Distributed Systems

CS425/ECE428

Feb 6 2023

Instructor: Radhika Mittal

Logistics Related

- HW2 release date has been pushed to Mon, Feb 20th. Accordingly, its due date has been pushed to Mon. Mar 6th.

- MP0 due on Wednesday.

- Note about exams on CampusWire:
  - Midterm: Mar 22-24, Finals: May 4
  - Reservation via PrairieTest.
    - You can reserve a slot for Midterms starting Mar 2nd
  - If you need DRES accommodations, please upload your Letter of Accommodations on the CBTF website.

Today's agenda

- **Global State**
  - Chapter 14.5
  - Goal: reason about how to capture the state across all processes of a distributed system without requiring time synchronization.
- **Multicast** (if time)

Recap

- State of each process (and each channel) in the system *at a given instant of time.*
  - Difficult to capture -- requires precisely synchronized time.

- Relax the problem: find a consistent global state.

- Chandy-Lamport algorithm to calculate global state.
  - Obeys causality (creates a consistent cut).
  - Does not interrupt the running distributed application.
  - Can be used to detect global properties.

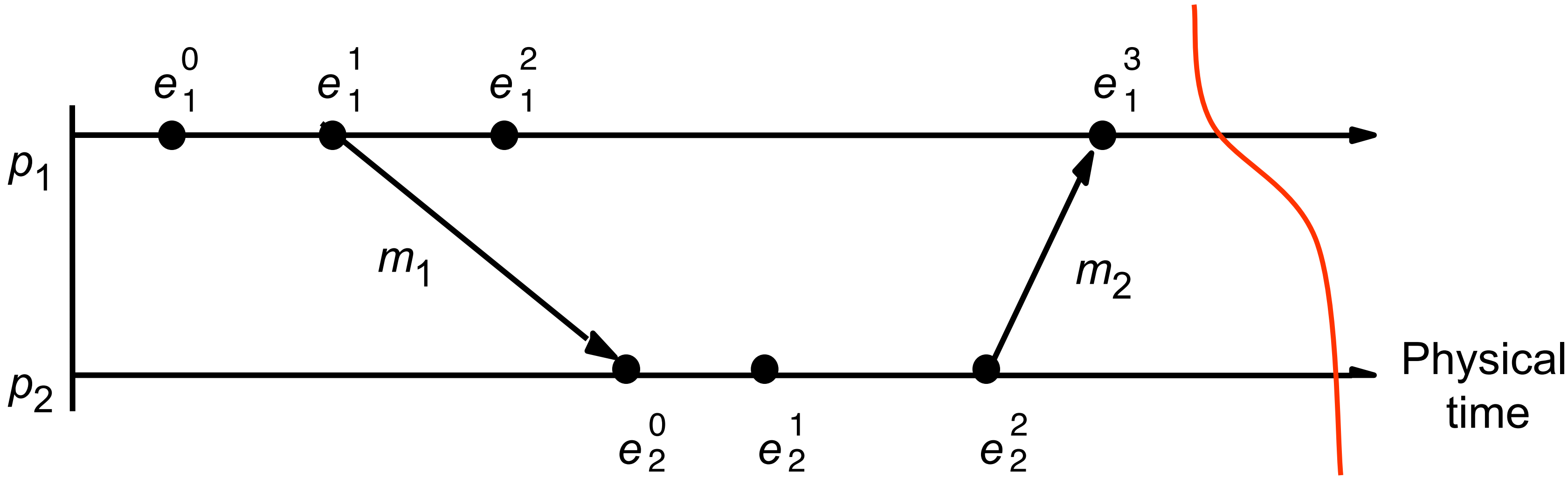
More notations and definitions

- history(p_i) = $h_i = \langle e_i^0, e_i^1, \ldots \rangle$
- global history: $H = \cup_i (h_i)$

- 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.

Example



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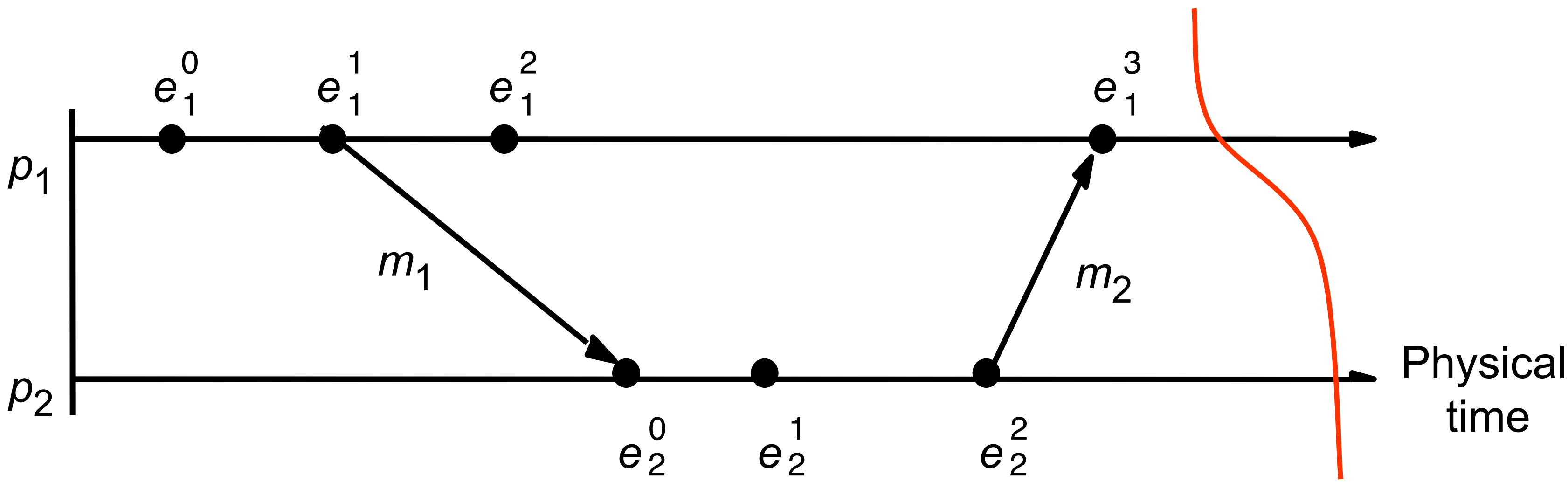

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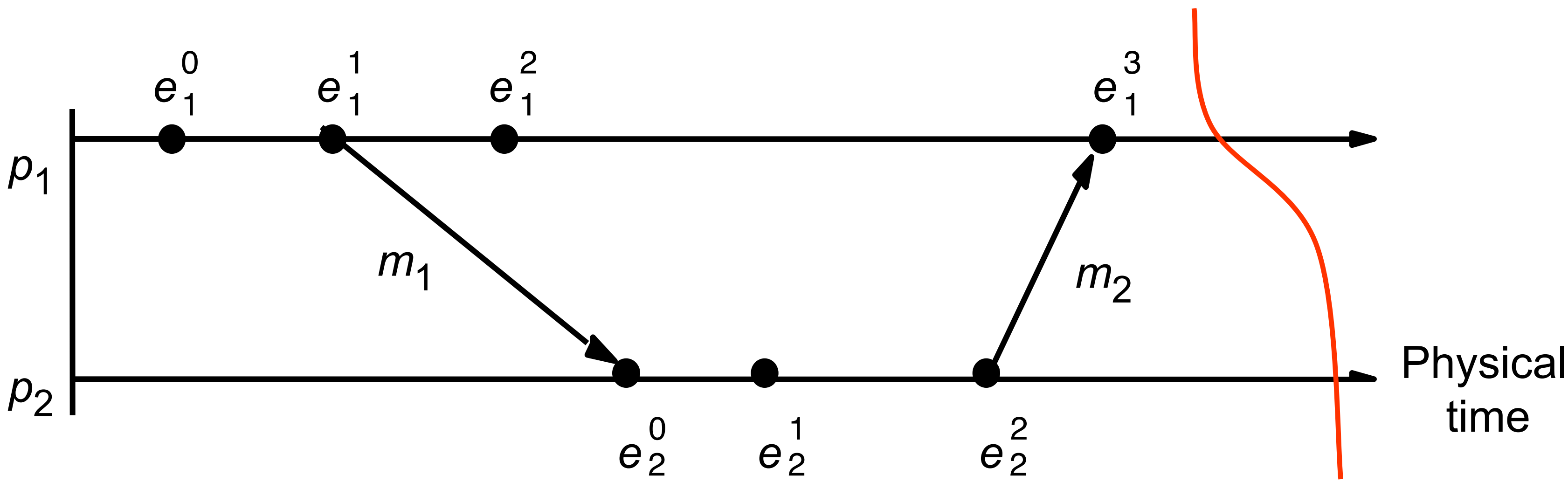

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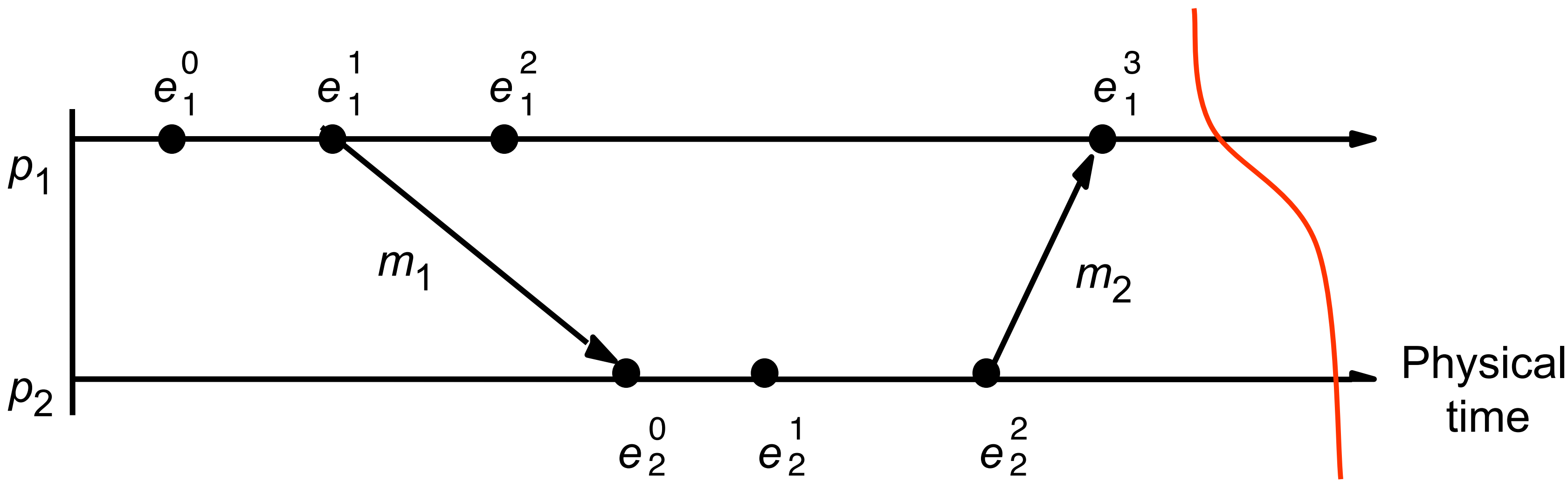

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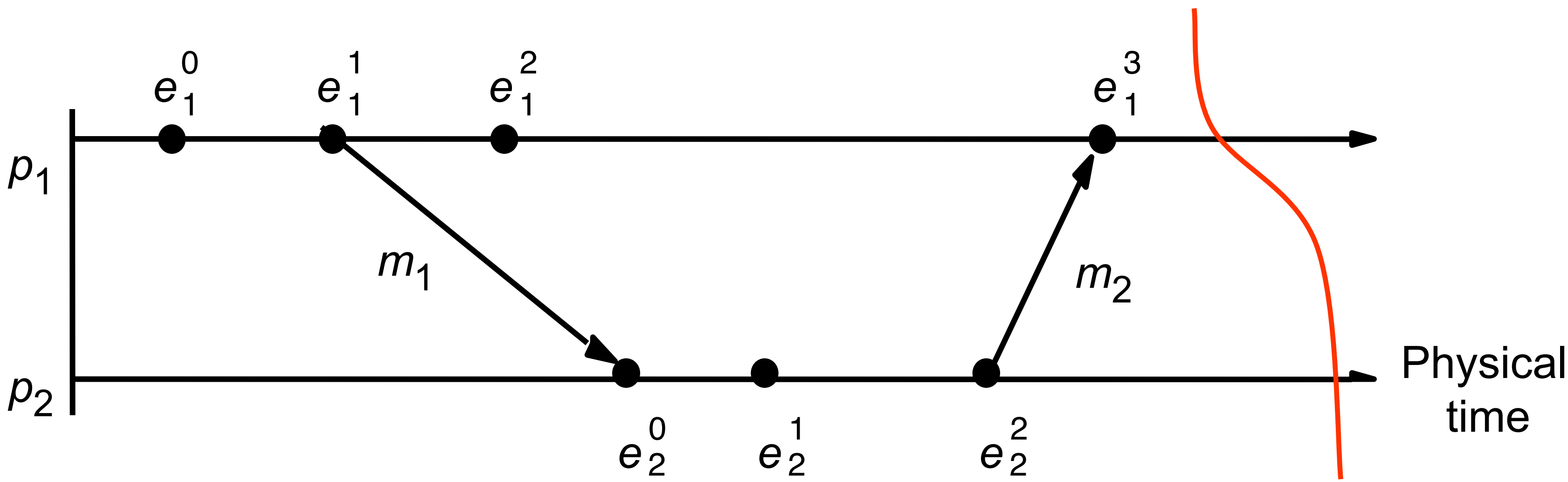

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- **global history**: $H = \cup_i (h_i)$

- A **run** is a total ordering of events in H that is consistent with each $\mathbf{h}_i$'s ordering.

