Distribution of Reconfiguration Languages maintaining Tree-like Communication Topology

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Synthesis for distributed systems

Synthesis Problem

Input: A specification φ
Output: A program P satisfying φ

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- Great if possible, but very hard.

Synthesis for distributed systems

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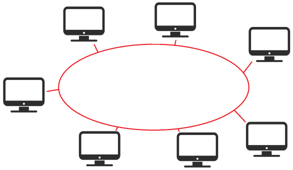
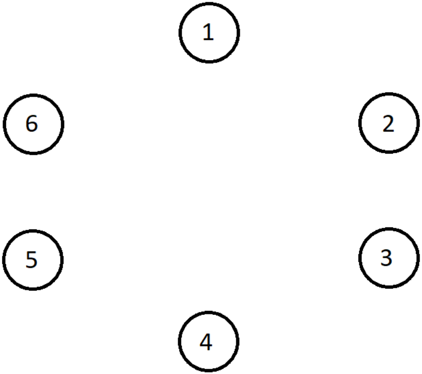
- Great if possible, but very hard.
- Distributed systems makes it even harder!
- Specifications are centralized, programs are distributed.



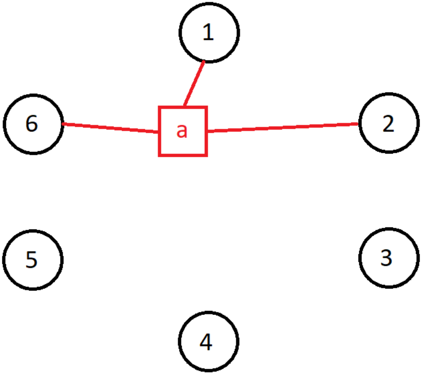
Distributed setting

Independent processes



Distributed setting

Independent processes communicating over channels



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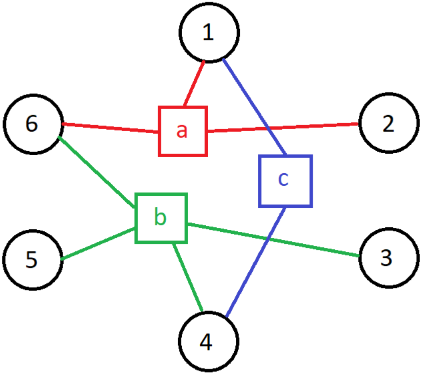

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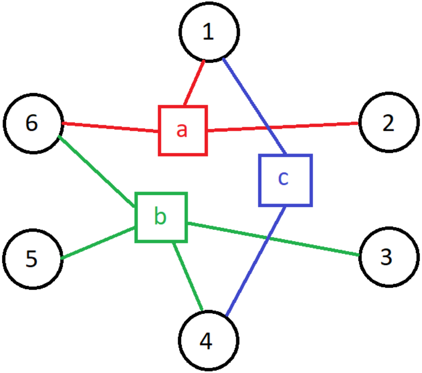

Some assumptions

- Asynchronous system
- Rendez-vous communication
- No sender/receiver distinction

Automaton model for distributed systems

Zielonka's Asynchronous Automata (AA)

Fix set of processes, channels, and communication topology

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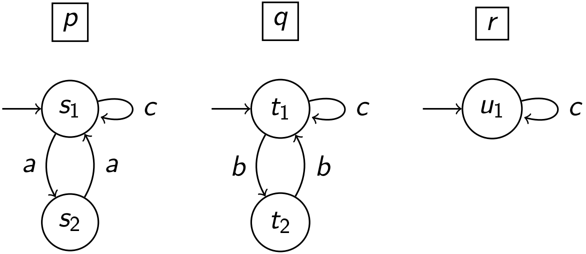

