KTH ROYAL INSTITUTE
OF TECHNOLOGY

Global state

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Global state

Time is very much related to the notion of a ***global state***.

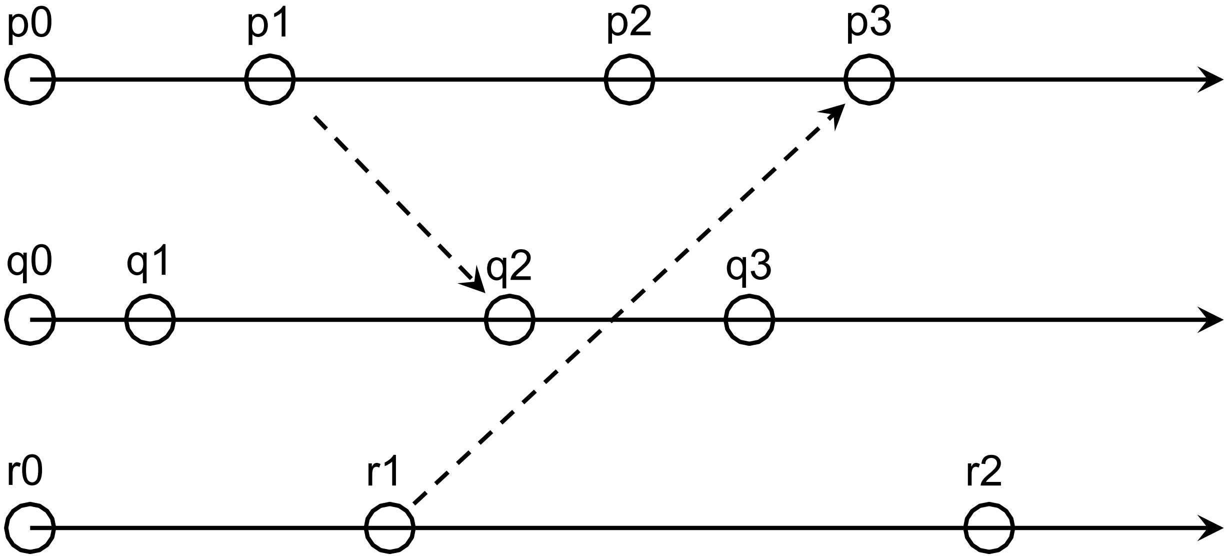
If we cannot agree on a time, how should we agree on a global state?

The global state is important:

- Garbage collection
- Deadlock detection
- Termination
- Debugging

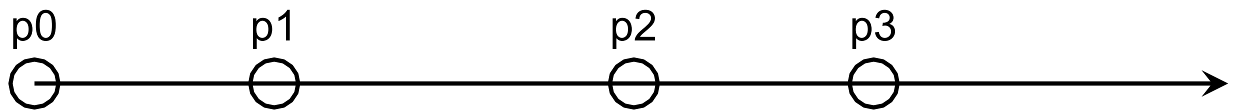
Global state

Given a partial order of events, can we say anything about the state of the system?



Local history and Local state

The ***history*** of a process is a sequence of events: <p0, p1, ..pn>



The ***state*** of a process is ***a description of the process*** after (before) an event.

- A state corresponds to a ***finite prefix of the process's history.***

Global history and Global state

What is the ***global history*** of concurrent distributed processes?

- The union of individual histories of all processes?
- Do all unions make sense?

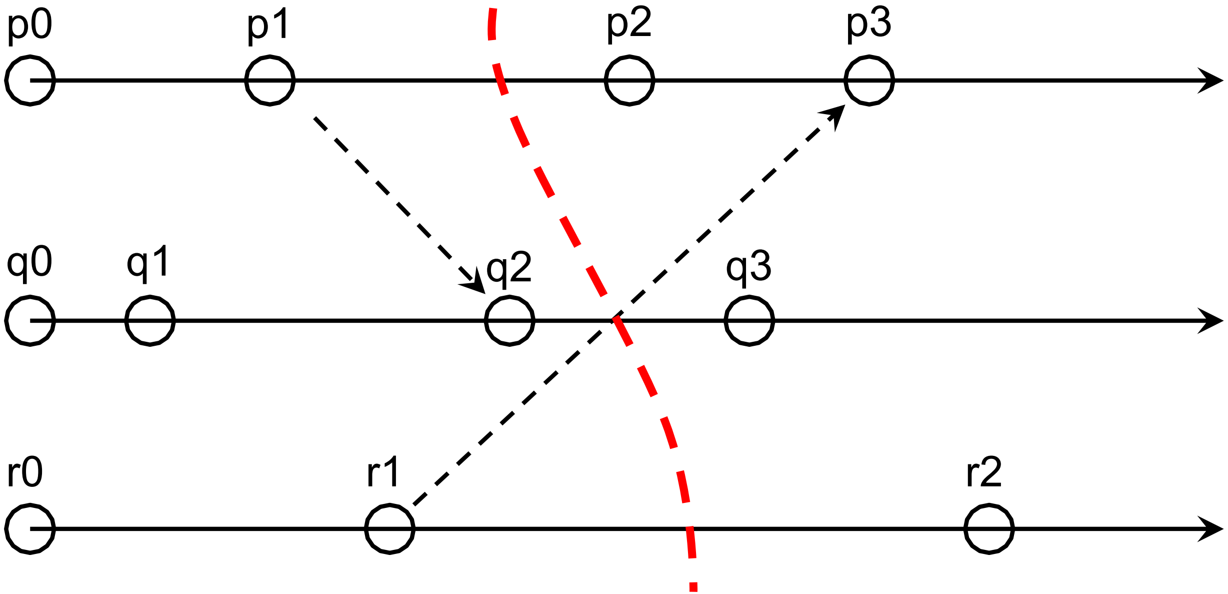
What is the ***global state*** of a distributed system?

- The union of states of individual processes?

A ***global state*** corresponds to the initial prefixes of the individual process histories.