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- Linearizations pass through consistent global states.

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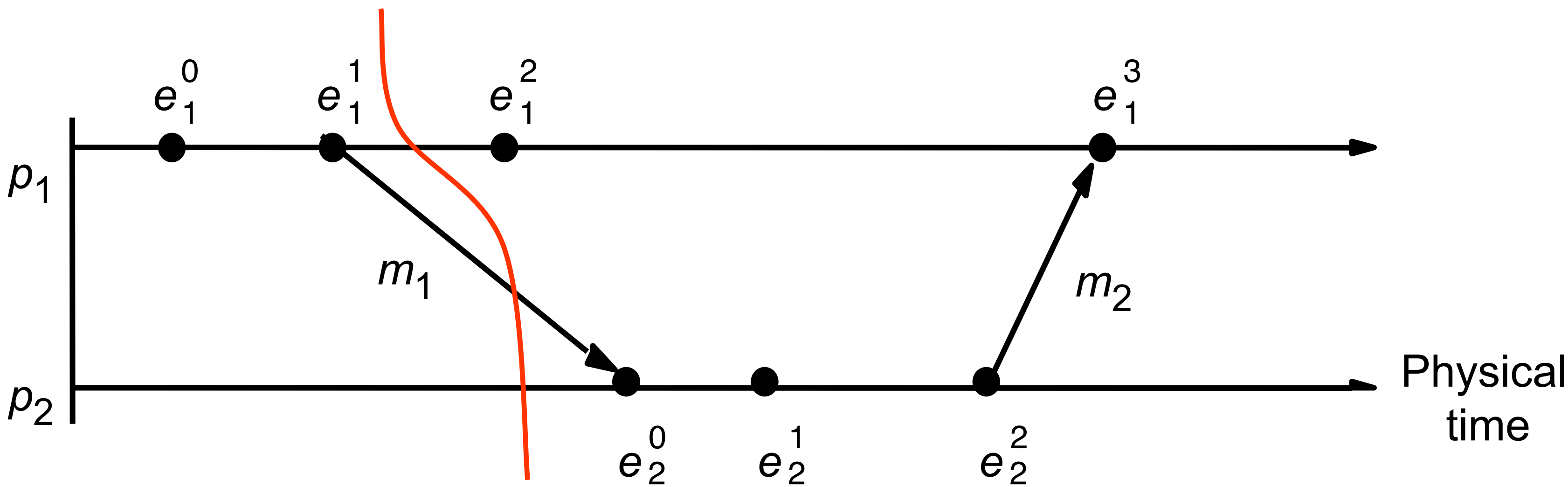

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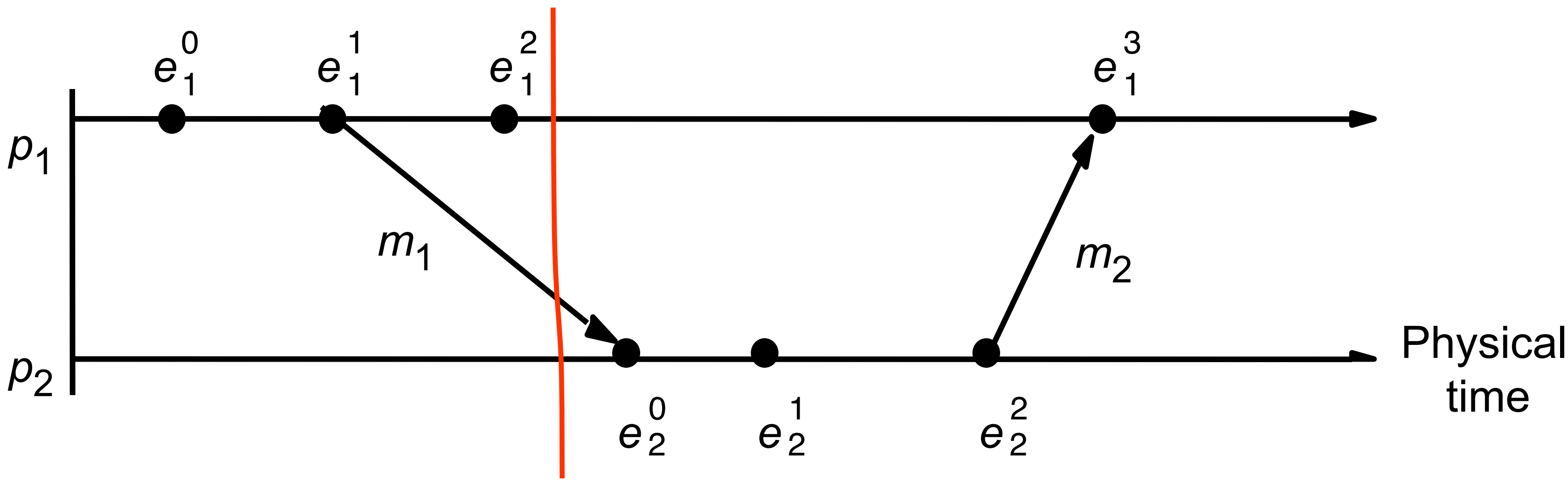

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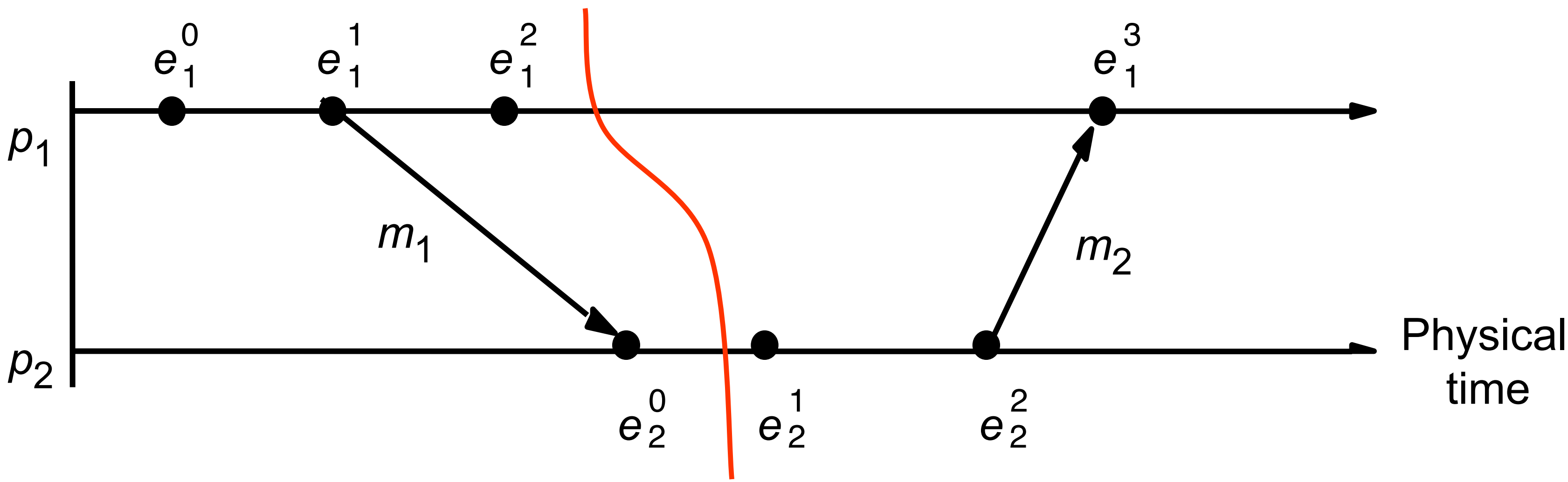

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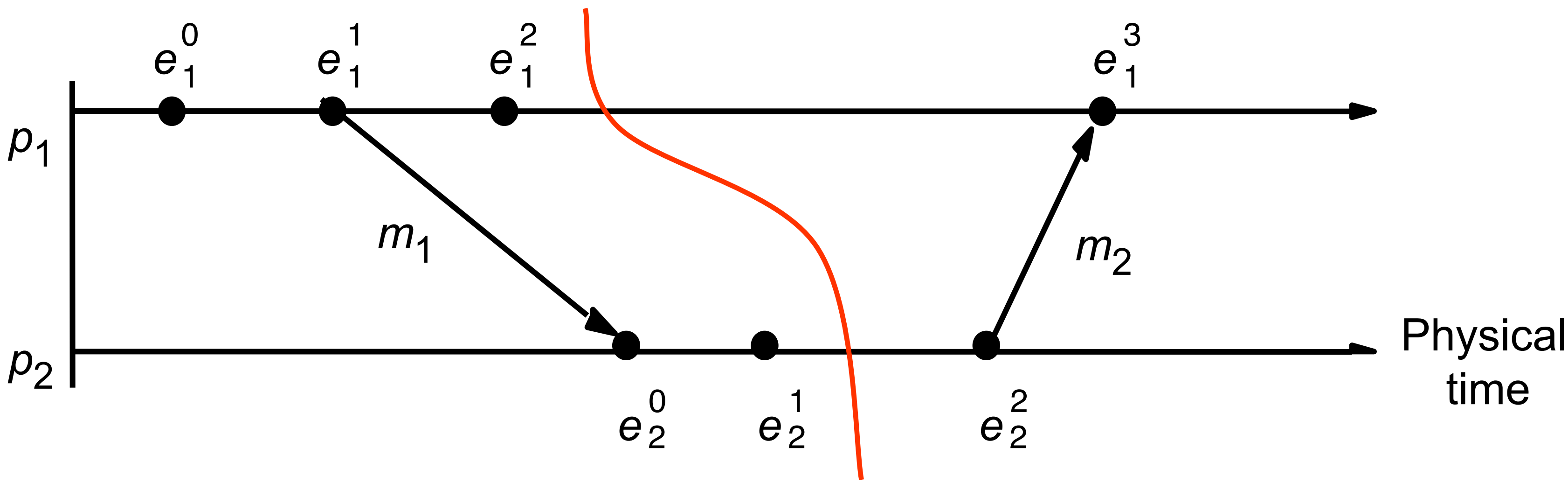

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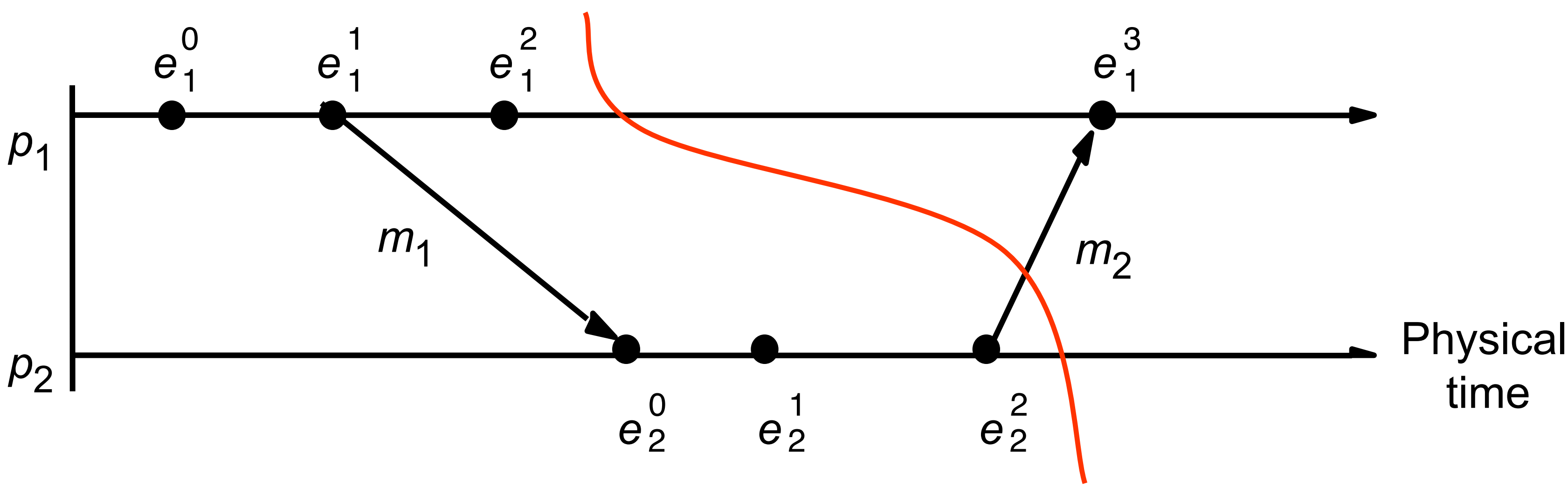