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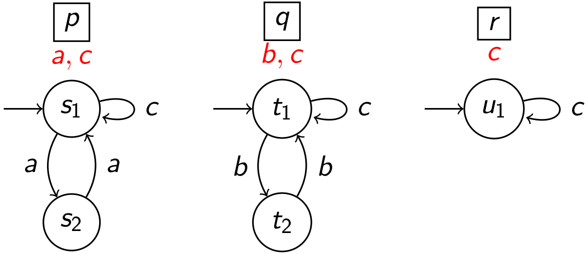

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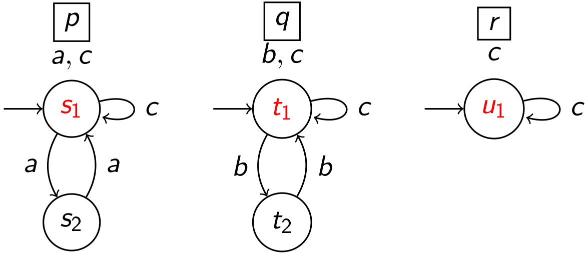

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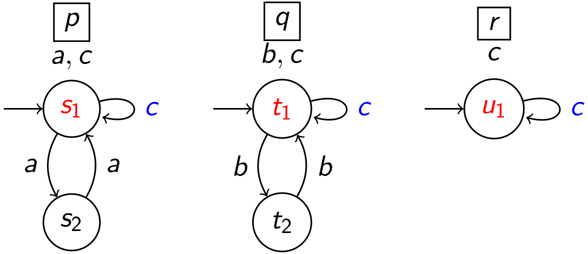

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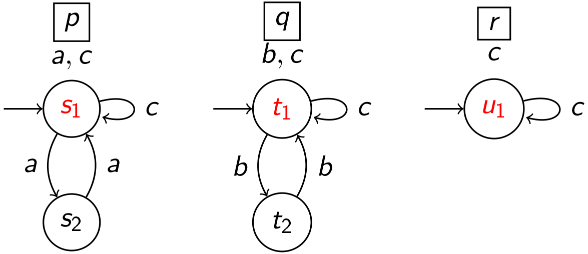

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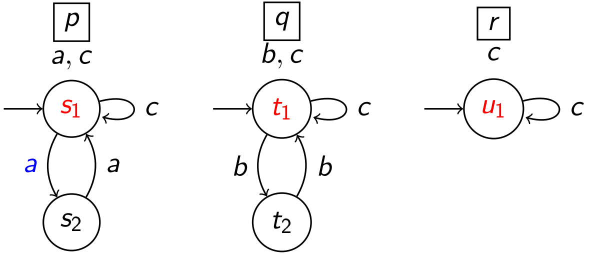

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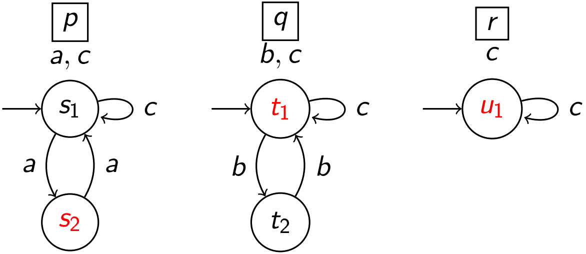

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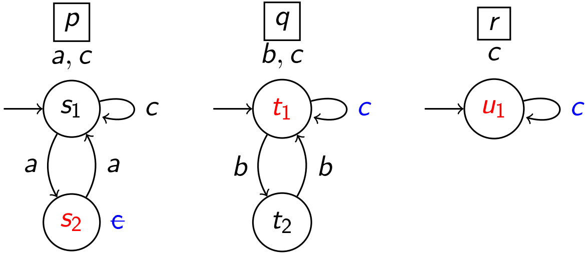

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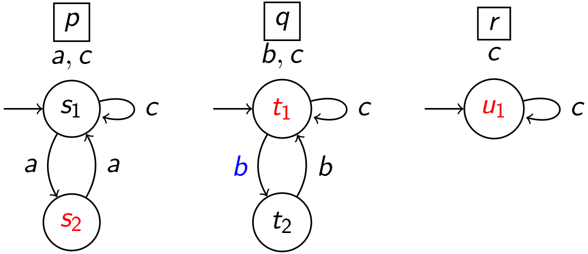