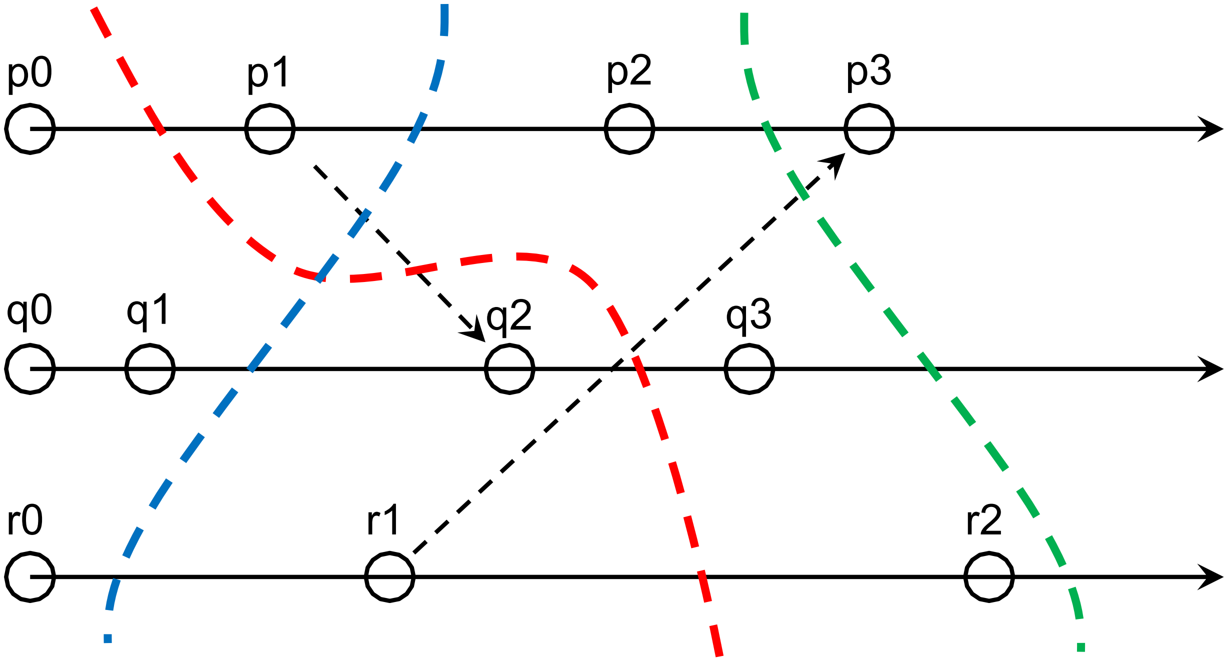
Global history and Cut

A ***cut*** is a subset in the global history up to a specific event in each history.

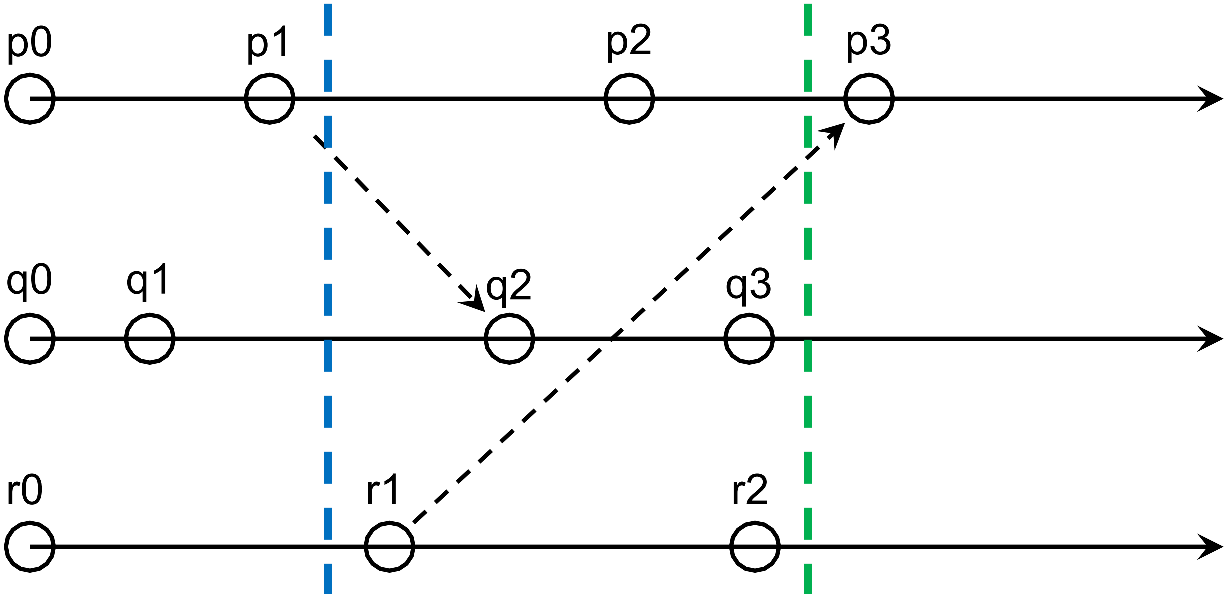


An event is in the *cut* if it belongs to the events of history up to the specific event.

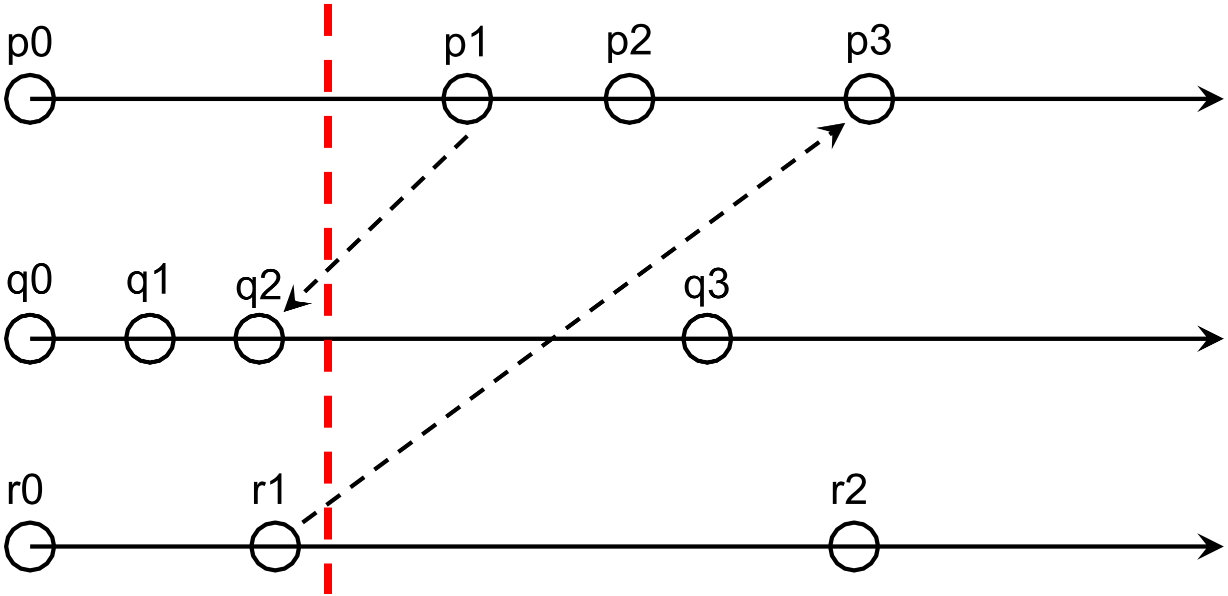
All cuts are equal, but ...