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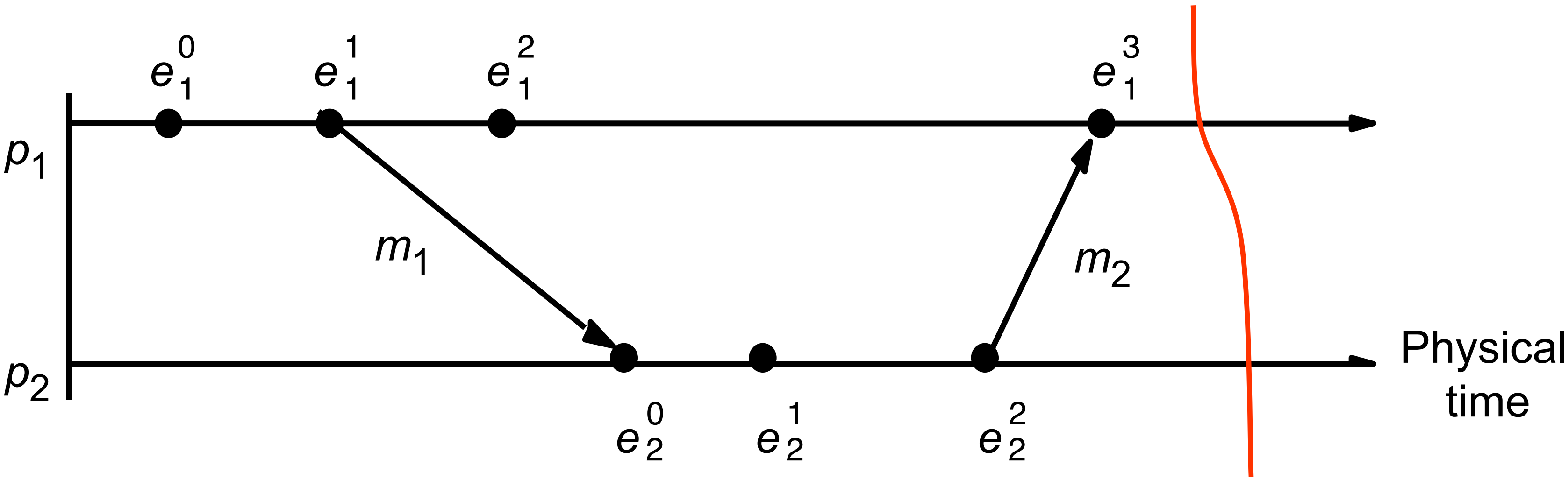

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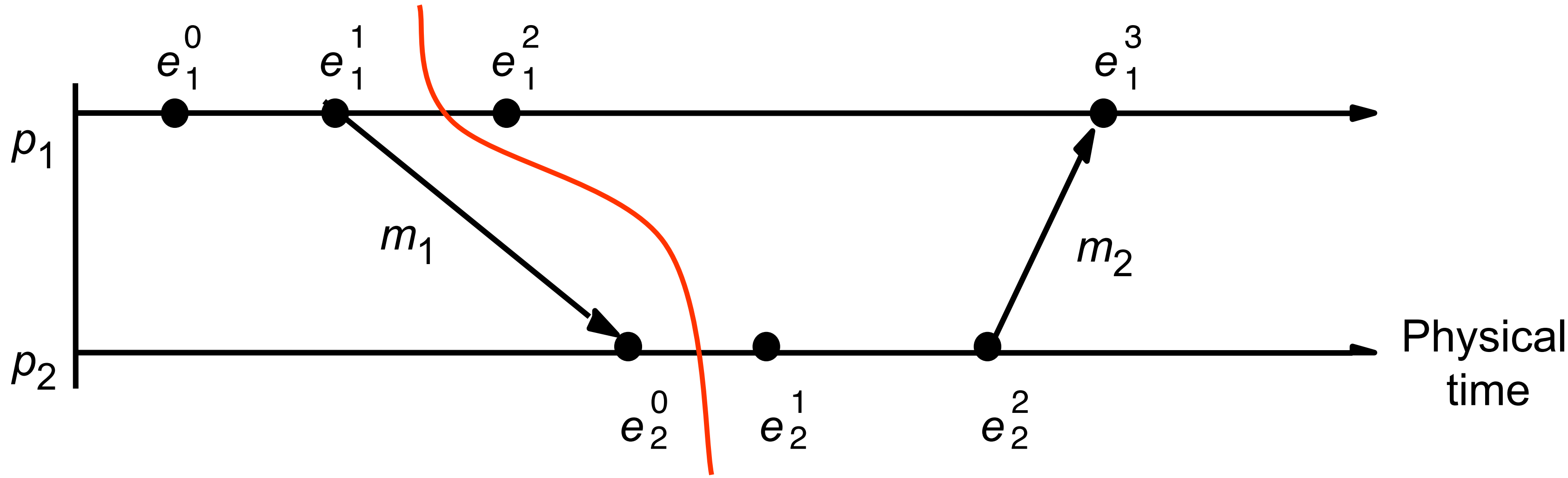

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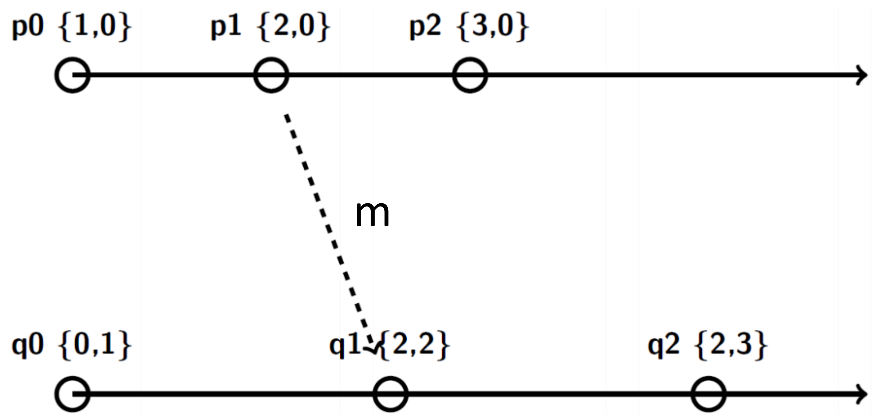
More notations and definitions

- Linearizations pass through consistent global states.
- A global state $\mathbf{S_k}$ is reachable from global state $\mathbf{S_i}$, if there is a linearization that passes through $\mathbf{S_i}$ and then through $\mathbf{S_k}$.
- The distributed system evolves as a series of transitions between global states S_0 , S_1 , ….

State Transitions: Example



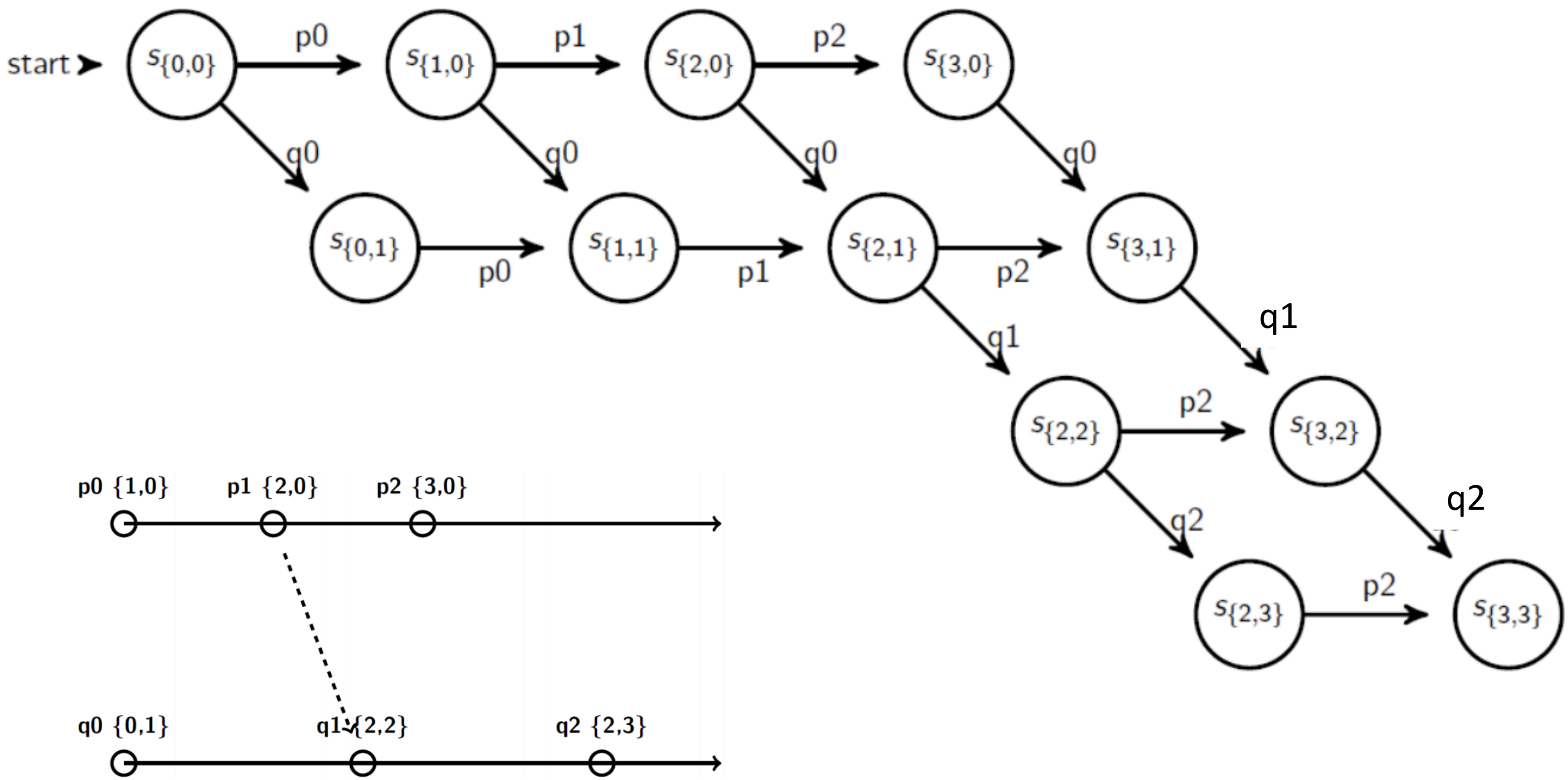
- Causal order:
  - p0 → p1 → p2
  - q0 → q1 → q2
  - p0 → p1 → q1 → q2
- Concurrent:
  - p0 || q0
  - p1 || q0
  - p2 || q0, p2 || q1, p2 || q2

Many linearizations:

- < p0, p1, p2, q0, q1, q2>
- < p0, q0, p1, q1, p2, q2>
- <q0, p0, p1, q1, p2, q2 >
- <q0, p0, p1, p2, q1,q2 >
- ……

State Transitions: Example

Execution Lattice. Each path represents a linearization.



