states
  - Consistent global state vs. inconsistent global state
- The "snapshot" algorithm
  - Take a snapshot of the local state
  - Broadcast a "marker" msg to tell other processes to record
  - Start recording all msgs coming in for each channel until receiving a "marker"
  - Outcome: a consistent global state

Acknowledgements

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