..some are more equal ..



.. than others

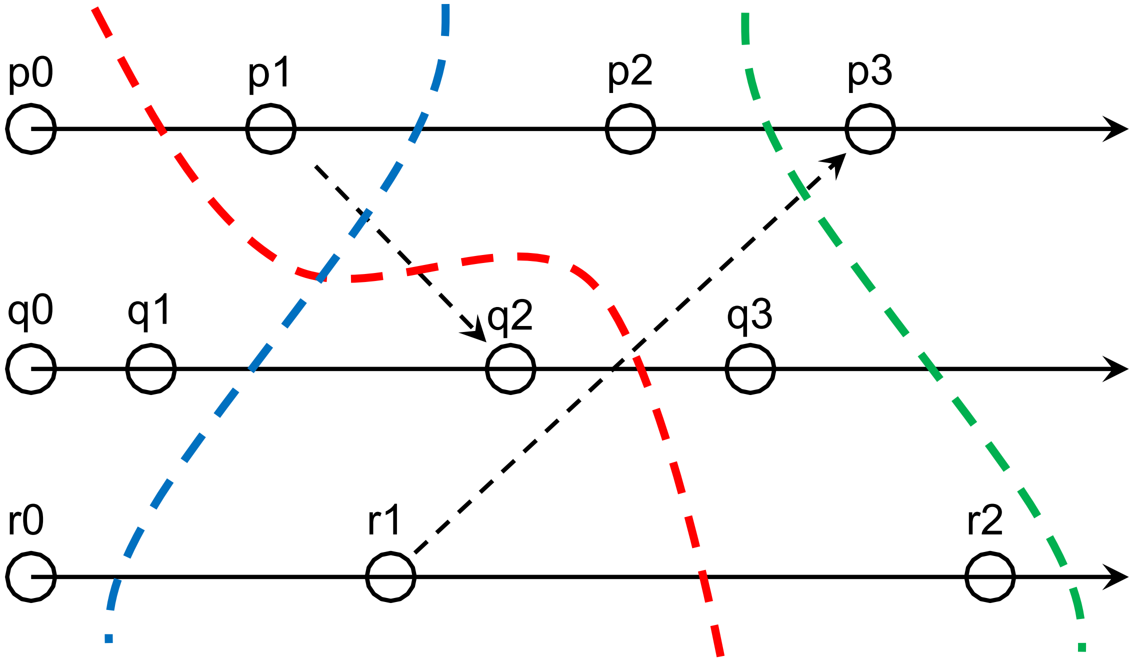


Consistent cuts

For each event *e* in the cut:

- if *f* happened before *e* then
- *f* is also in the cut.

- In other words, **a cut C is consistent if, for each event it contains, it also contains all the events that happened before that event.**

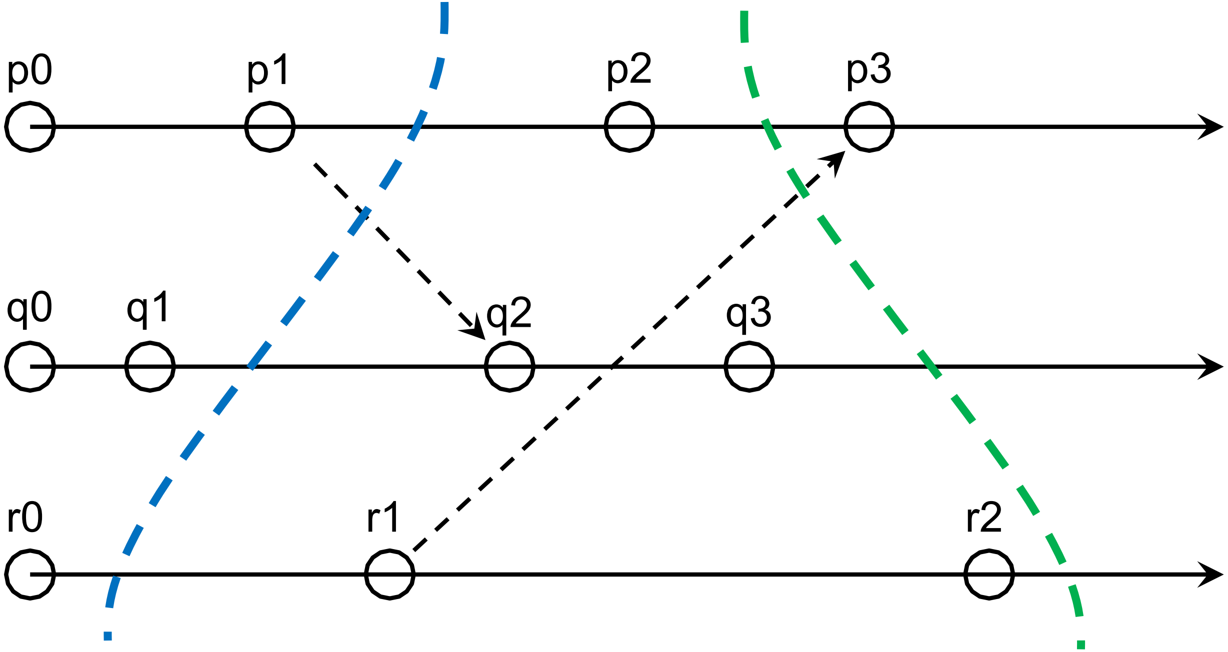


Consistent global state

A ***consistent cut*** corresponds to a ***consistent global state***.

