An Automata Based Approach for Synchronizable Mailbox Communication

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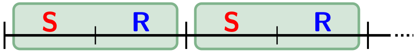
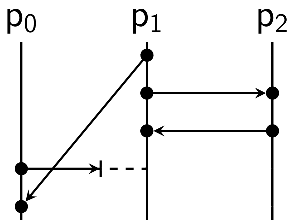
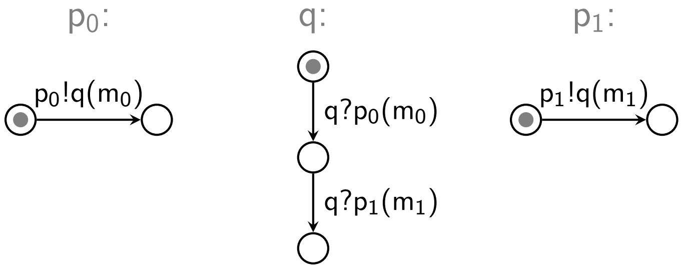




Mailbox semantics



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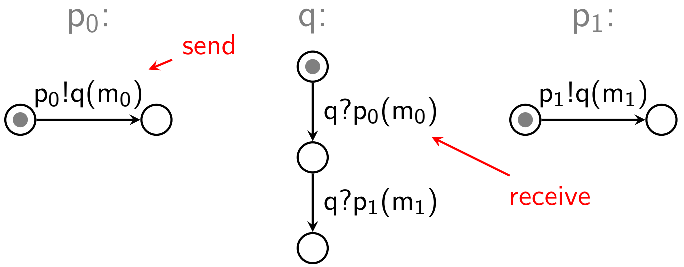

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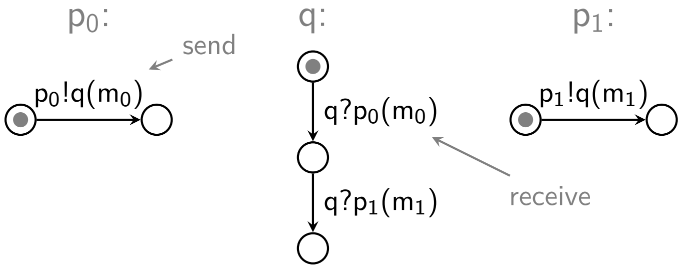

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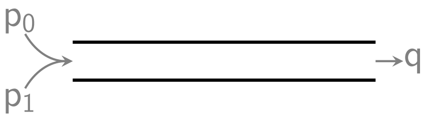

One *FIFO* channel per process.

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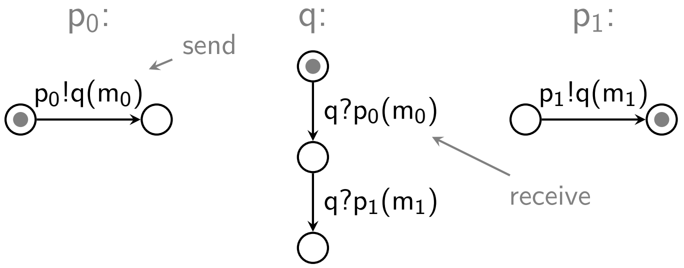

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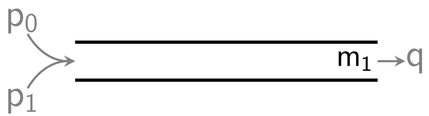

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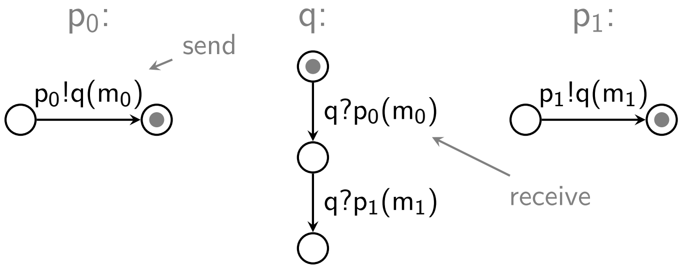

