# Distributed Systems

## *CS 425 / CSE 424 / ECE 428*

## Global Snapshots

**Reading: Sections 11.5 (4th ed), 14.5 (5th ed)**

# Last Lecture

- Time synchronization
  - Berkeley algorithm
  - Cristian's algorithm
  - NTP
  - Is it possible to synchronize two servers' clocks with error=0?
- Lamport's timestamps
  - Logical timestamps
  - Do the clock values of two servers need to be the same?
  - What are "concurrent" events?
- Vector Timestamps

# *Example of a Global State*

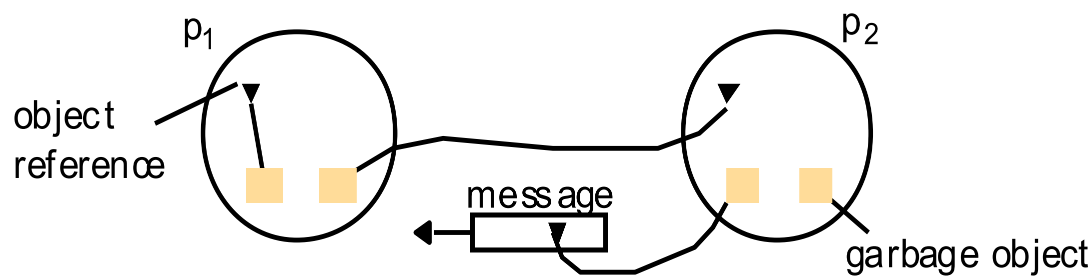

[United Nations photo by Paul Skipworth for Eastman Kodak Company ©1995 ]

# *The distributed version is challenging and important*

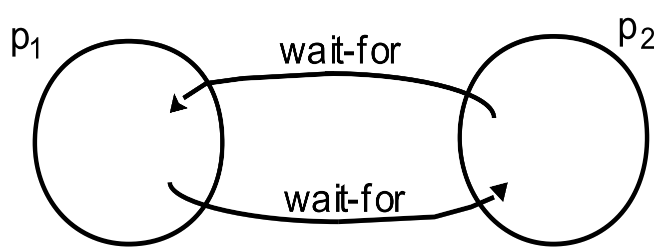
- How would you take this photograph if each country's premier were sitting in their respective capital, and sending messages to each other?
- That's the challenge of distributed global snapshots!
- In a cloud: multiple servers handling multiple concurrent events and interacting with each other
- Without the ability to obtain a global photograph of the system, it would be a chaotic system (with potentially lots of inconsistencies)

# *Detecting Global Properties*

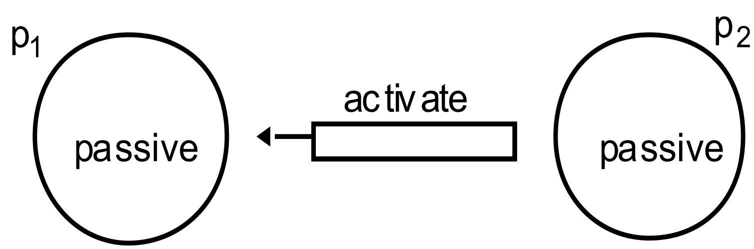
a. Garbage collection




b. Deadlock




c. Termination



# *Algorithms to Find Global States*

- **Why?**
  - (Distributed) garbage collection
  - (Distributed) deadlock detection, termination
  - Two clients buy the last flight ticket at around the same time

- **What?**
  - Global state
    = state of all processes + state of all communication channels
  - Capture the instantaneous *state* of each process
  - And the instantaneous *state* of each communication channel, i.e., *messages* in transit on the channels

- **How?**
  - We'll see this lecture!