- It is a ***possible state*** without contradictions
- it is ***consistent with*** the ***actual execution***
- the actual execution might not have passed through the state, even though it's consistent

Consistent, but not actual states

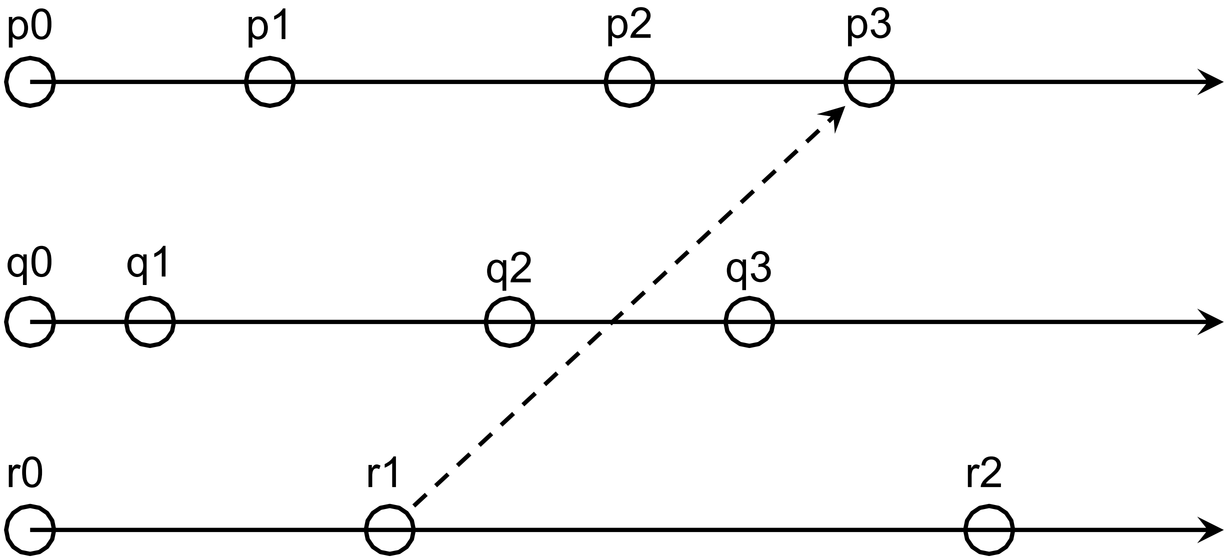


All *real-time cuts* are *consistent*, but who knows the real time?

Linearization

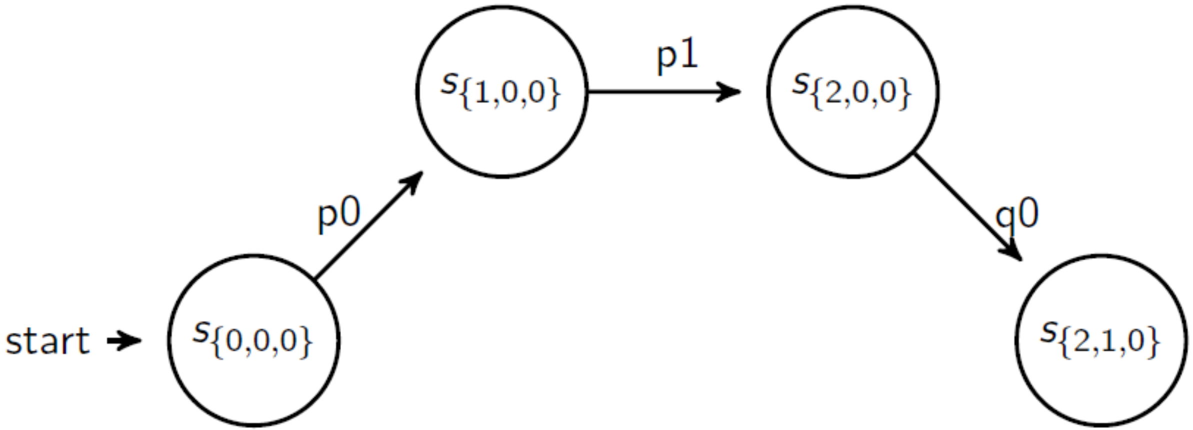
- A ***run*** is a total ordering of all events in a global history ***consistent with each local history***.
- A ***linearization*** or ***consistent run*** is a run that describes transitions between ***consistent global states***.
- A state *S*' is ***reachable*** from state *S* if there is a ***linearization*** from *S* to *S*'.

Linearization



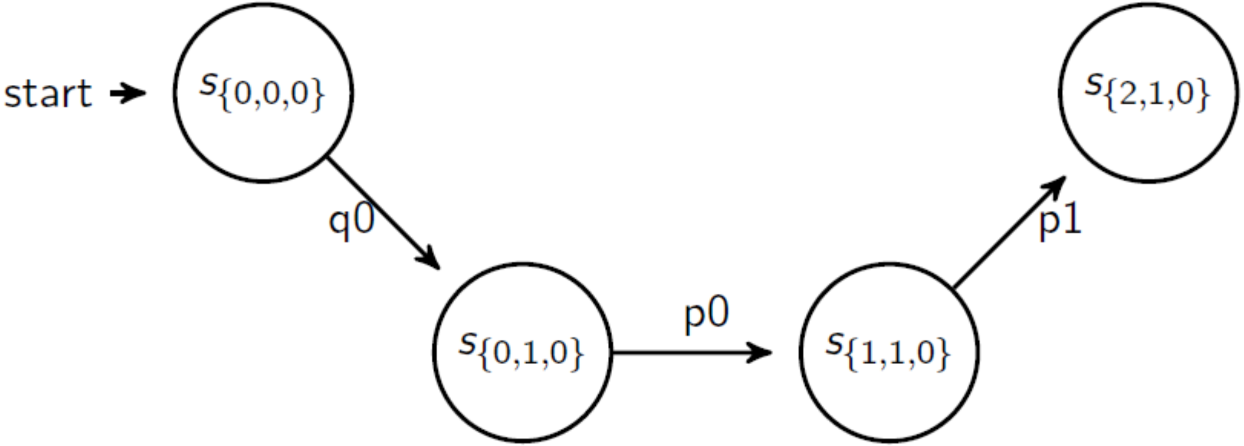
Possible state transitions

[p0, p1, q0, r0, q1, r1, p2, p3, q2, r2, q3]