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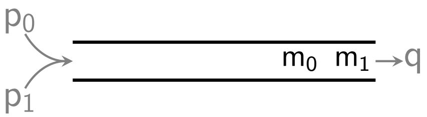

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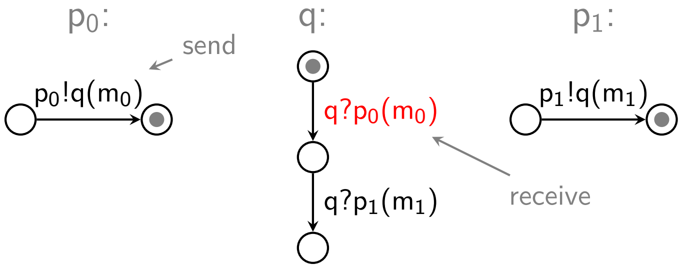

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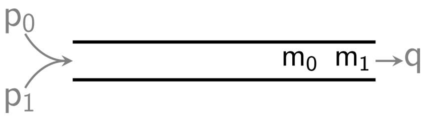

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Mailbox executions

Executions that are possible for peer-to-peer communication may not be possible for mailbox.

Restriction

State reachability is **undecidable** [Brand-Zafiropulo 1983]:

Requires restrictions.

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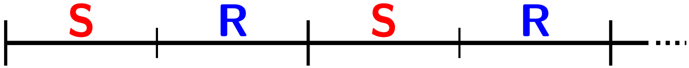
Exchange: Sequence of actions with all sends before receives.

Usual for round-based systems (distributed algorithms)



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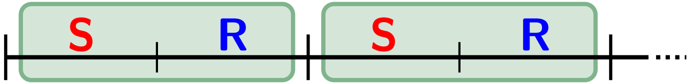
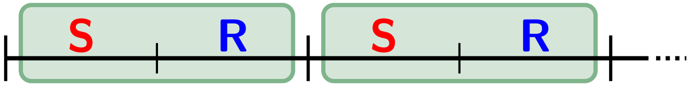


Synchronizability

A CFM is synchronizable if every execution can be reordered into a sequence of exchanges (**no message split**).

Synchronizability



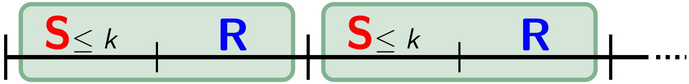
Synchronizability $\implies$ State reachability decidable?

Synchronizability decidable?

k-synchronizability

k-**exchanges** [Bouajjani et al. 2018]: Exchanges with at most *k* sends.

A CFM is *k*-**synchronizable** if every execution can be reordered into a sequence of *k*-exchanges (no message split).



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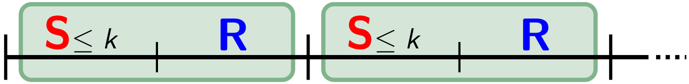

Prev. results [Bouajjani et al. 2018,Di Giusto et al. 2020/2021]

- Reachability is decidable under k-synchronizability (PSPACE).
- For fixed k, "is the CFM k-synchronizable?" is PSPACE.
- "Is there some k such that the CFM is k-synchronizable?" is decidable (no complexity).

Warning: Slightly different definition for synchronizability.

Reachability

Exchange normal form

In mailbox semantics, every exchange is equivalent to the sequence where receives are **in the same order** as the sends.

- $\mathsf{p!q_0(m_0)}\,\mathsf{p!q_1(m_1)}$
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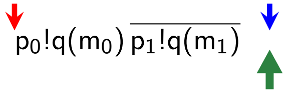

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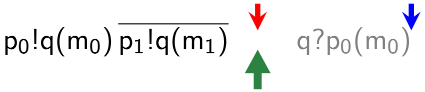
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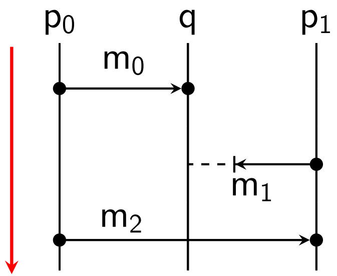
Mailbox MSC

Message Sequence Charts (MSC)

Partial-order representation of executions:
process order + message arcs .
Two executions are **equivalent** if they have the same MSC.