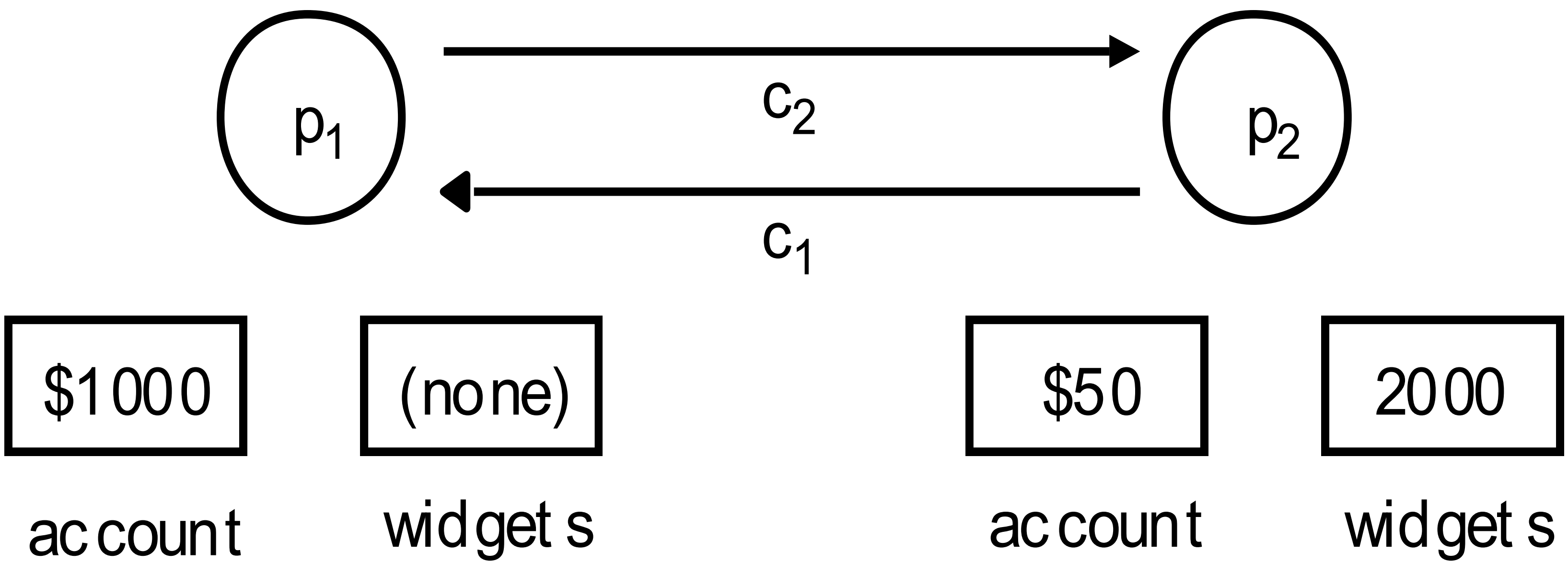
# *Obvious First Solution…*

- Synchronize clocks of all processes
- Ask all processes to record their states at some time t