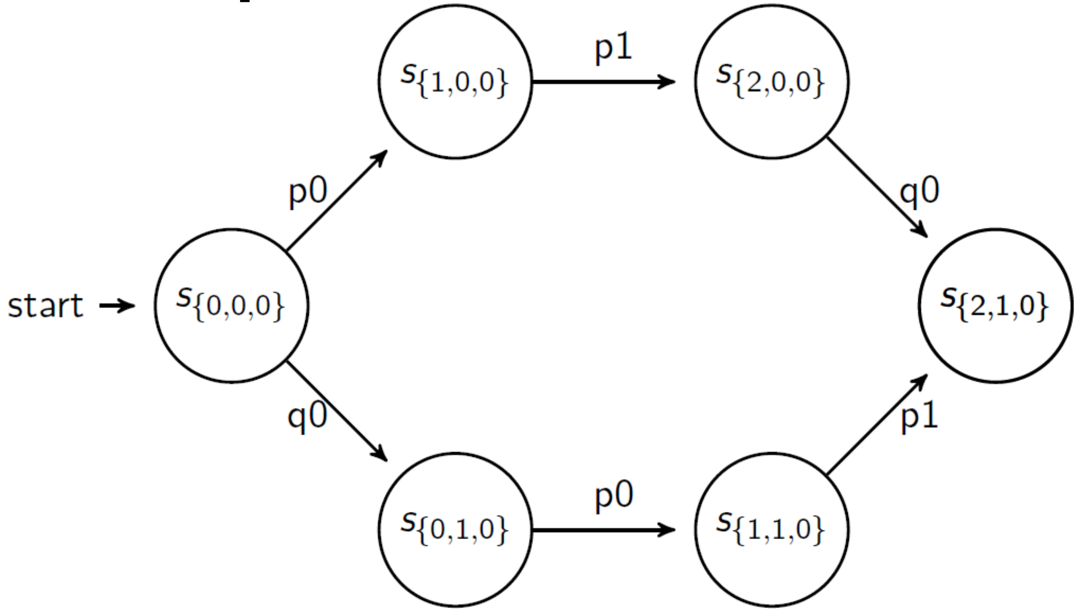


Possible state transitions

[q0, p0, p1, r0, q1, r1, p2, p3, q2, r2, q3]



Possible paths



Each path is a consistent run, a linearization, one of which the execution actually took.

Why is this important?

- If we can collect all events and know the happened before order, then we can construct all possible linearizations.
- We know that the actual execution took one of these paths.
- Can we say something about the execution even though we do not know which path was taken?
  - **Yes, we can reason about some property of all the executions, e.g., absence of deadlock, that can be described as a predicate.**

Global state predicate

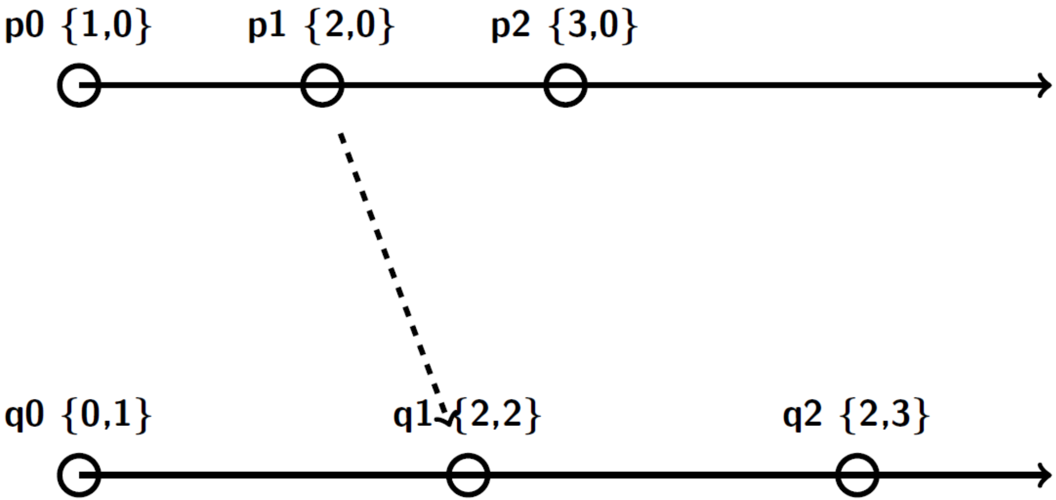
A global state predicate is a property that is true or false for a global state.

- ***Safety*** - a predicate is never (or always) true in any state.
- ***Liveness*** - a predicate that eventually evaluates to true.

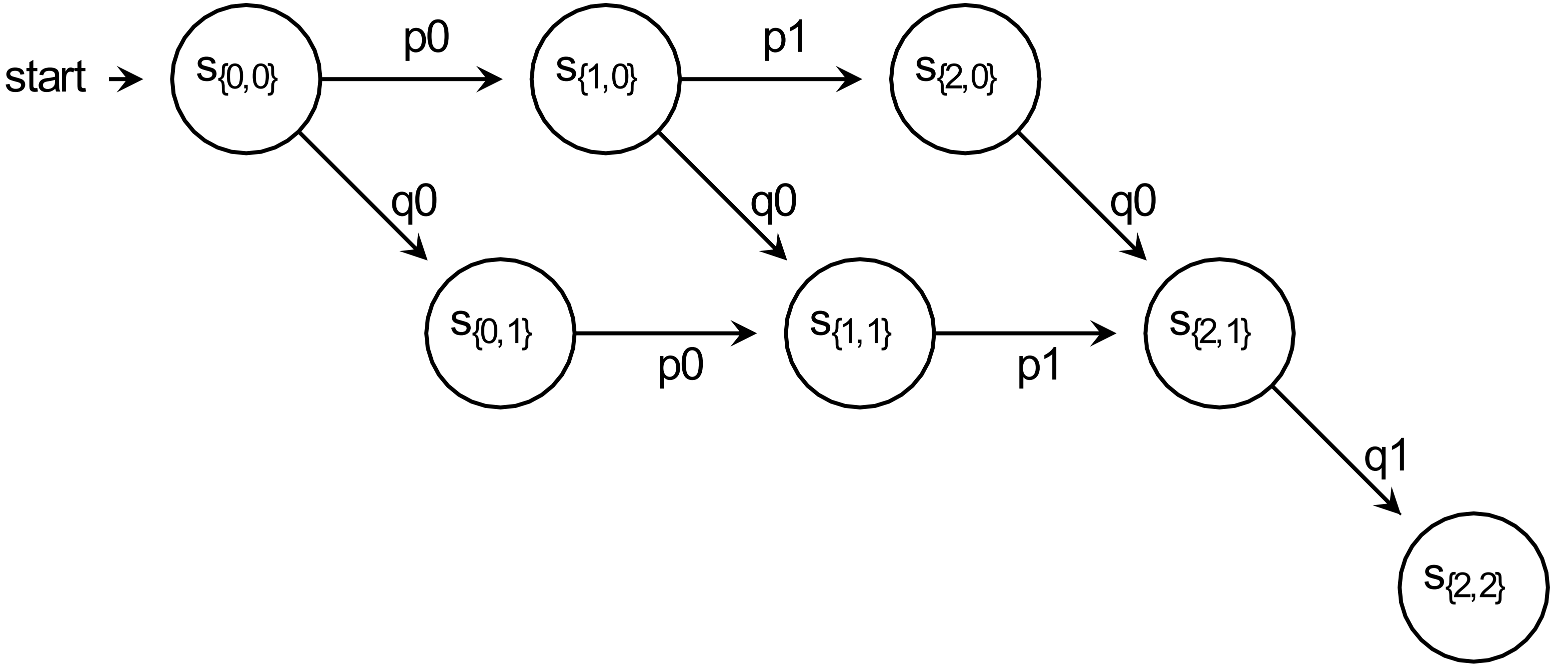
How do we determine if a property holds in an execution?