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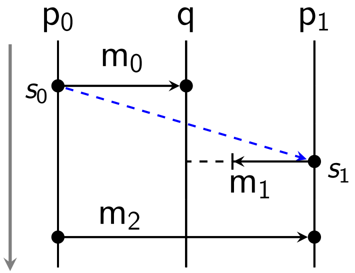

Two sends to the same process, s_0 and s_1, are *mailbox-ordered* if:

- s_0 is matched (with r_0)
- s_1 is unmatched, or is matched with r_1 and $r_0 < r_1$

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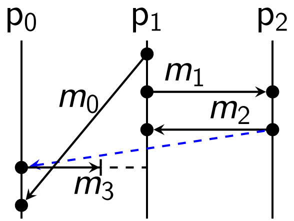

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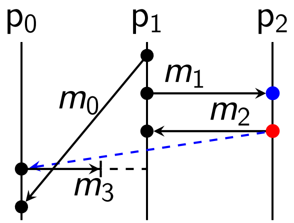

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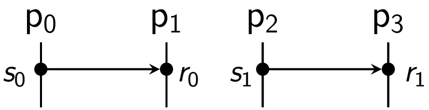

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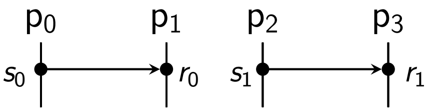

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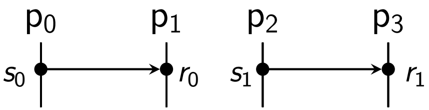
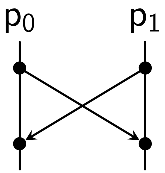
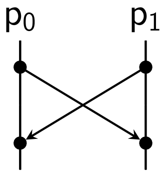


- *concurrent* messages **atomic**



Atomicity: A graphical approach



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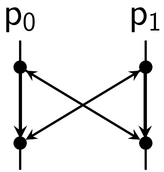

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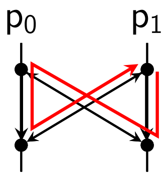

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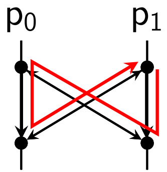

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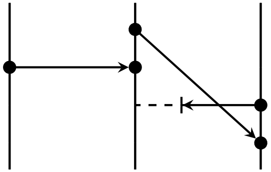

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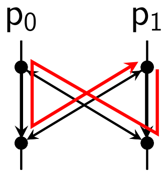

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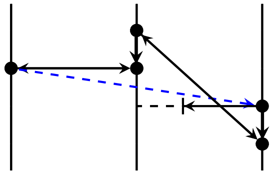

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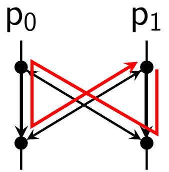

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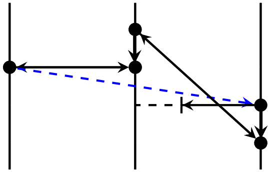


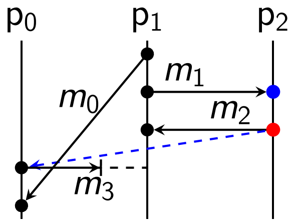
Atomicity of exchanges

The language of *marked send sequences* of atomic exchanges is **regular** (exp-size automaton built *on-the-fly*, PSPACE).

Checking synchronizability

What does not synchronizable mean?

Execution that cannot be reordered into a sequence of exchanges:



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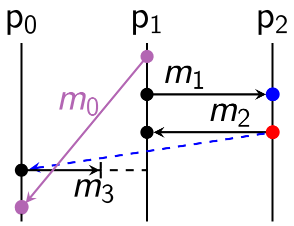

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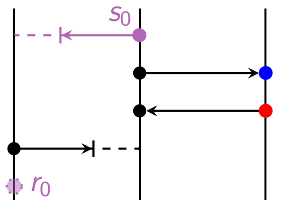
Removing last action makes it synchronizable!