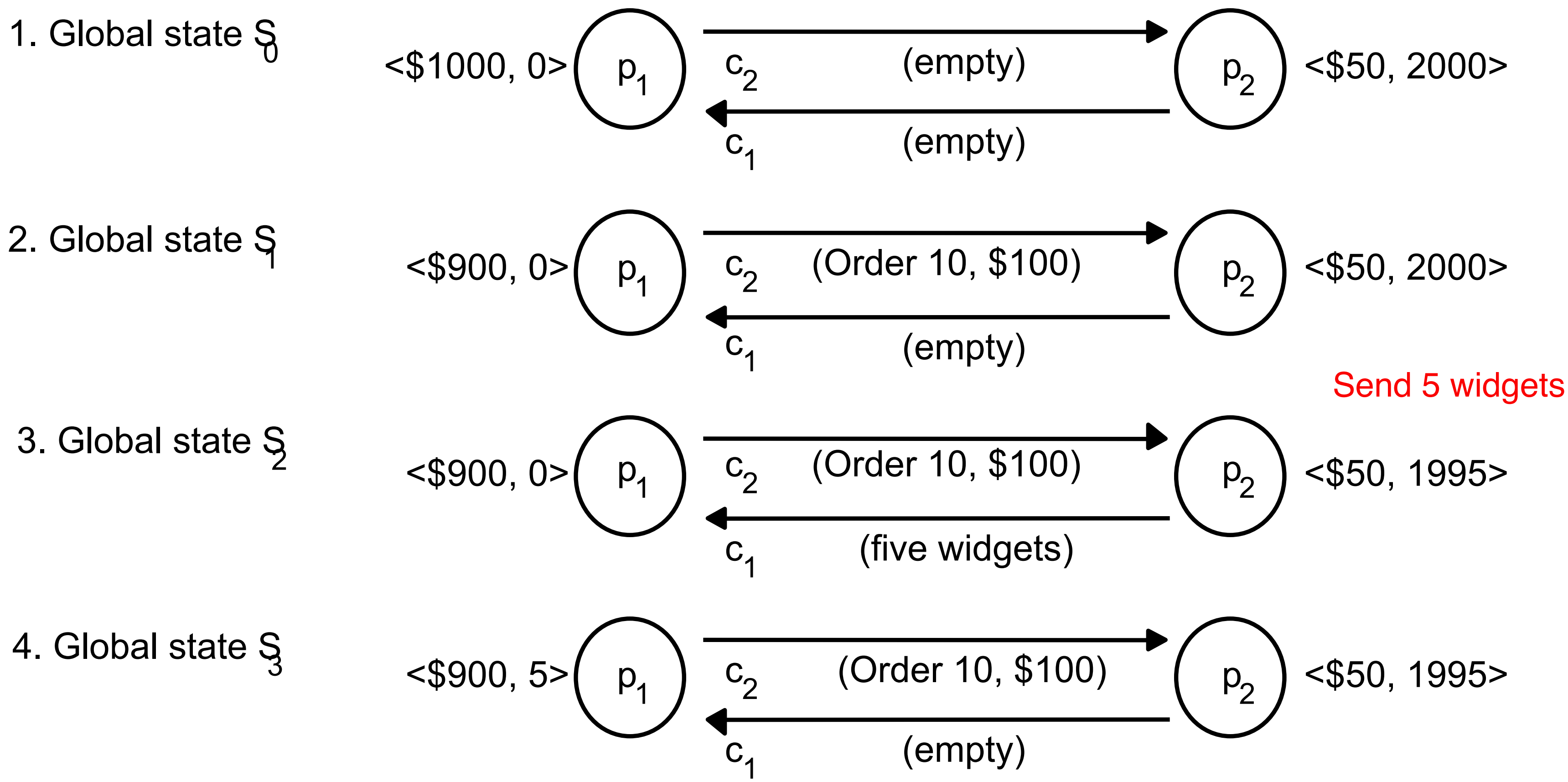
- Time synchronization possible only approximately
- What about messages in transit?

- Synchronization not required – causality is enough!