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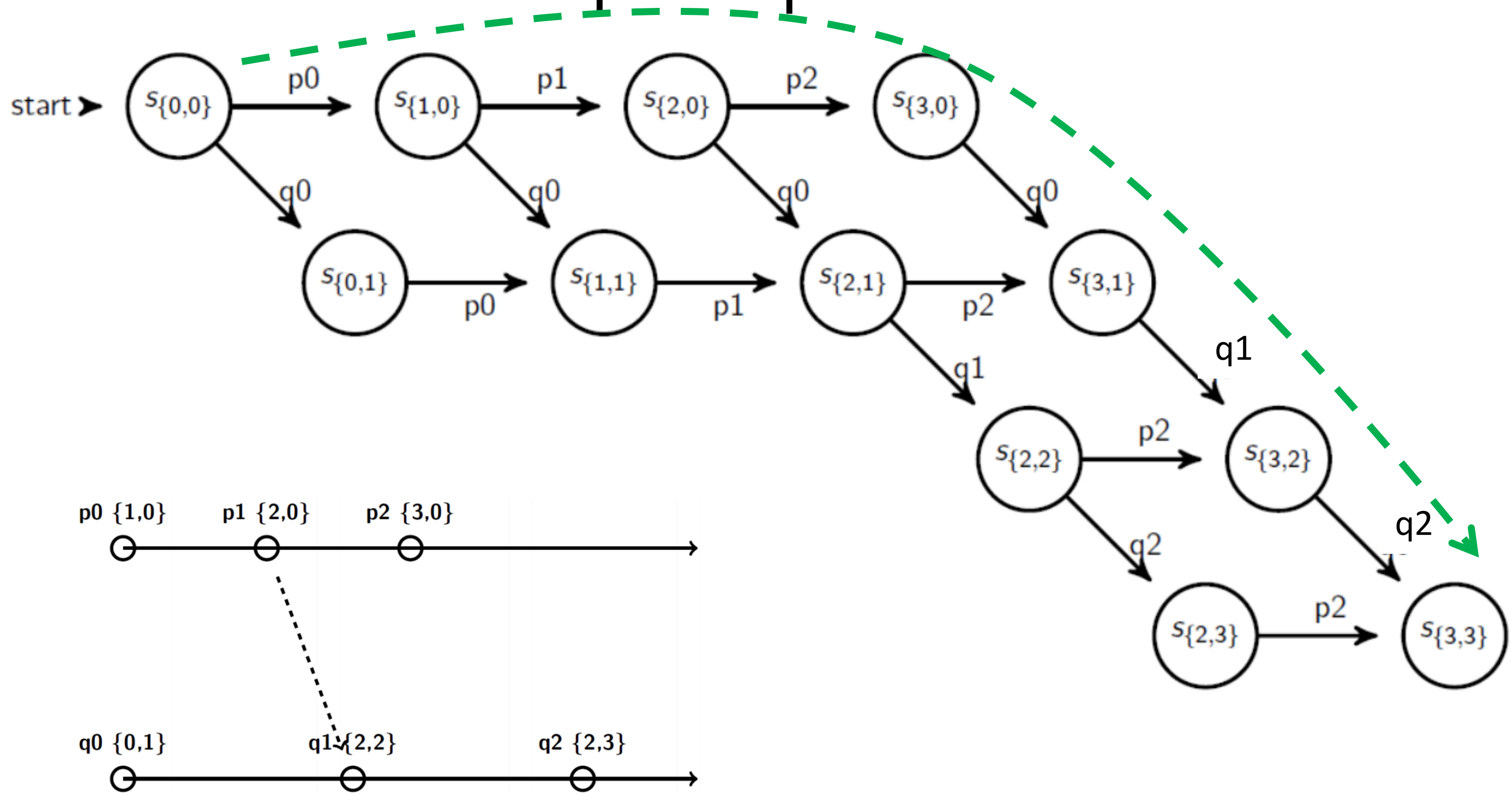

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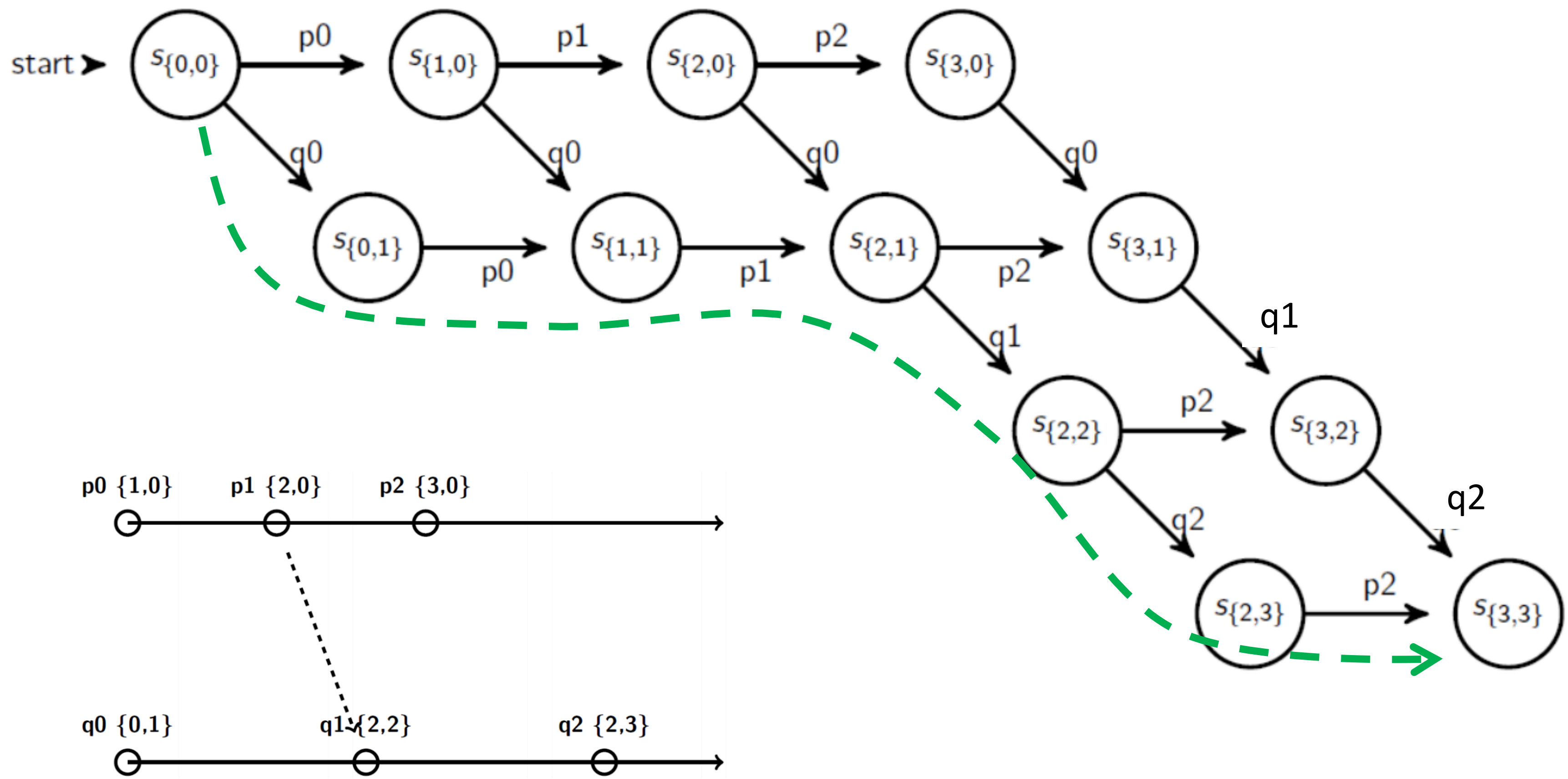

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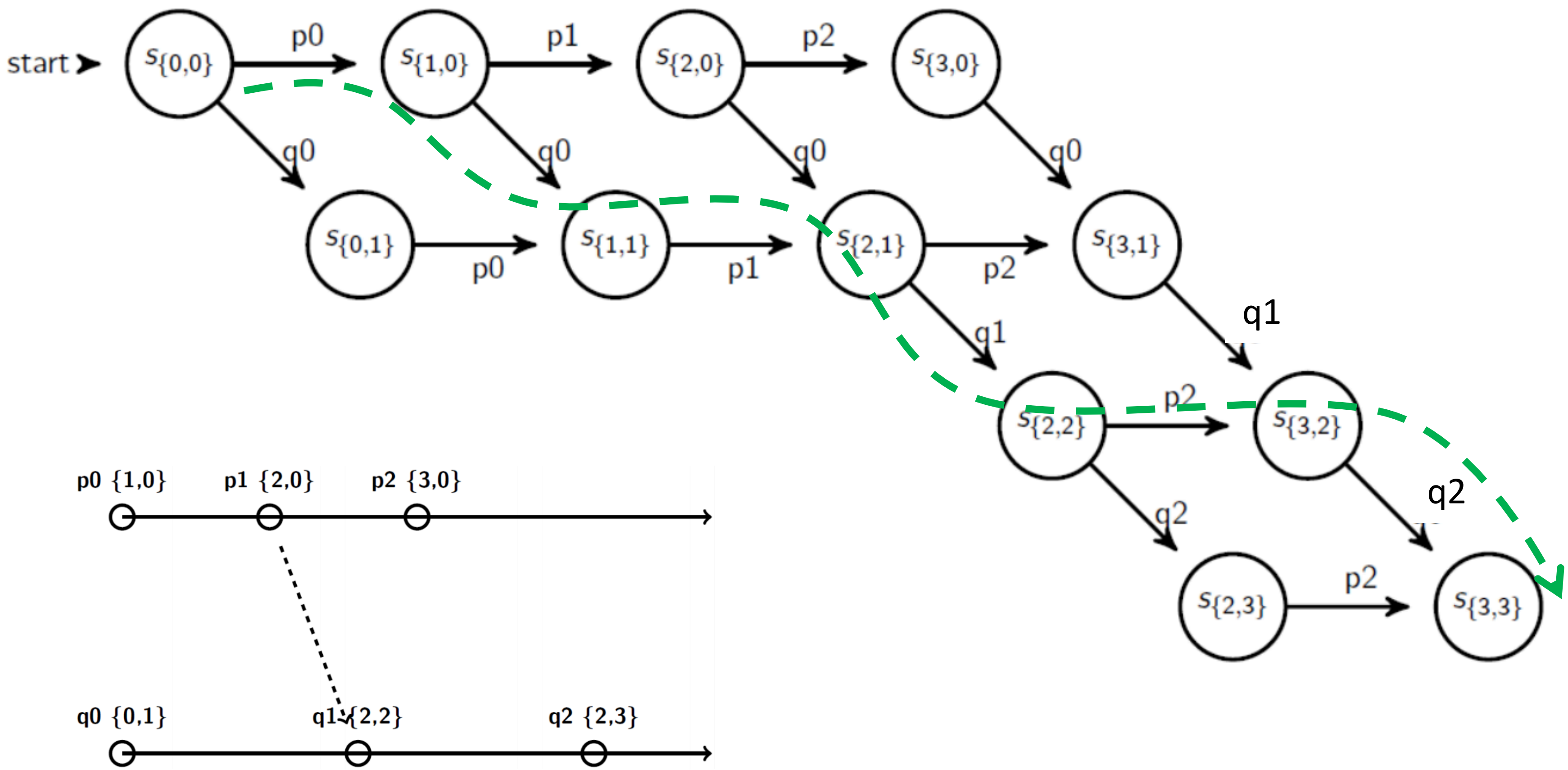

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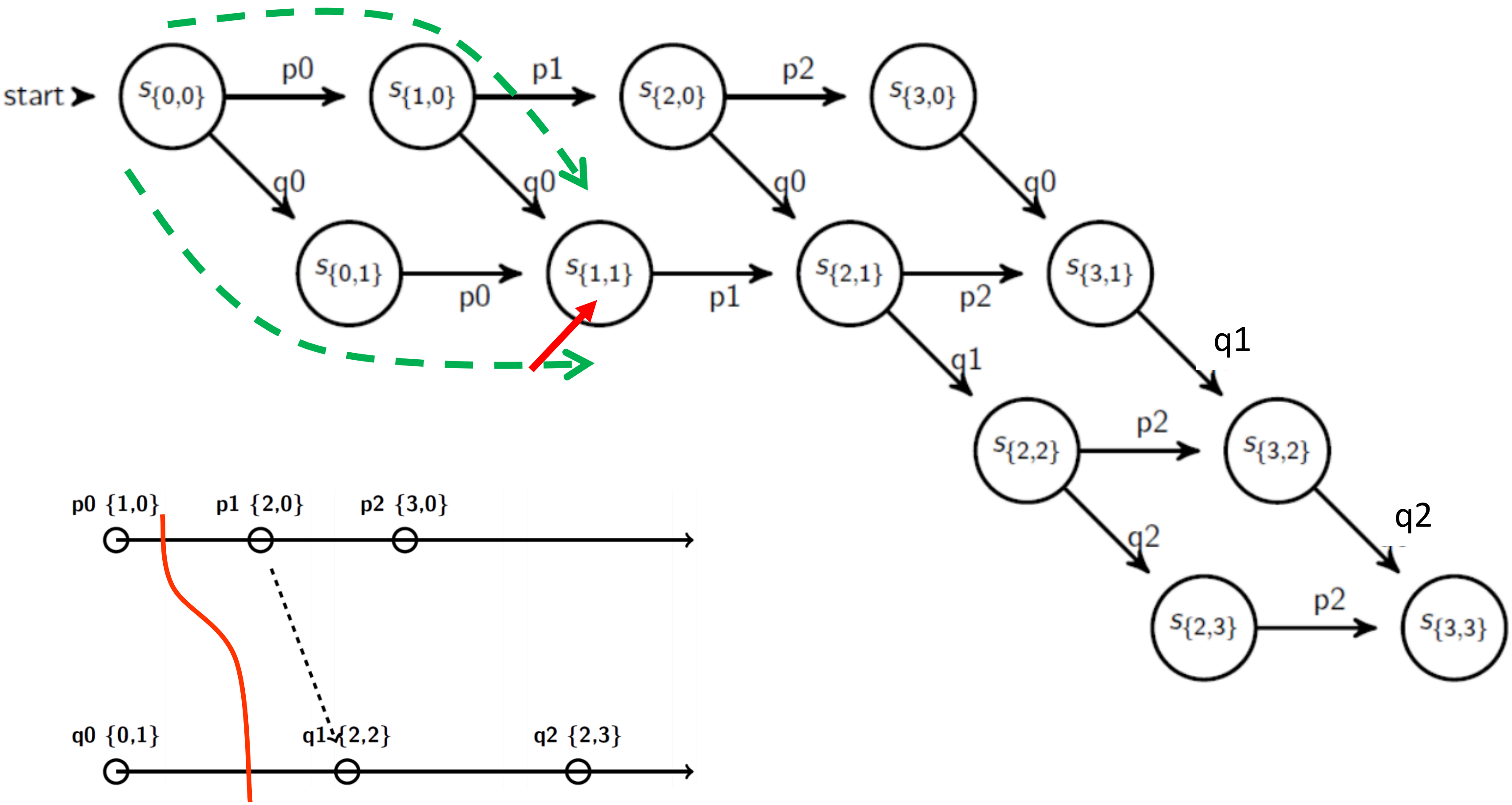