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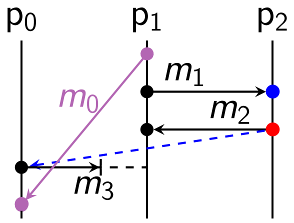

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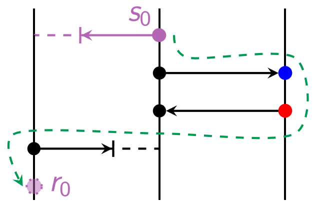
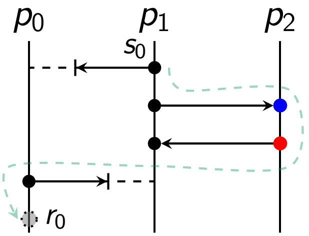


Need to check a path going from *first send action* s_0 through a receive then a send and ending before the future receive r_0

Path between exchanges



Need a way to connect path between *atomic* exchanges

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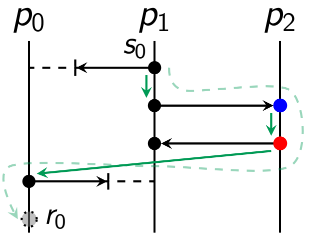

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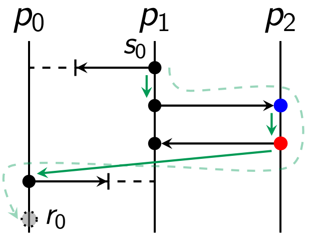

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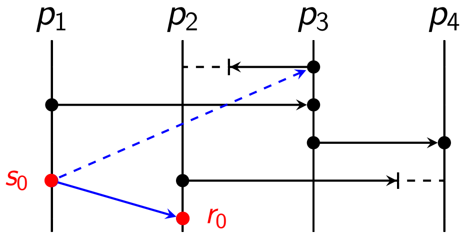

Not always first send that gets "unmatched" from last action.

Need to check for validity while guessing the sequence of exchanges. . .

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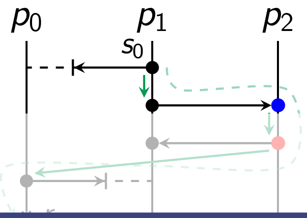

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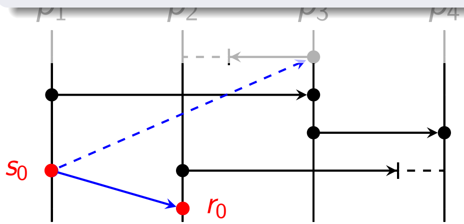
Synchronizability

Checking if a given CFM is synchronizable for mailbox semantics is PSPACE-complete



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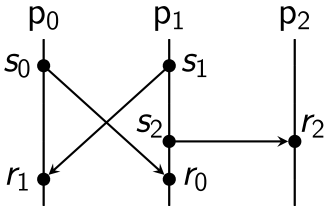

Harder than it seems.

$s_0\ s_1\ r_1\ s_2\ r_2\ r_0$

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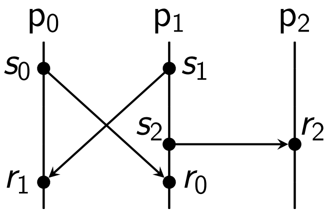

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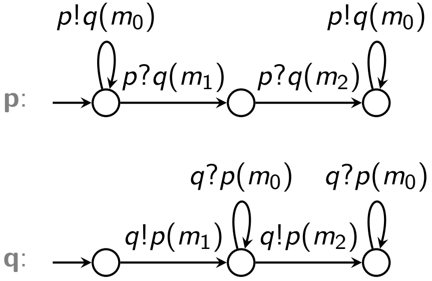

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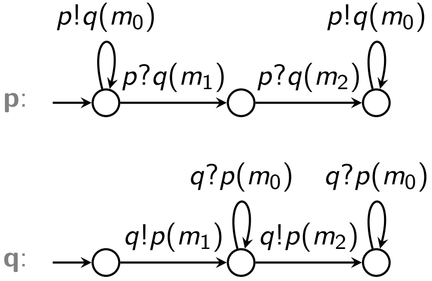