$\rho = (s_1, t_1, u_1) \rightarrow^{c} (s_1, t_1, u_1) \rightarrow^{a} (s_2, t_1, u_1) \rightarrow^{b} \ldots$

$w = cab\ldots$

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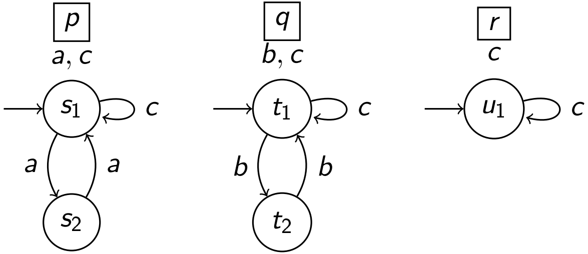

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$w = cab\ldots$ Language: all c preceded by even number of a & b

Zielonka's distributivity theorem

Theorem [Zielonka, 1987]

Given a communication topology and a diamond-closed DFA $\mathcal{A}$, one can build an asynchronous automaton $\mathcal{A}_{||}$ recognizing the same language as $\mathcal{A}$.

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- Complexity: exp. in $|Proc|$, poly. in $|\mathcal{A}|$ [Genest et al., 2010]
- On trees: $O(|\mathcal{A}|^2)$ construction [Krishna & Muscholl, 2013]
(tree = binary channels and acyclic topology)

Reconfiguration

▶ What if processes could change dynamically the channels they listen to? Applications in:

- Swarm protocols (connected based on distance)
- Privacy (need-to-know)
- Energy constraints (turn off communications if not needed)

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Goal of this presentation

▶ Adapt the tree construction to this setting:

- Input language contains instructions for reconfiguration
- Output automaton should implement them only with local information

Reconfigurable automaton model

Reconfigurable Asynchronous Automata (RAA)

Fix set of processes, channels, and ~~communication topology~~

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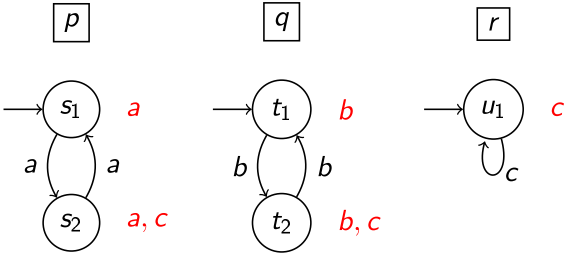

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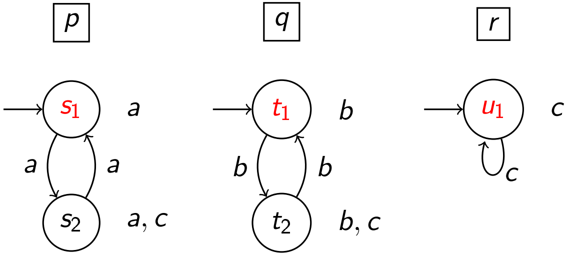

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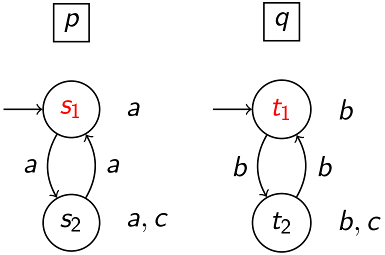

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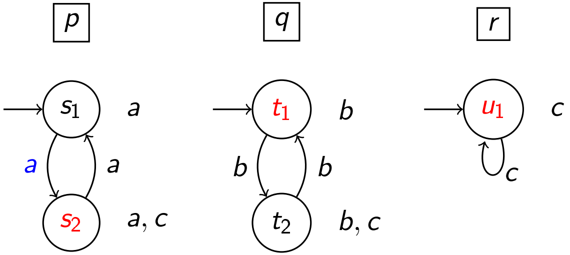