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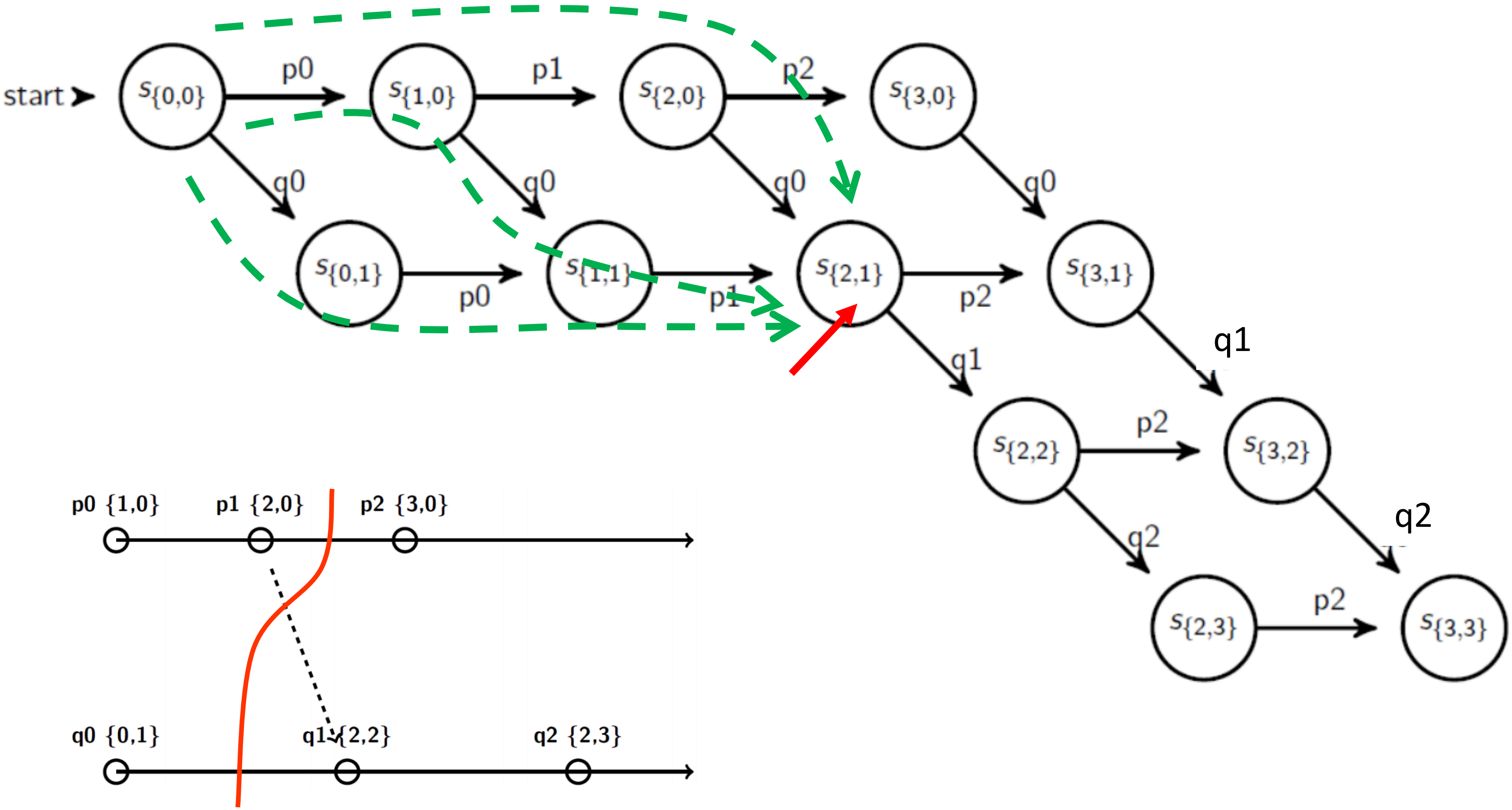

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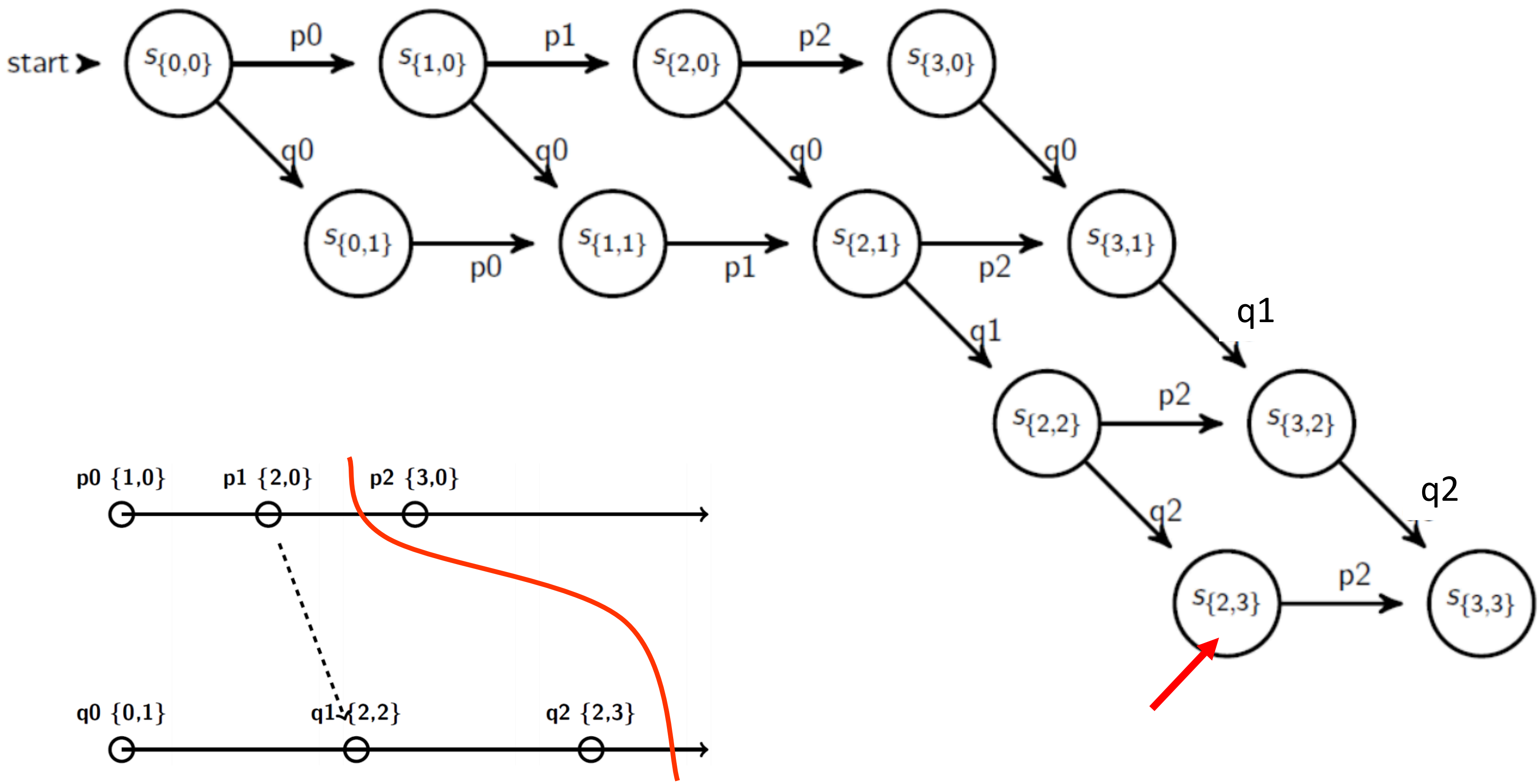

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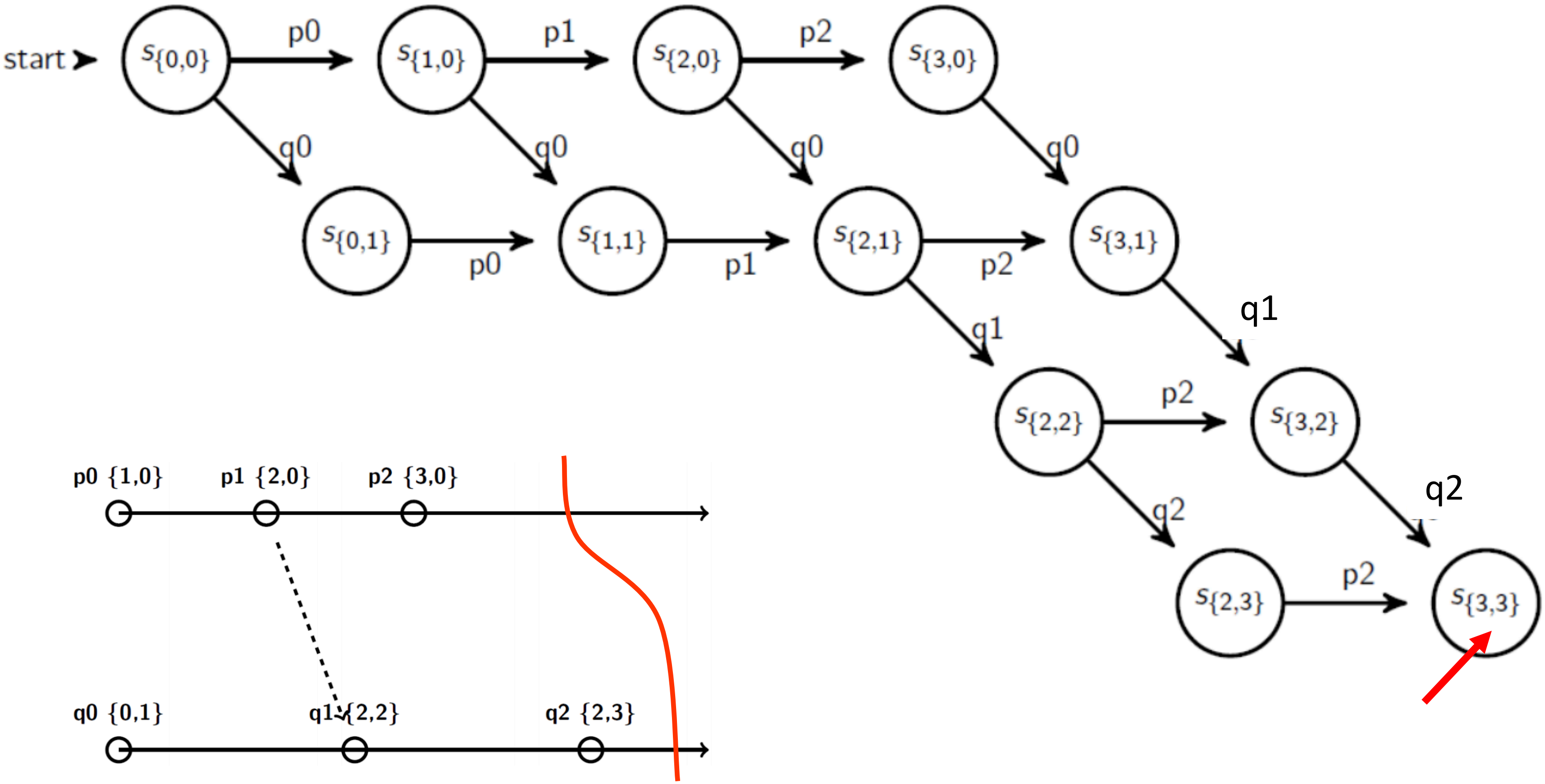