# *Two Processes and Their Initial States*



# *Execution of the Processes*



# *Process Histories and States*

- 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: $H = \cup_i (h_i)$

  global state: $S = \cup_i (S_i^{k_i})$

  a cut $C \subseteq H = h_1^{c1} \cup h_2^{c2} \cup \ldots \cup h_n^{cn}$

  the frontier of $C = \{e_i^{ci}, i = 1,2, \ldots n\}$

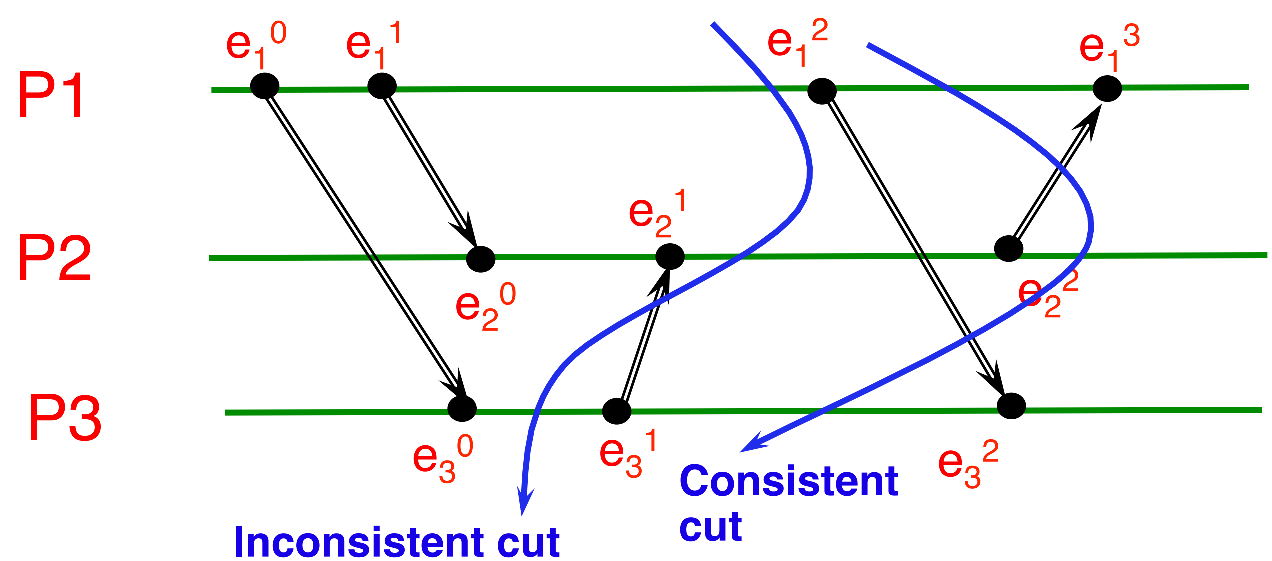
# *Consistent States*

Lamport's "happens-before"

- A cut C is **consistent** if and only if

$$\forall_{e \in C} (\text{if } f \rightarrow e \text{ then } f \in C)$$

- A global state S is **consistent** if and only if it corresponds to a consistent cut



# *The "Snapshot" Algorithm*

- **Records a set of process and channel states such that the combination is a consistent global state.**

- ***Assumptions (System Model!):***
  - **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**
  - **No failure, all messages arrive intact, exactly once**
  - **Any process may initiate the snapshot (by sending "Marker" message)**
  - **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)**

# The "Snapshot" Algorithm (2)

1. **Marker sending rule for initiator process $P_0$**
   - Record own state. After $P_0$ has recorded its own state
     - for each outgoing channel C,
       send a <u>marker message</u> 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

# Chandy and Lamport's 'Snapshot' Algorithm

*Marker receiving rule for process* $p_i$

On $p_i$'s receipt of a *marker* message over channel $c$:

*if* ($p_i$ has not yet recorded its state) it

records its process state now;

records the state of $c$ as the empty set;

turns on recording of messages arriving over other incoming channels;

*else*

$p_i$ records the state of $c$ as the set of messages it has received over $c$ since it saved its state.