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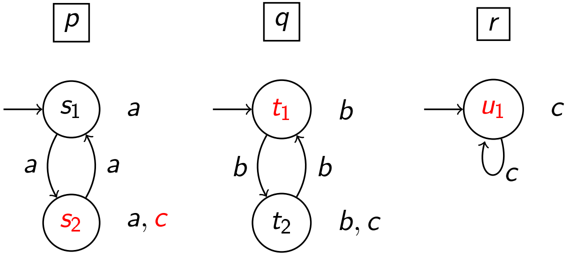

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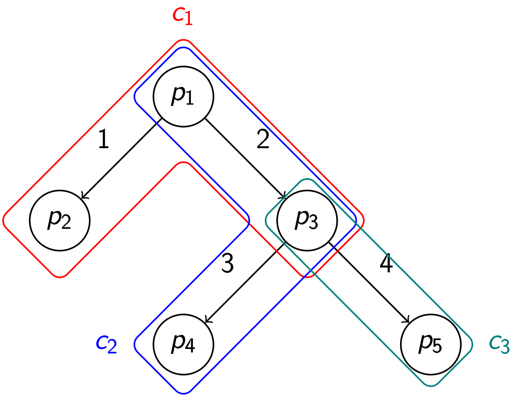
Tree-like Communication Topologies



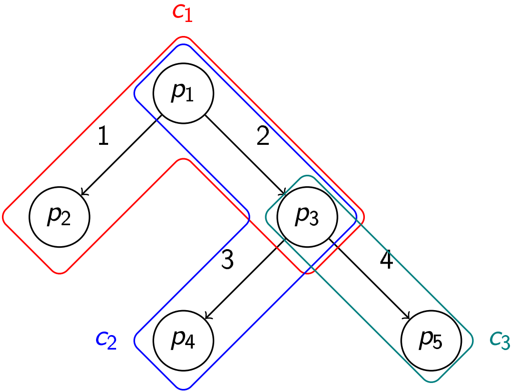
Tree-like:

- Underlying spanning tree
- Channels are connected
- Edges are covered

Reconfiguration Language

Includes reconfiguration operations with each communication:

nop, swap, move, connect, disconnect



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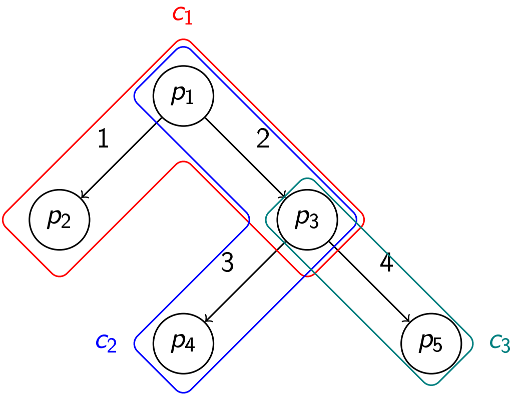
c_1:nop, swap, move, connect, disconnect



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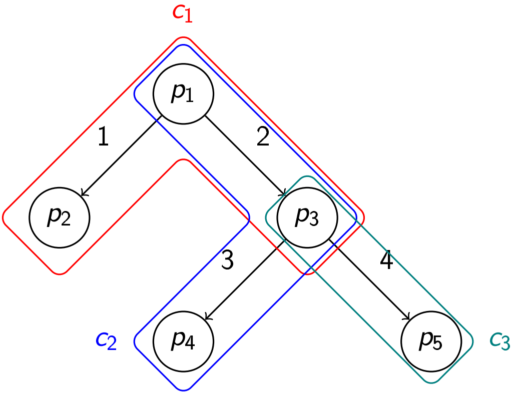
nop, c_2:swap(2), move, connect, disconnect