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Global State Predicates

- A global-state-predicate is a property that is *true* or *false* for a global state.
  - Is there a deadlock?
  - Has the distributed algorithm terminated?
- Two ways of reasoning about predicates (or system properties) as global state gets transformed by events.
  - Liveness
  - Safety

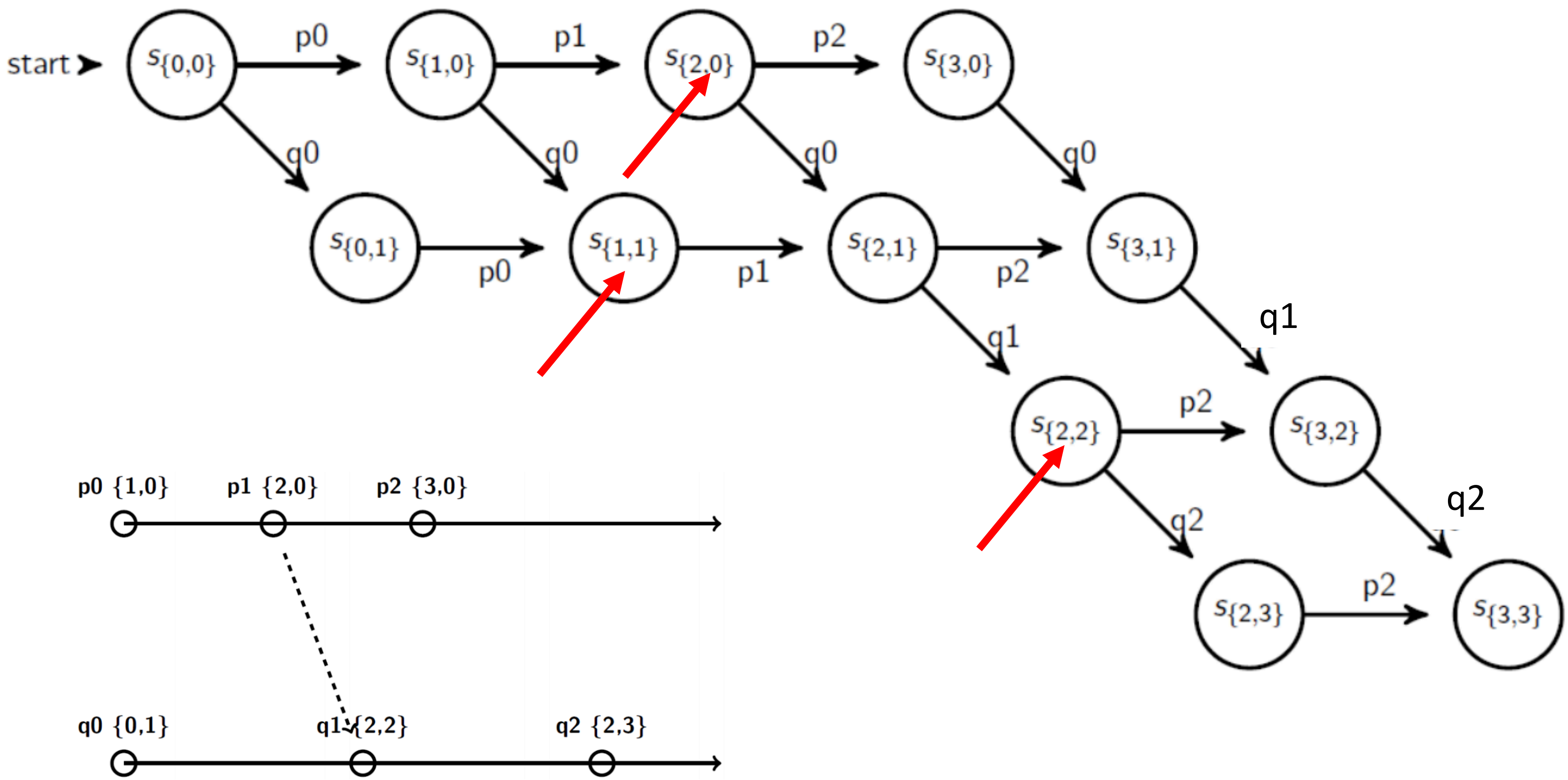
Liveness

- **Liveness = guarantee that something good will happen, eventually**
- **Examples:**
  - A distributed computation will terminate.
  - "Completeness" in failure detectors: the failure will be detected.
  - All processes will eventually decide on a value.
- A global state S_0 satisfies a **liveness** property P iff:
  - For all linearizations starting from S_0, P is true for some state S_L reachable from S_0.
  - $liveness(P(S_0)) \equiv \forall L \in$ linearizations from S_0, L passes through a S_L & $P(S_L)$ = true

Liveness Example

If predicate is true only in the marked states, does it satisfy liveness?

Yes



Liveness Example

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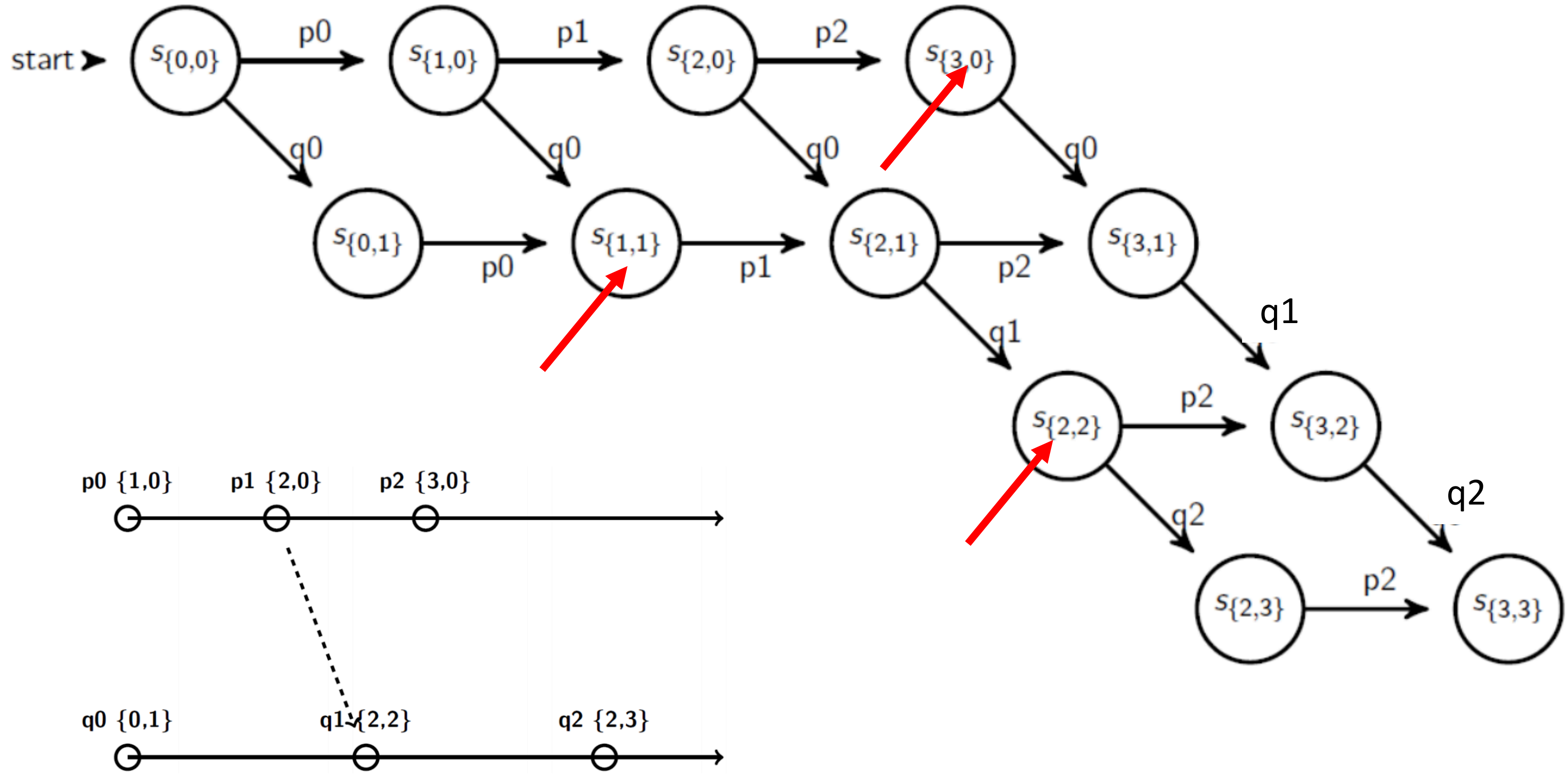

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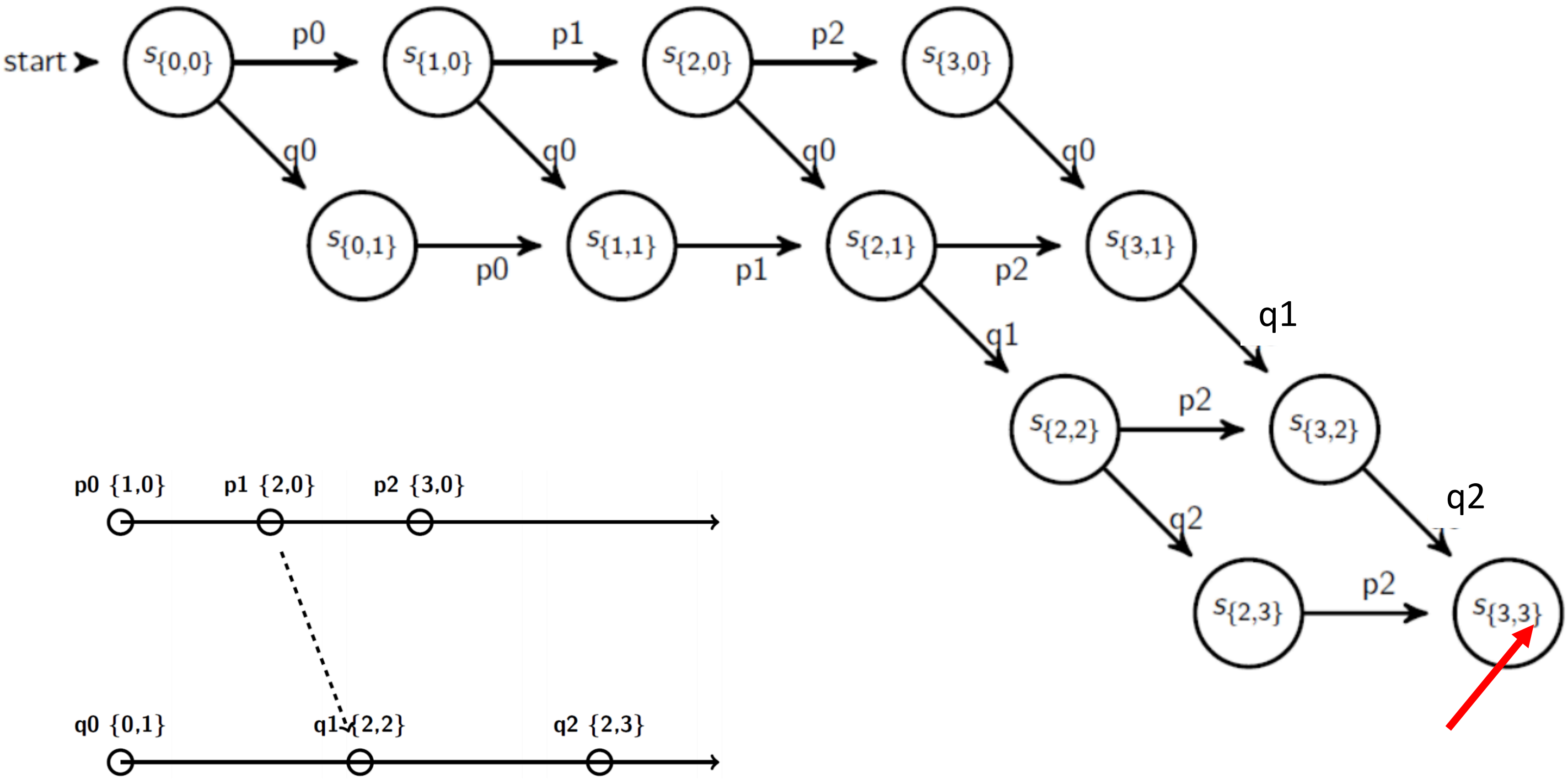