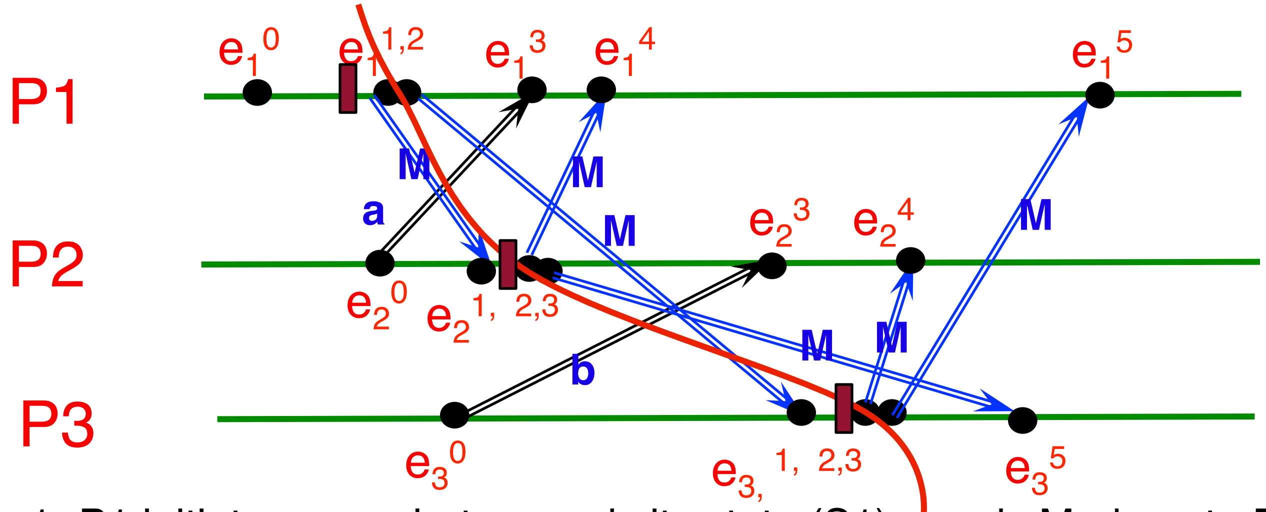
*end if*

*Marker sending rule for process* $p_i$

After $p_i$ has recorded its state, for each outgoing channel $c$:

$p_i$ sends one marker message over $c$ (before it sends any other message over $c$).

# Snapshot Example




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}

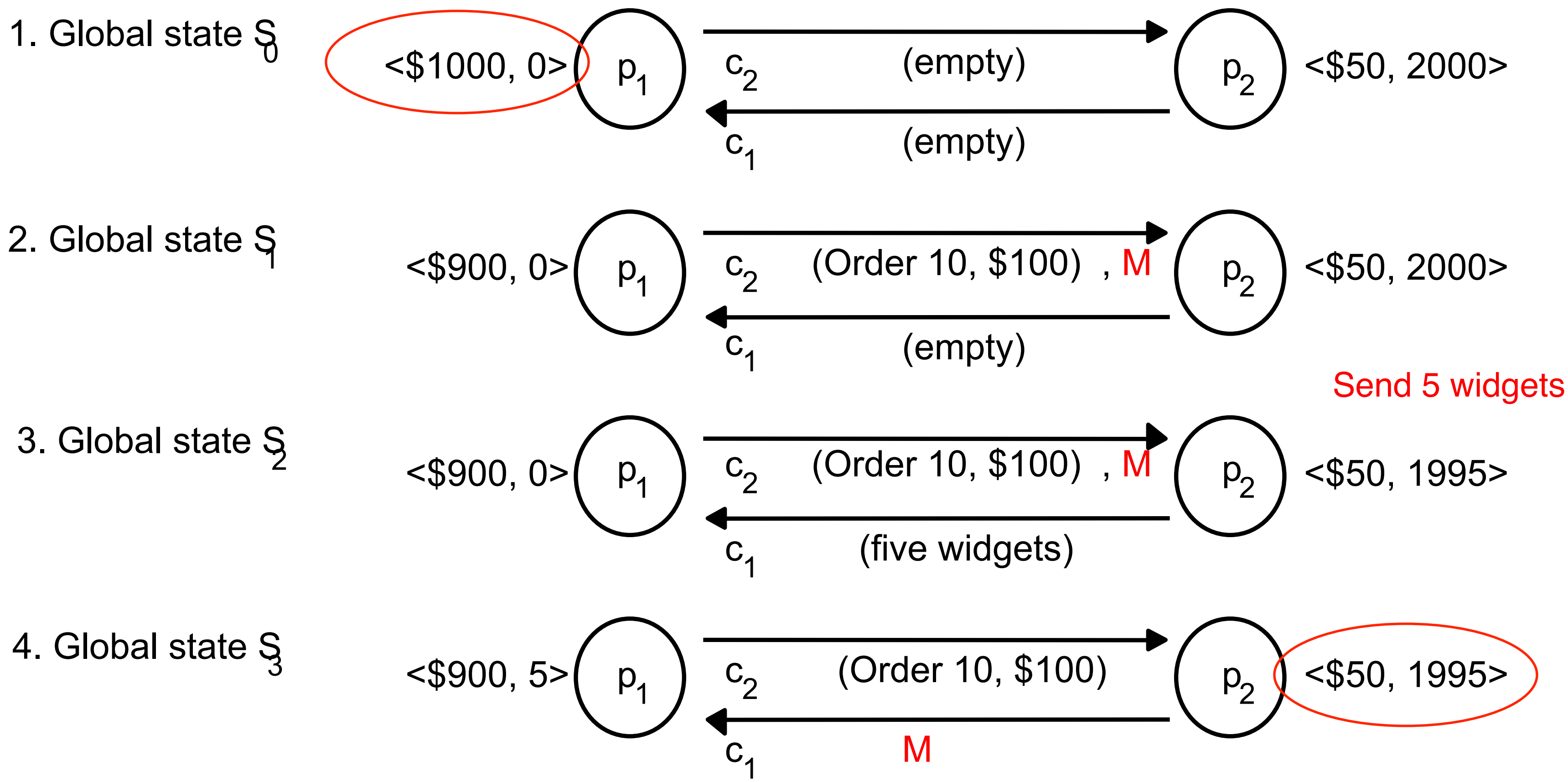
4- P3 receives Marker over C13, records its state (S3), sets state(C13) = {} sends Marker to P1 & P2; turns on recording for channel C23