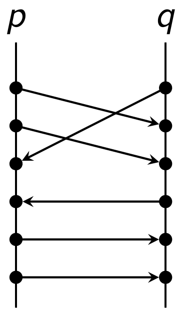

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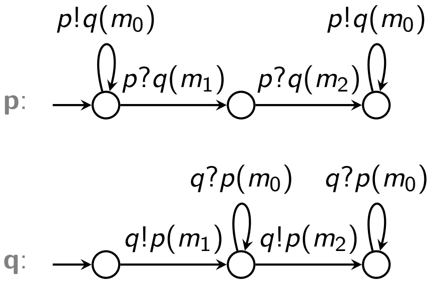

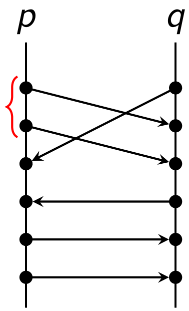

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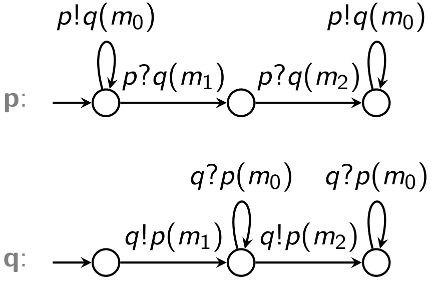

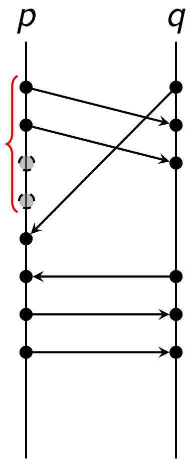

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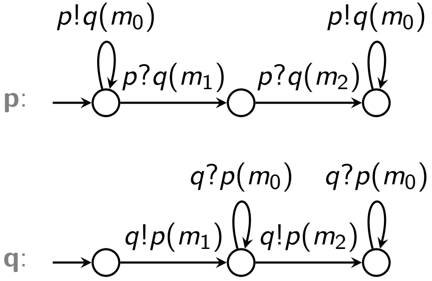
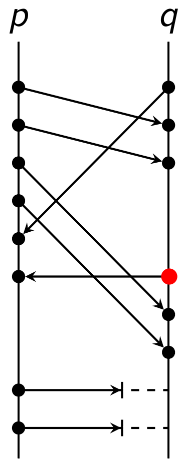
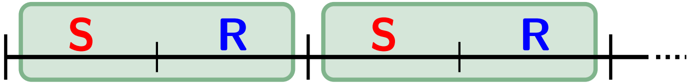




Conclusion



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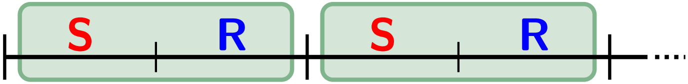

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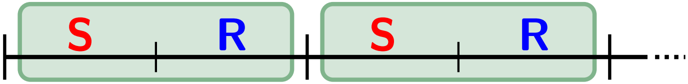

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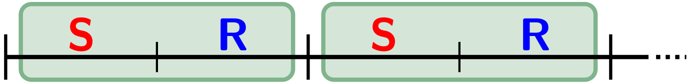

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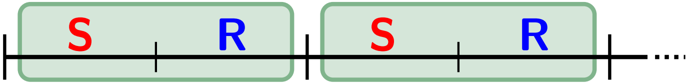

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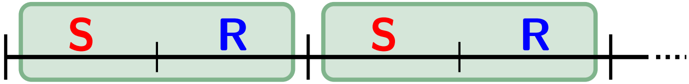

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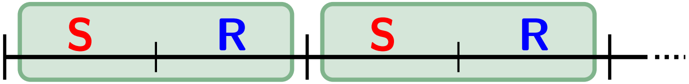

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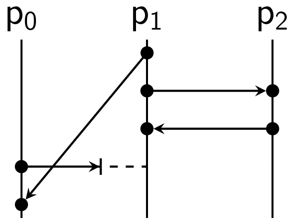
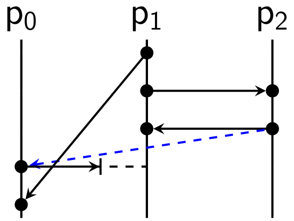
THANK YOU