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Safety

- Safety = guarantee that something bad will never happen.
- Examples:
  - There is no deadlock in a distributed transaction system.
  - "Accuracy" in failure detectors: an alive process is not detected as failed.
  - No two processes decide on different values.
- A global state S_0 satisfies a **safety** property P iff:
  - For all states S reachable from S_0, P(S) is true.
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Safety Example

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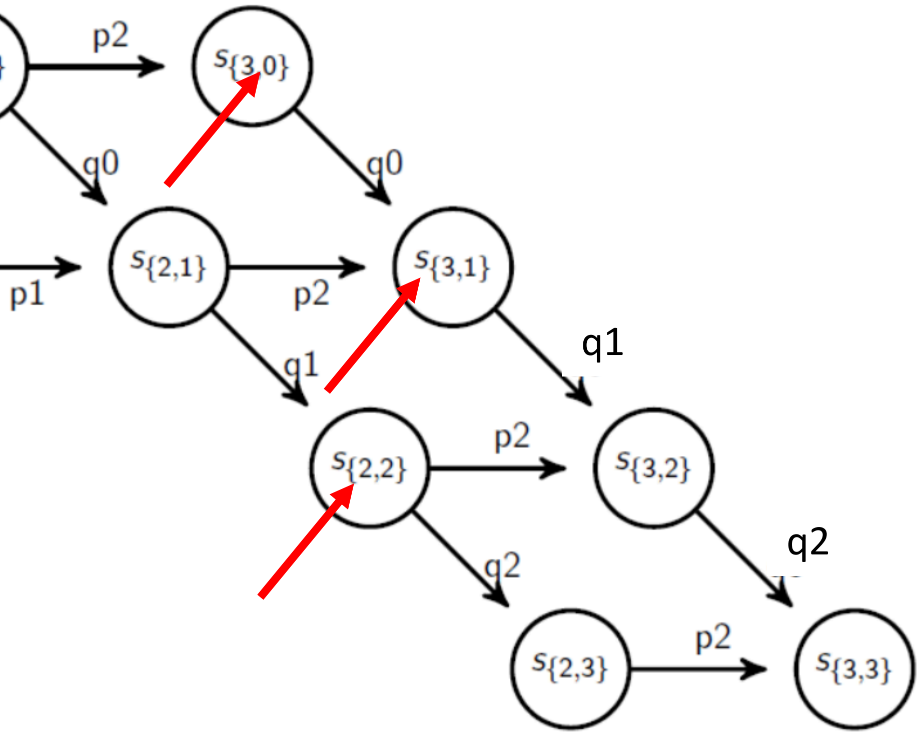
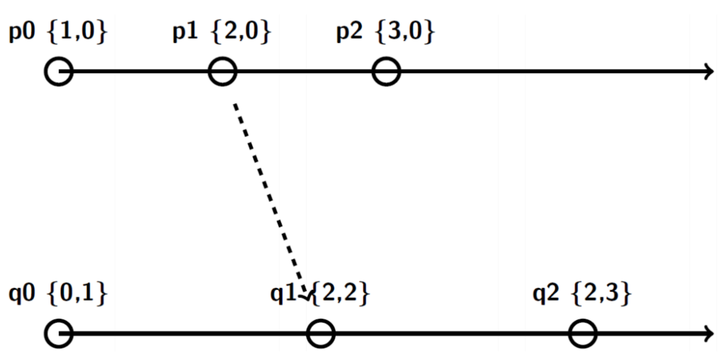
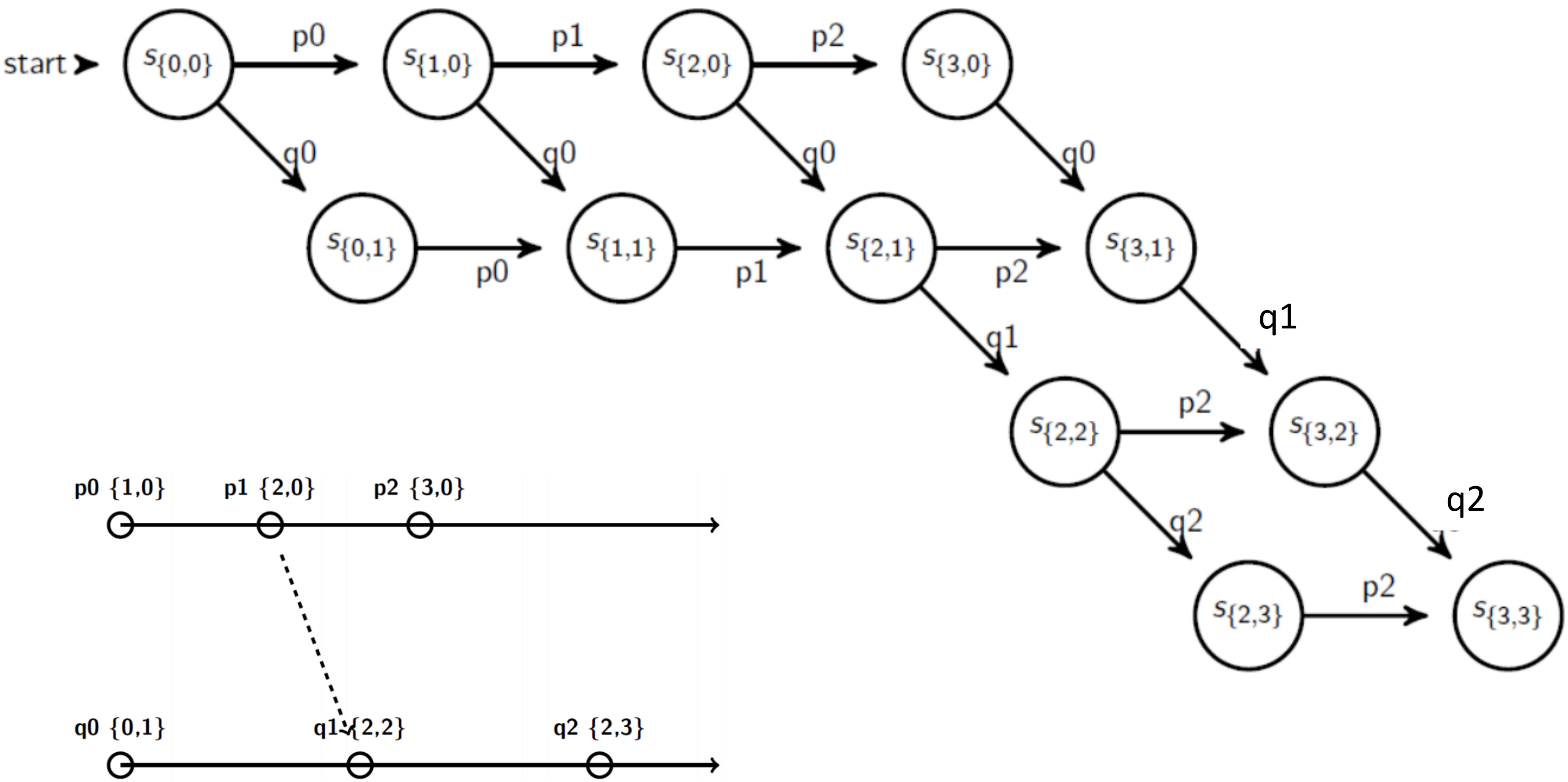




Safety Example

If predicate is true only in the **unmarked** states, does it satisfy safety?

Yes



Safety

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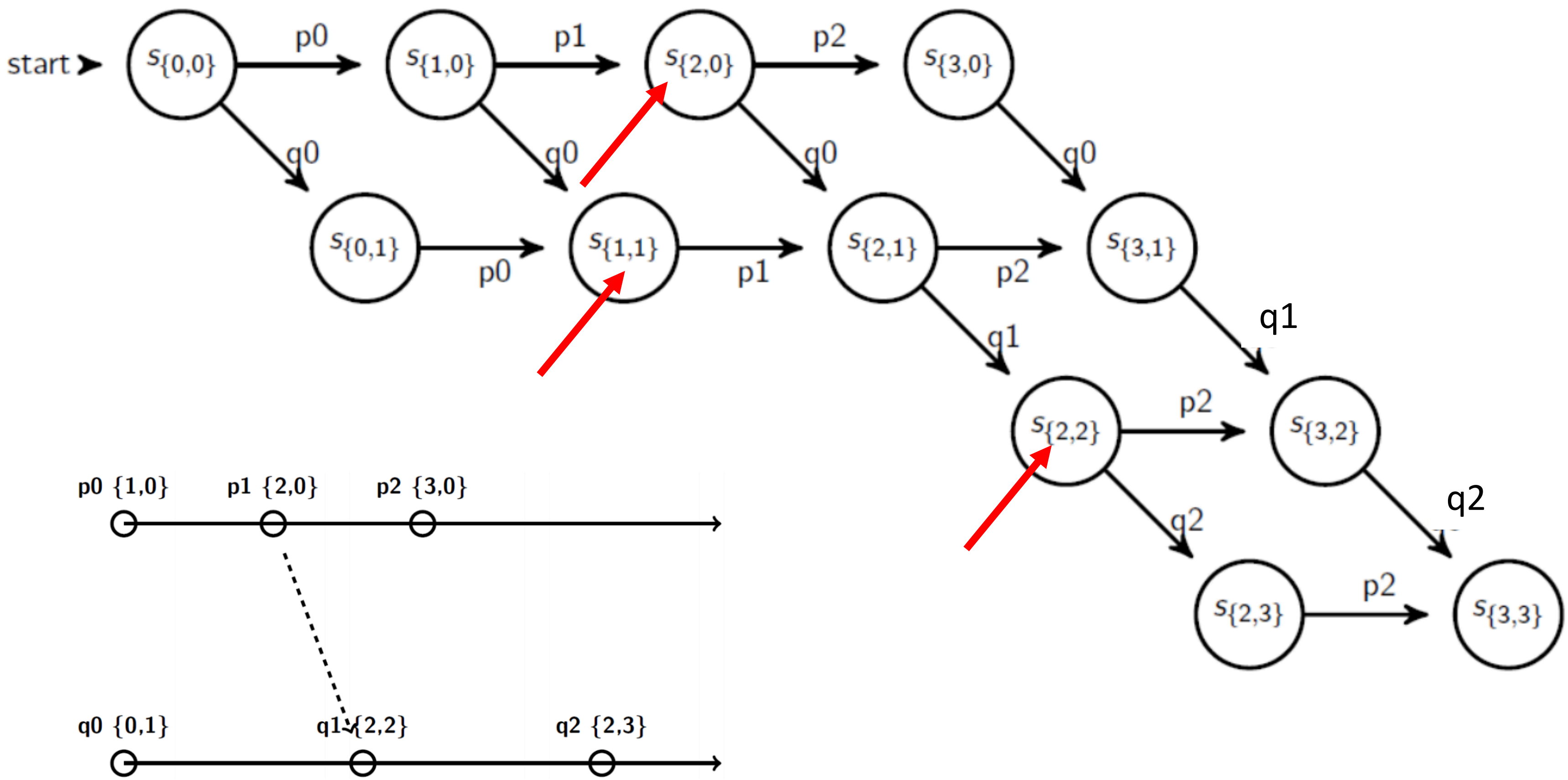
Liveness Example

Technically satisfies liveness, but difficult to capture or reason about.



Stable Global Predicates

- once true, stays true forever afterwards (for stable liveness)

Stable Global Predicates

If predicate is true only in the marked states, is it stable?