Let’s capture all linearizations

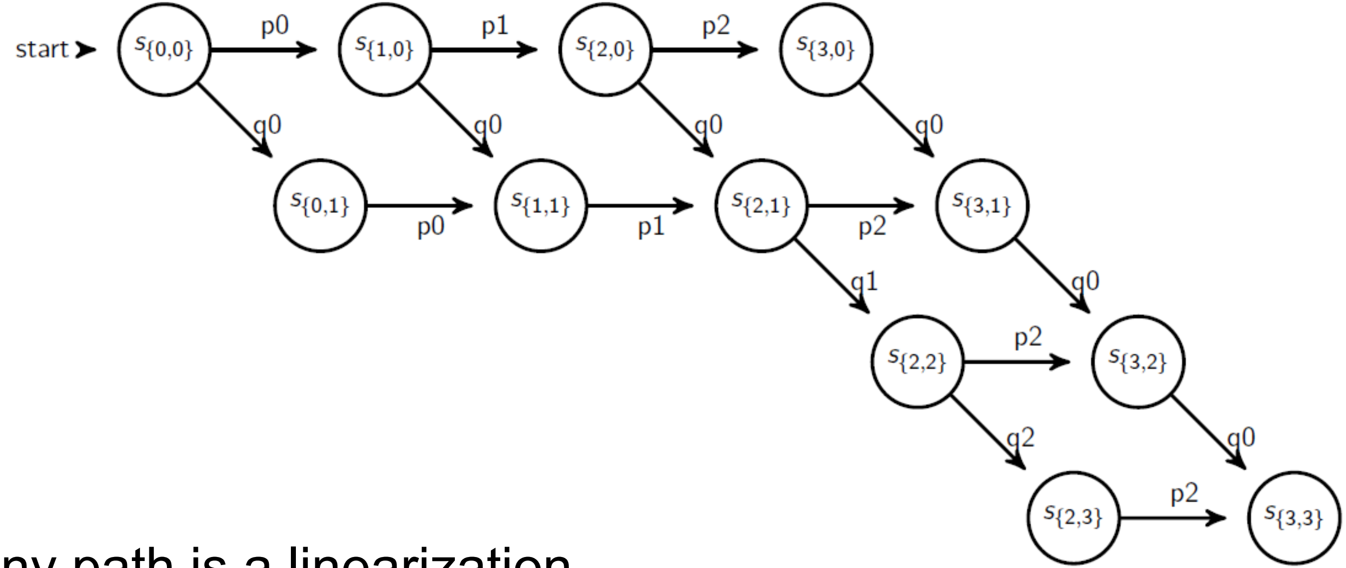
Idea - use vector clocks, and collect all events of the execution.



Construct all linearizations



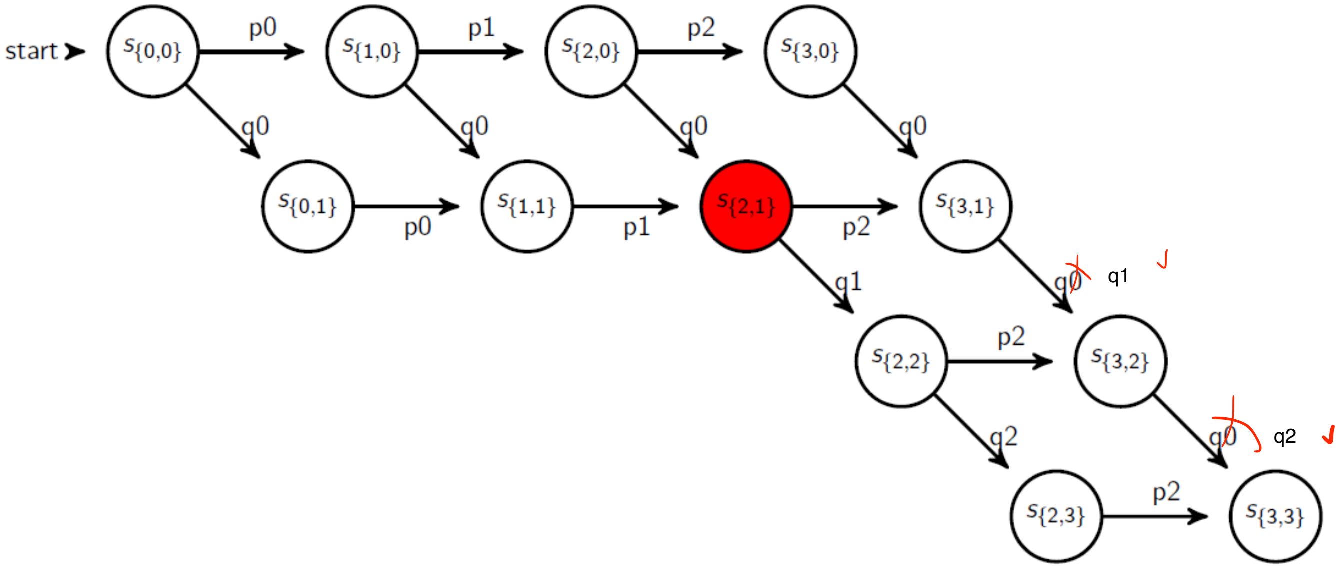
An execution lattice



Any path is a linearization.