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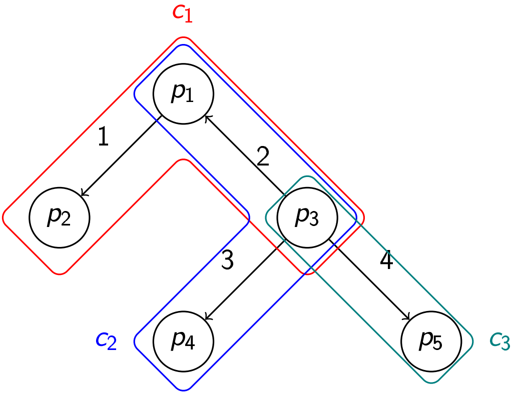

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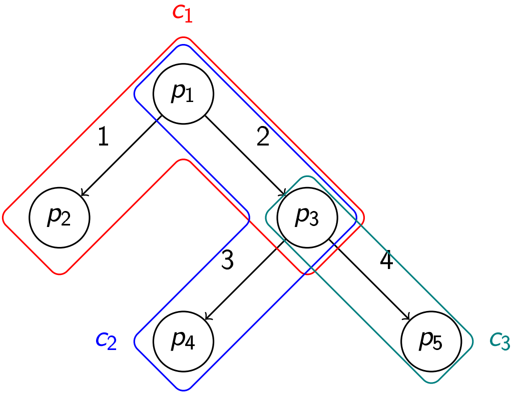

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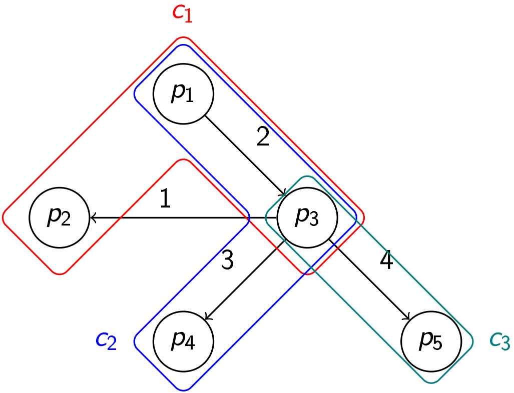

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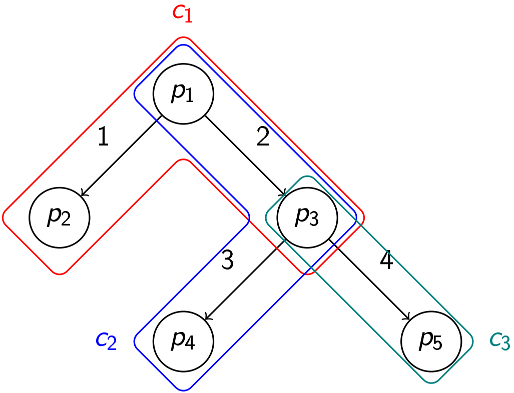

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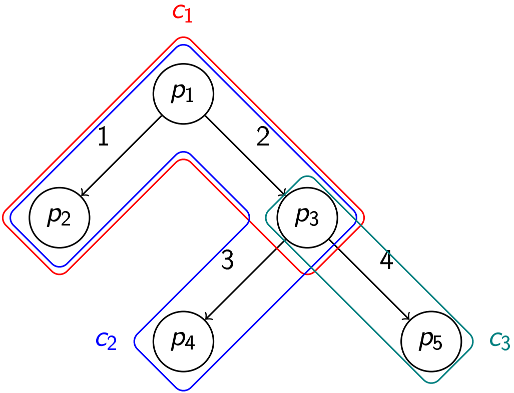