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) = {}

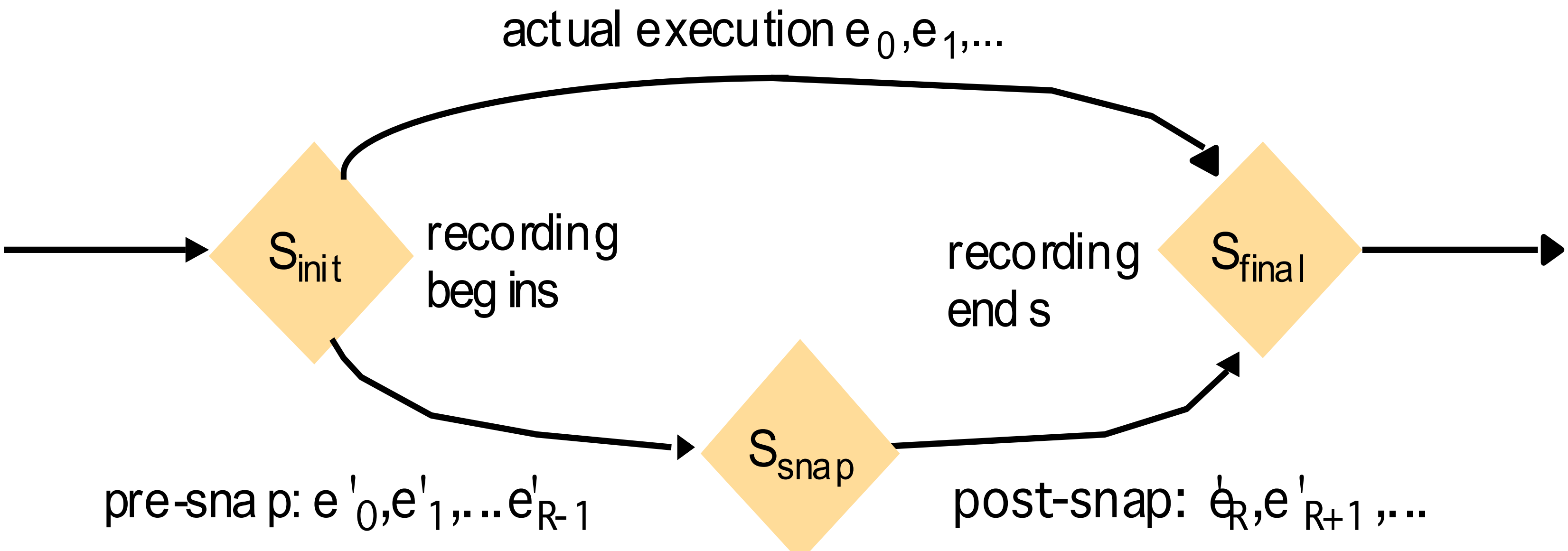
# Earlier Example with Snapshot Algorithm




recorded $C_1$ channel state = (five widgets)

recorded $C_2$ channel state = empty

# *Provable Assertion: Chandy-Lamport algo. determines a consistent cut*




**Let $e_i$ and $e_j$ be events occurring at $p_i$ and $p_j$, respectively such that $e_i \rightarrow e_j$**
**The snapshot algorithm ensures that**