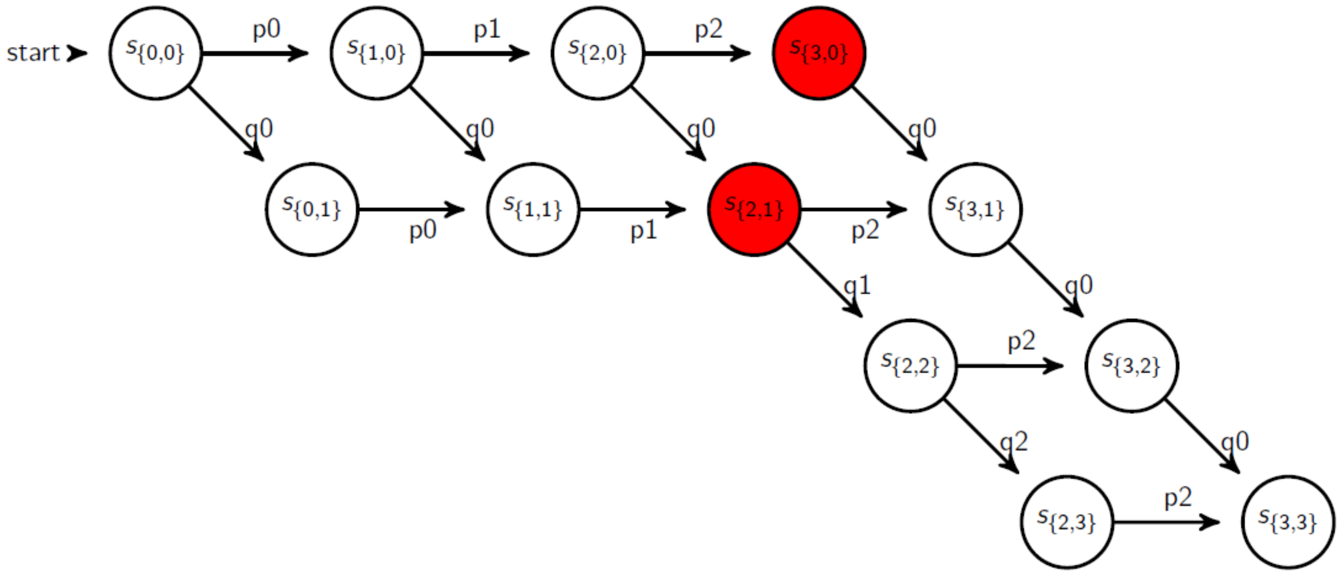
The actual execution took one path.

Possibly true



If a predicate is true in a consistent global state of the lattice, it is *possibly true* in the execution.

Definitely true



If we cannot find a path from the initial state to the final state without reaching a state for which a predicate is true, then the predicate is *definitely true* during the execution.

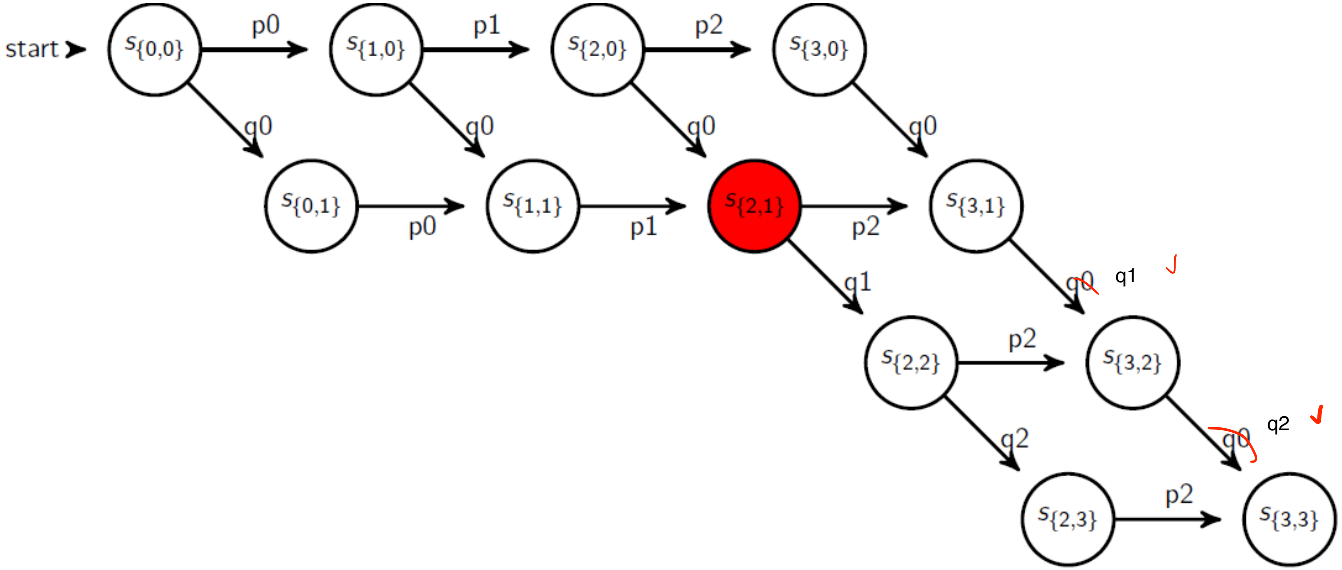
Stable and non-stable

We differentiate between:

- ***Stable***: if a predicate is true, it remains true for all reachable states
- ***Non-stable***: if a predicate can become true and then later become false

Stable is good

What do I know if a stable predicate is true for state $S_{\{2,1\}}$?



Let’s capture a possible state

Idea: capture a consistent global state that was possibly true in the execution.

If a stable predicate is true for this state, it is true in the actual execution.

How do we capture a state?