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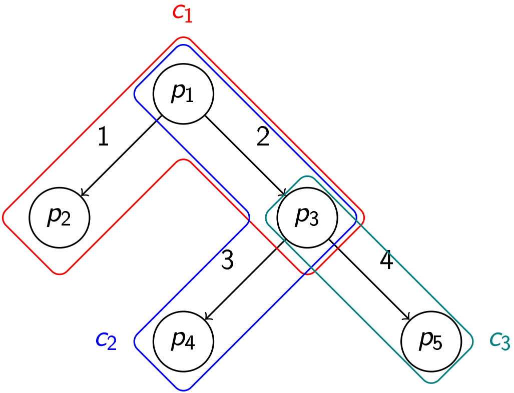

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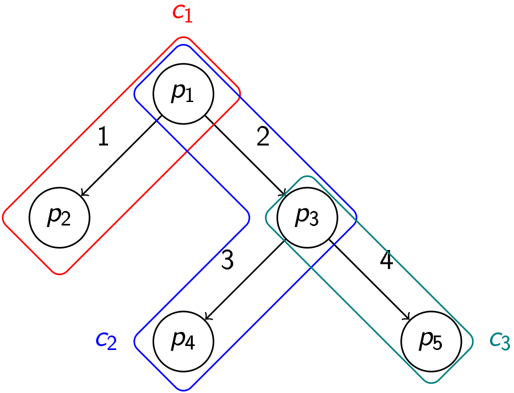

Our result

Reminder: Zielonka's Theorem

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Our result

Theorem

Given an initial tree-like topology and a diamond-closed DFA $\mathcal{A}$ for reconfiguration languages, one can build a reconfigurable asynchronous automaton $\mathcal{A}_{||}$ recognizing the same language as $\mathcal{A}$.

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Given an initial tree-like topology and a diamond-closed DFA $\mathcal{A}$ for reconfiguration languages, one can build a reconfigurable asynchronous automaton $\mathcal{A}_{||}$ recognizing the same language as $\mathcal{A}$.

- Complexity: polynomial in the size of $\mathcal{A}$

Idea of the construction

Two things to maintain: state and communication topology

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- State: process p maintains two states $(s_p, t_p) \in S^2$
  - s_p: most up-to-date known by p
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On communication involving parent q:

- combine s_p, s_q, and t_p to get new state s'

Need to know topology to compute new state!

Idea of the construction

Two things to maintain: state and communication topology

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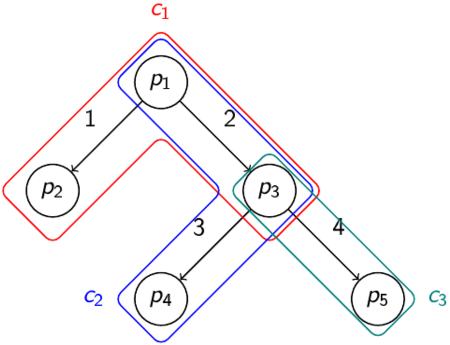

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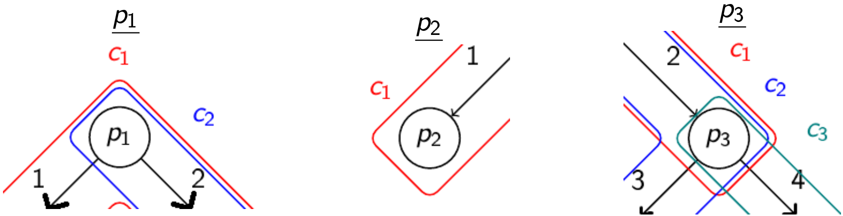

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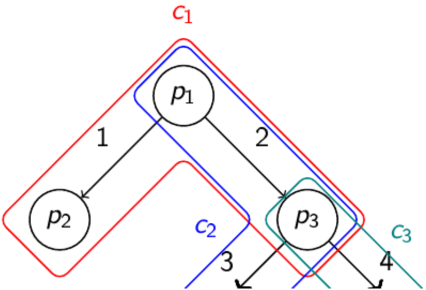
On c_1 communication, combine all local views:



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