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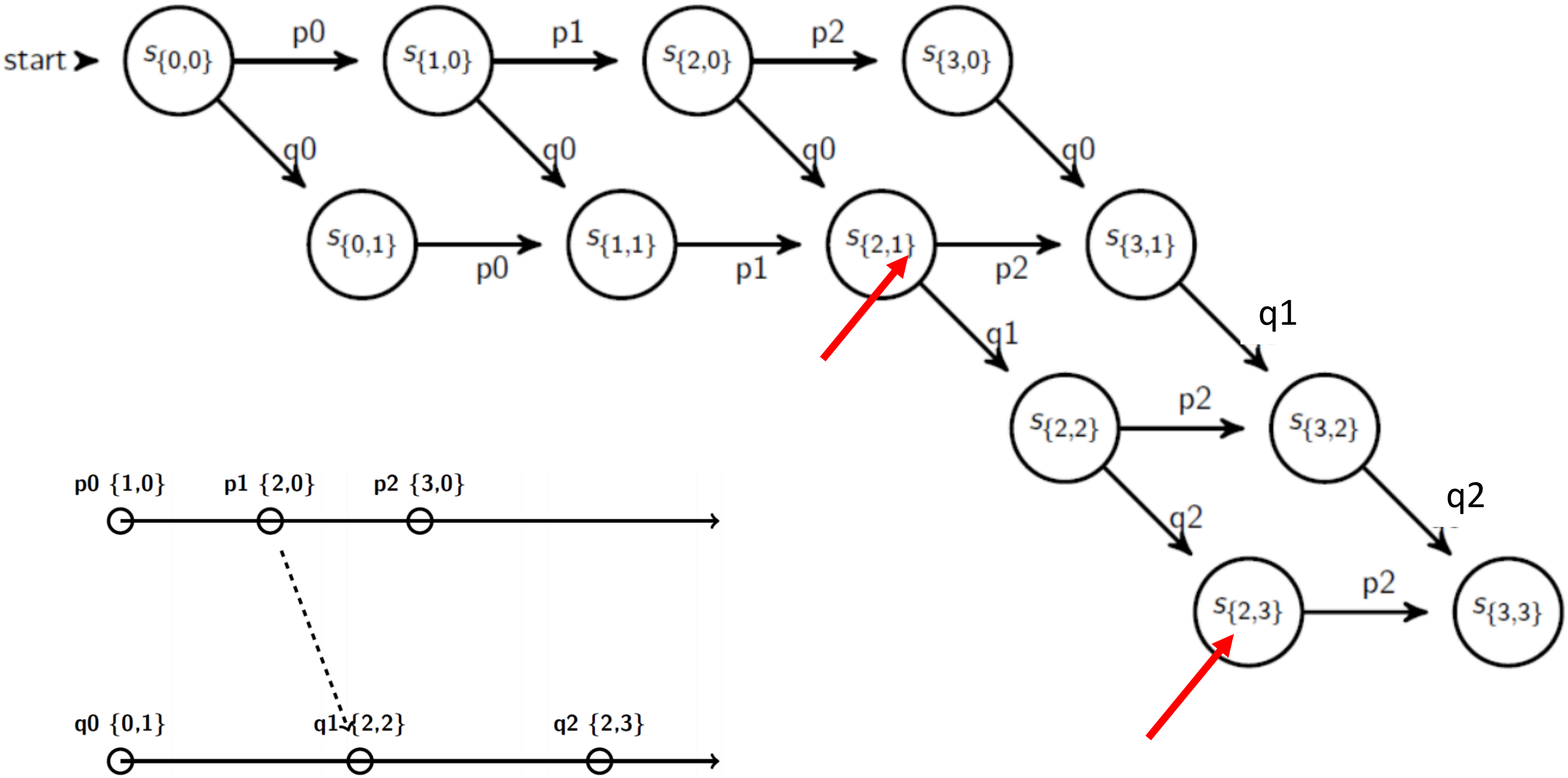

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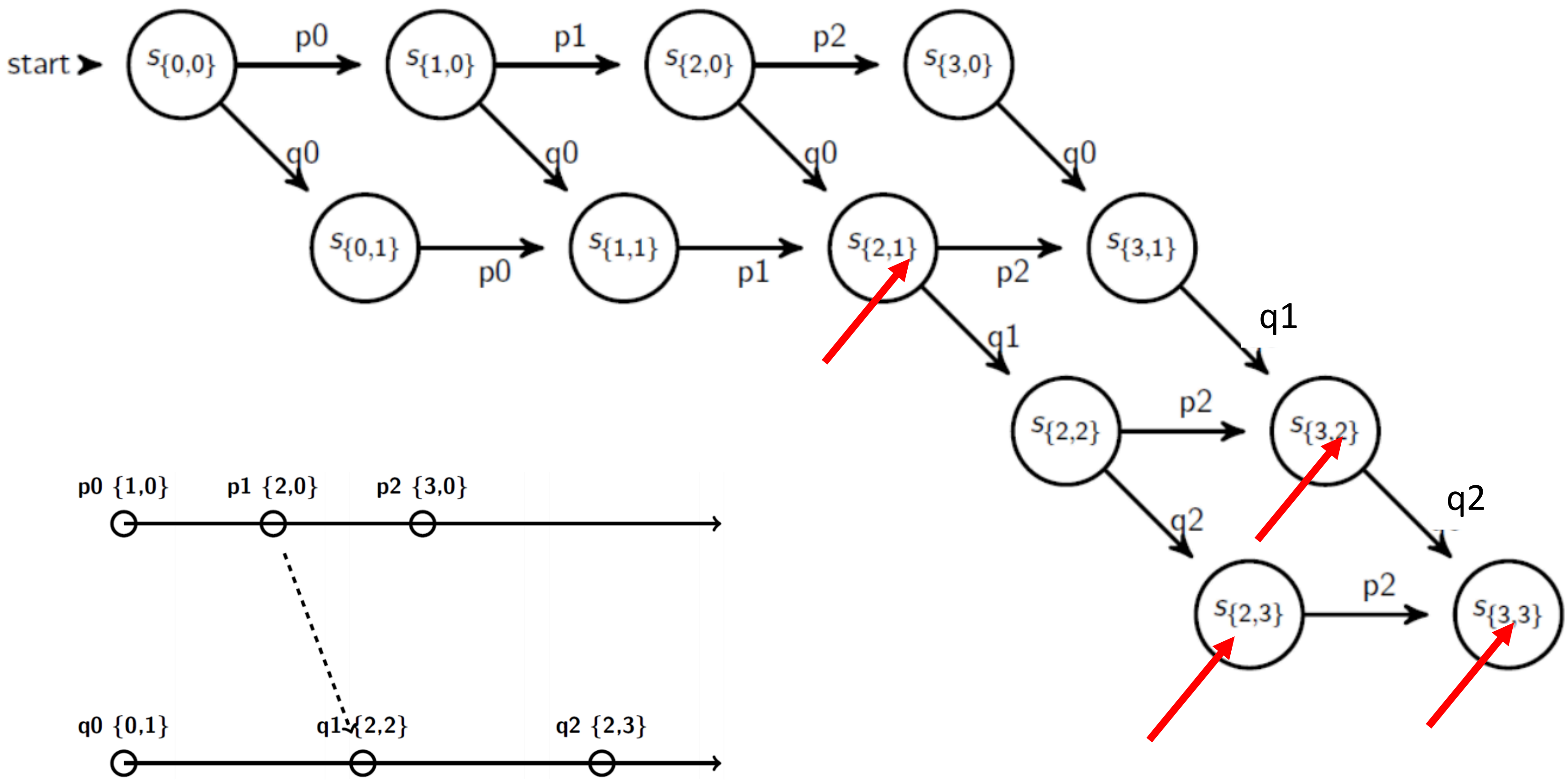

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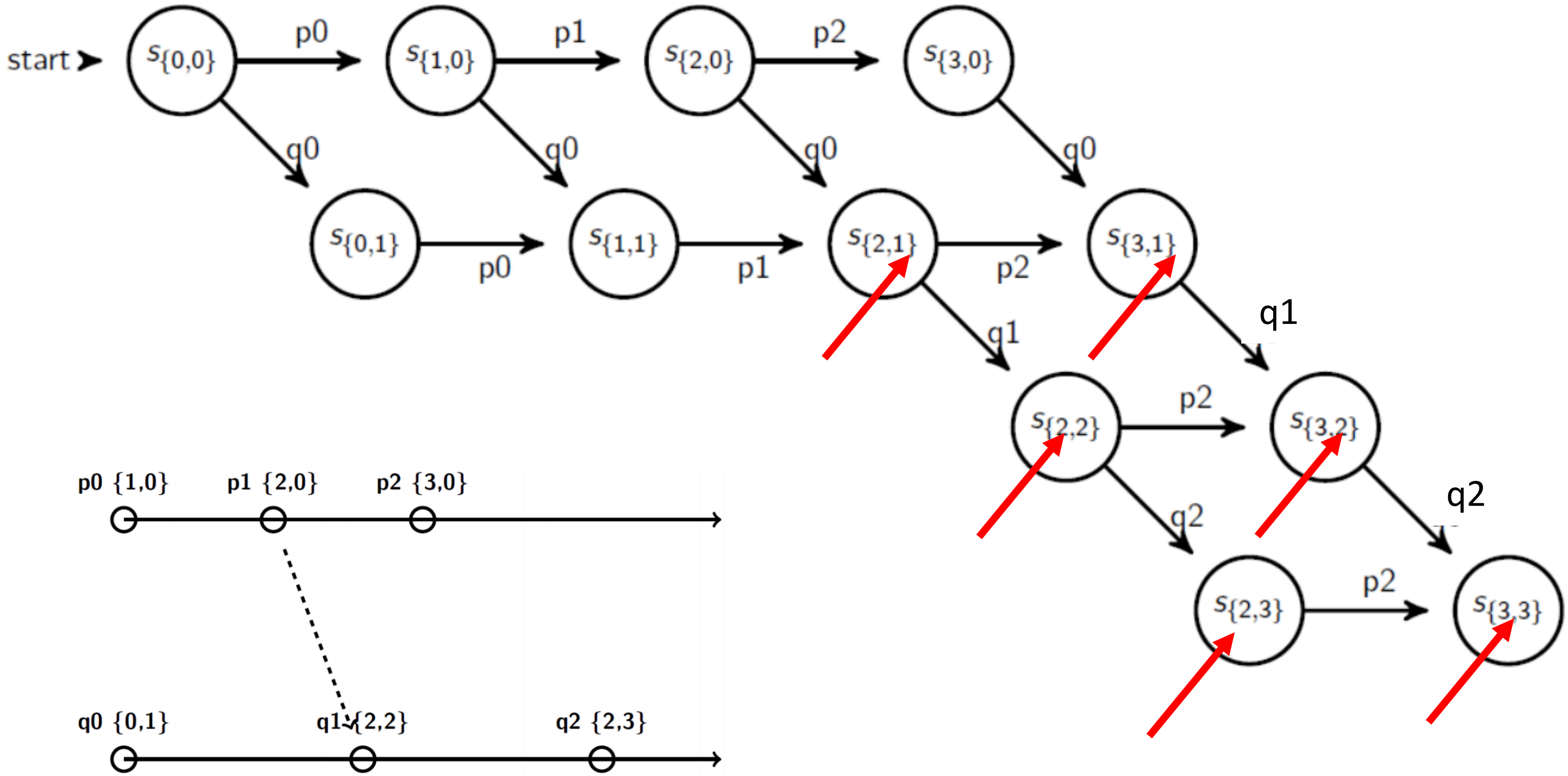

Stable Global Predicates

- once true for a state S, stays true for all states reachable from S (for stable liveness)
- once false for a state S, stays false for all states reachable from S (for stable non-safety)
- Stable liveness examples (once true, always true)
  - Computation has terminated.
- Stable non-safety examples (once false, always false)
  - There is no deadlock.
  - An object is not orphaned.
- *All stable global properties can be detected using the Chandy-Lamport algorithm.*

Global Snapshot Summary

- The ability to calculate global snapshots in a distributed system is very important.
- But don't want to interrupt running distributed application.
- Chandy-Lamport algorithm calculates global snapshot.
- Obeys causality (creates a consistent cut).
- Can be used to detect global properties.
- Safety vs. Liveness.

Rest of today's agenda

- **Multicast**
  - Chapter 15.4

- **Goal:** reason about desirable properties for message delivery among a group of processes.

Communication modes

- **Unicast**
  - Messages are sent from exactly one process to one process.
- **Broadcast**
  - Messages are sent from exactly one process to all processes on the network.
- **Multicast**
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any one process to a group of processes on the network.

Where is multicast used?

- Distributed storage
  - Write to an object are multicast across replica servers.
  - Membership information (e.g., heartbeats) is multicast across all servers in cluster.
- Online scoreboards (ESPN, French Open, FIFA World Cup)
  - Multicast to group of clients interested in the scores.
- Stock Exchanges
  - Group is the set of broker computers.
- ……

Communication modes

- **Unicast**
  - Messages are sent from exactly one process to one process.
    - *Best effort:* if a message is delivered it would be intact; no reliability guarantees.
    - *Reliable:* guarantees delivery of messages.
    - *In order:* messages will be delivered in the same order that they are sent.
- **Broadcast**
  - Messages are sent from exactly one process to all processes on the network.
- **Multicast**
  - Messages broadcast within a group of processes.
  - A multicast message is sent from any one process to the group of processes on the network.
  - *How do we define (and achieve) reliable or ordered multicast? (next class)*