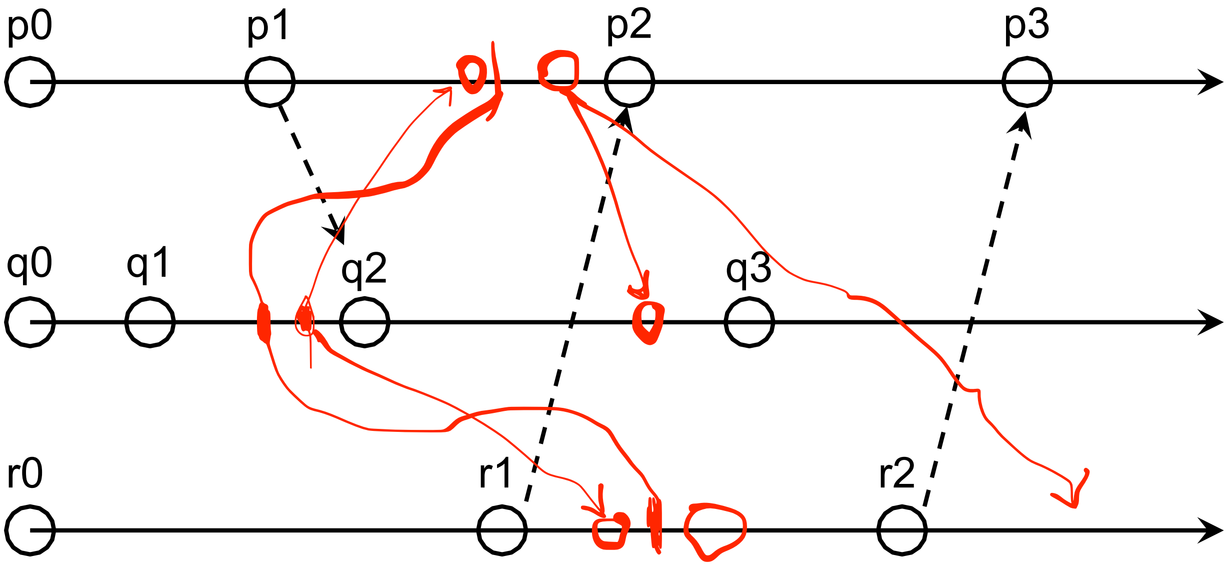
Snapshot - Chandy and Lamport

A node initiates a snapshot when it receives a *marker*.

- Record the local state and
- send a *marker* on all outgoing channels.
- Record all incoming messages on each channel…
- until you receive a marker.
- When the last channel is closed, you have a local and a set of messages.

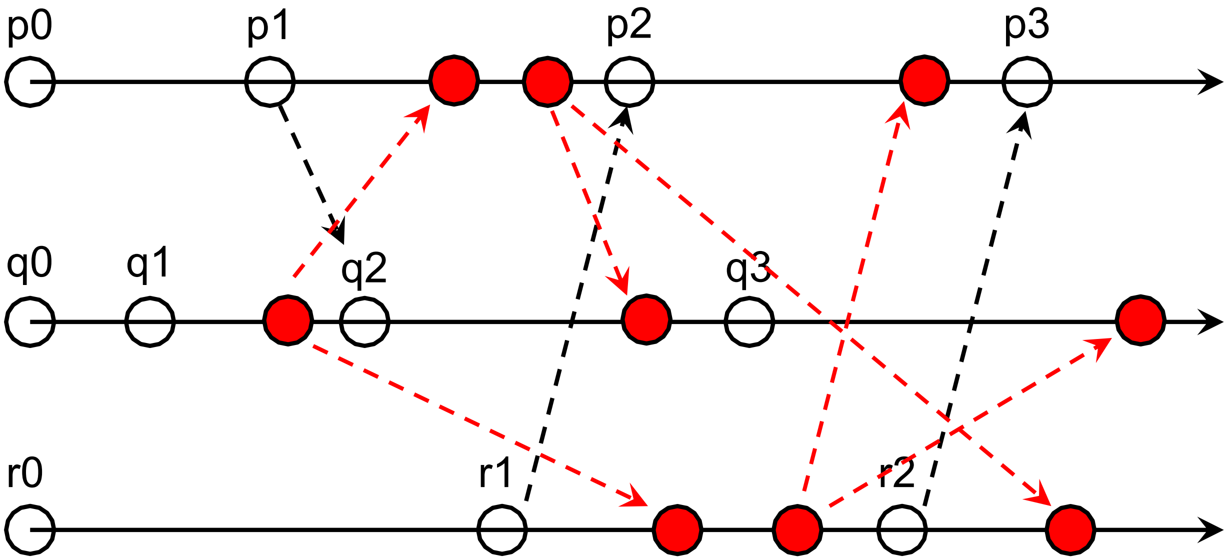
Ask one node to initiate the snapshot, collect all local states and messages and construct a global state.

Snapshot markers



What messages are collected by which node?

Snapshot markers



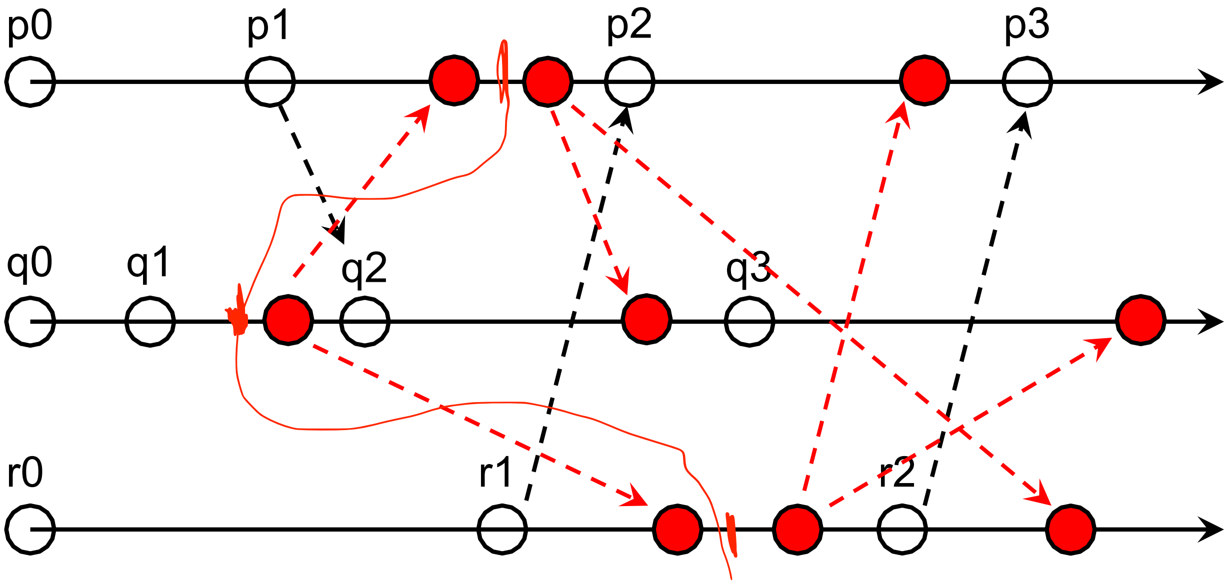
What messages are collected by which node?

What messages are collected by which node?

P: records its state after p1;
channel Q-P: empty;
channel R-P: message r1

Q: records its state after q1;
channel P-Q: message p1;
channel R-Q: empty

R: records its state after r1;
P-R: empty;
Q-R: empty



Snapshot

- Allows us to collect a global state during execution.
- It only allows us to determine stable predicates.

Summary

The happened before order gives us *consistent cuts or consistent global states*.

Using vector clocks, we can time stamp states, *construct all possible linearizations* and evaluate if predicates hold true in the execution.

A snapshot can record a consistent state that can be used to evaluate ***stable predicates***.