- **if $e_j$ is in the cut then $e_i$ is also in the cut.**
- **if $e_j \rightarrow p_j$ records its state, then it must be true that $e_i \rightarrow p_i$ records its state. Why?**

***➔A stable predicate that is true in S-snap must be true in S-final***

# *Global States useful for detecting Global Predicates*

- A cut is consistent if and only if it does not violate causality
- A *Run* is a total ordering of events in H that is consistent with each $h_i$'s ordering
- A Linearization is a run consistent with happens-before ($\rightarrow$) relation in H.
- Linearizations pass through consistent global states.
- A global state $S_k$ is reachable from global state $S_i$, if there is a linearization, L, that passes through $S_i$ and then through $S_k$.
- The distributed system evolves as a series of transitions between global states $S_0$ , $S_1$ , ….

# *Global State Predicates*

- A ***global-state-predicate*** is a function from the set of global states to {true, false} , e.g., deadlock, termination
- If *P* is a global-state predicate of reaching termination, then a global state S0 satisfies liveness if:

  $liveness(P(S_0)) \equiv \exists L_{\in \text{linearizations from S0}}, S_L : L \text{ passes through } S_L \,\&\, P(S_L) = true$

- A ***stable*** global-state-predicate is one that once it becomes true, it remains true in subsequent global states, e.g., an object O is orphaned
- if *P* is a global-state-predicate of being deadlocked, then a global state S0 satisfies this safety if:

  $safety(P(S_0)) \equiv \forall S \text{ reachable from } S_0, P(S) = false$

# *Quick Note – Liveness versus Safety*

**Can be confusing, but terms are relevant outside CS too:**

- **Liveness=guarantee that something good will happen eventually**
  - **"Guarantee of termination" is a liveness property**
  - **Guarantee that "at least one of the atheletes in the 100m final will win gold" is liveness**
  - **A criminal will eventually be jailed**
- **Safety=guarantee that something bad will never happen**
  - **Deadlock avoidance algorithms provide safety**
  - **A peace treaty between two nations provides safety**
  - **An innocent person will never be jailed**
- **Can be difficult to satisfy both liveness and safety!**