Difference of synchronizability

Weak-Synchronizability [Di Giusto et. al. 2020]



Synchronizability [Delpy et. al. 2024]



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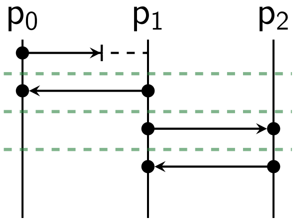

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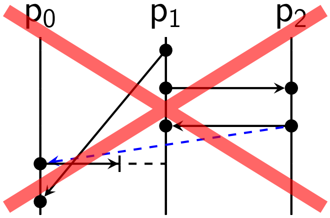

Not synchronizable

Atomicity: Automata check

Need a bounded technique: **Path labelling:** Ordered list of elements in the *marked sends* sequence displaying a path.

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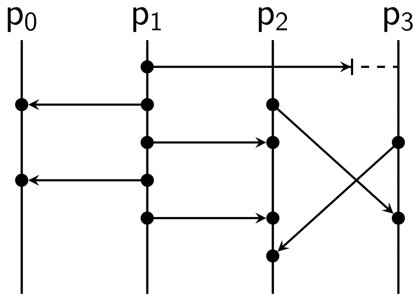

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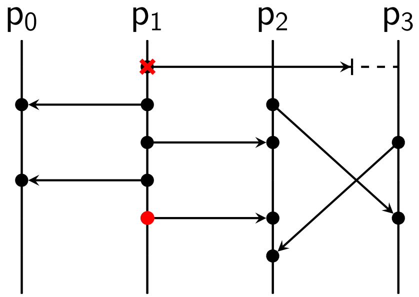

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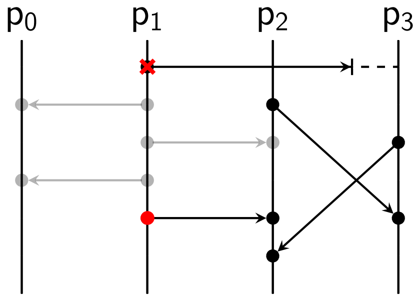

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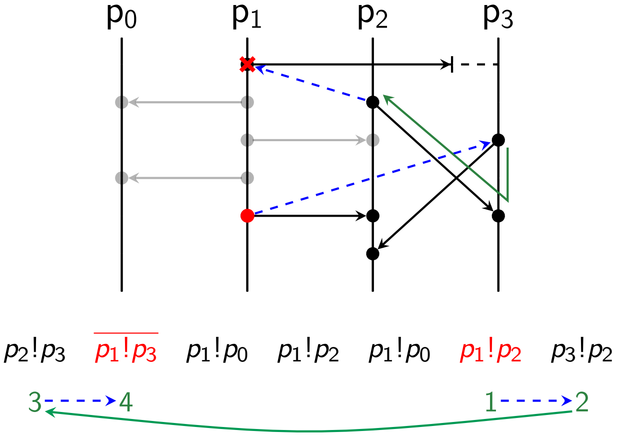

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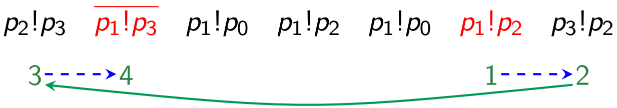

Exists path labelling of **linear** size in the number of processes if path in augmented msc.

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$$\begin{tikzcd}
p_2!p_3 & \overline{p_1!p_3} & p_1!p_0 & p_1!p_2 & p_1!p_0 & p_1!p_2 & p_3!p_2 \\
3 \arrow[r, dashed] & 4 & & & & 1 \arrow[r, dashed] & 2 \arrow[llllll, bend left]
\end{tikzcd}$$

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A sequence is atomic *iff*

- For each active process, a path from its last action to its first.
- A cycle contains all active processes.

Atomicity of exchanges

The language of marked sends sequences equivalent to atomic exchanges is **regular** (EXPSPACE automaton that can be build *on the fly*).