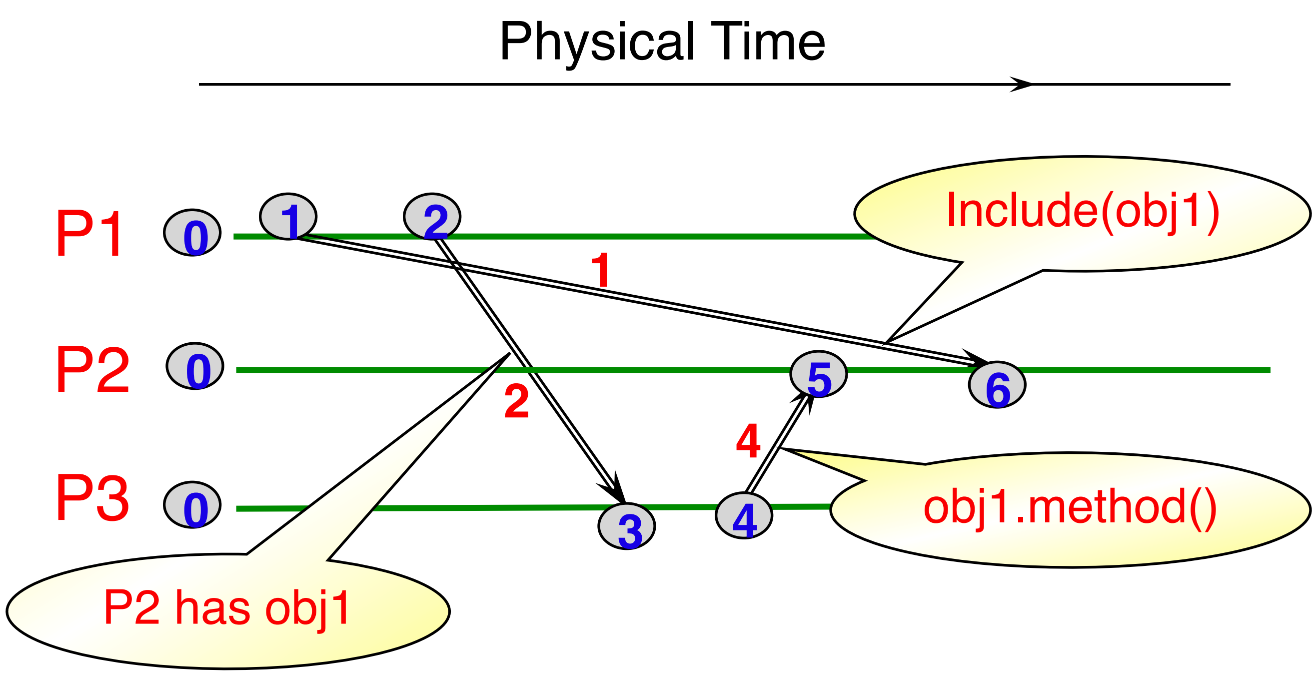
# *Summary, Announcements*

- **This class: importance of global snapshots, Chandy and Lamport algorithm, violation of causality**

- **Next topic: Multicast, broadcast, impossibility of consensus in asynchronous systems (see course website for readings, to be posted soon)**

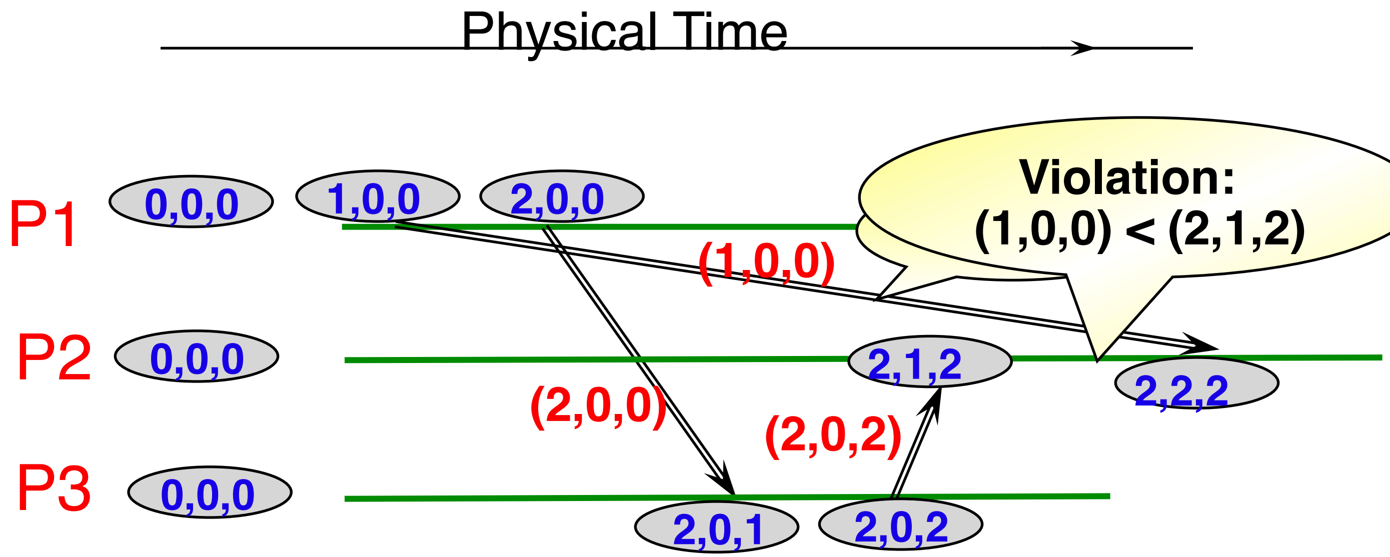
# *Optional Slides*

# Side Issue: Causality Violation




- Causality violation occurs when order of messages causes an action based on information that another host has not yet received.
- In designing a DS, potential for causality violation is important

# *Detecting Causality Violation*




- Potential causality violation can be detected by vector timestamps.
- If the vector timestamp of a message is less than the local vector timestamp, on arrival, there is a potential causality violation.