Natural Specifications Yield Decidability for Distributed Synthesis of Asynchronous Systems

Nathalie Sznajder

LSV, ENS Cachan, France

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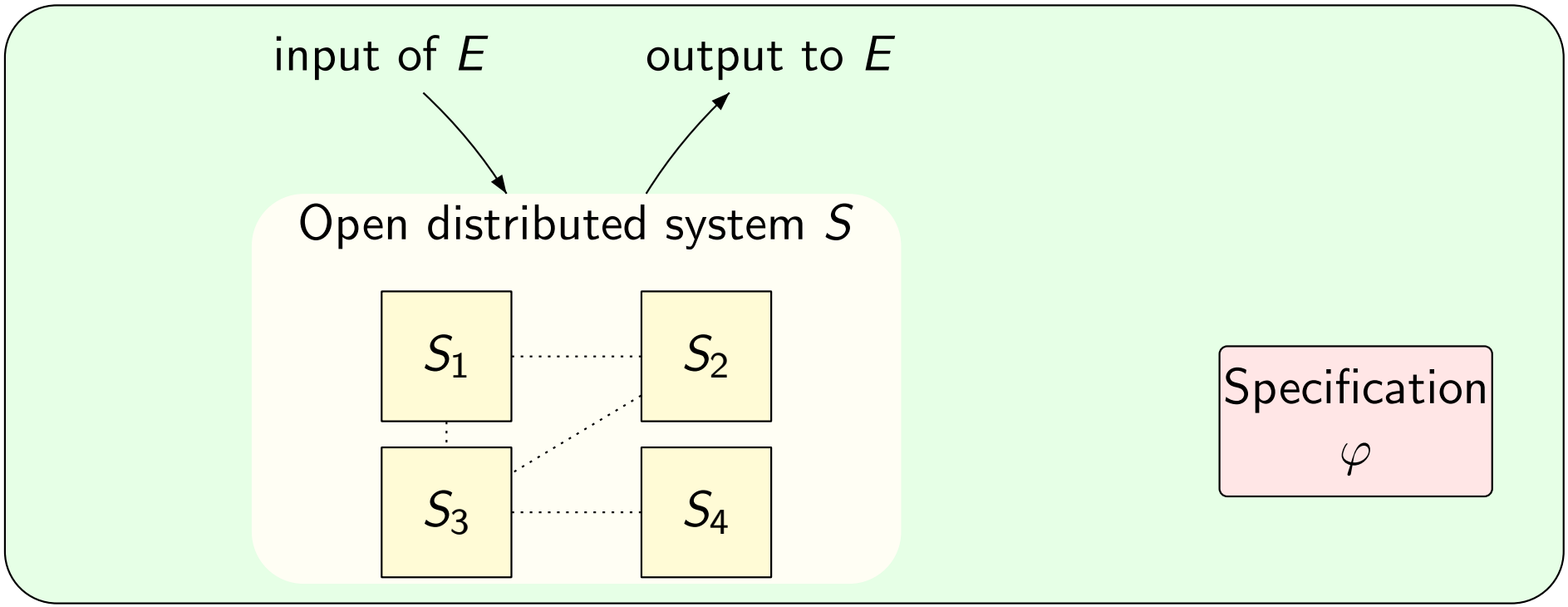
Czech Republic

Joint work with Thomas Chatain and Paul Gastin

Synthesis of a distributed reactive system



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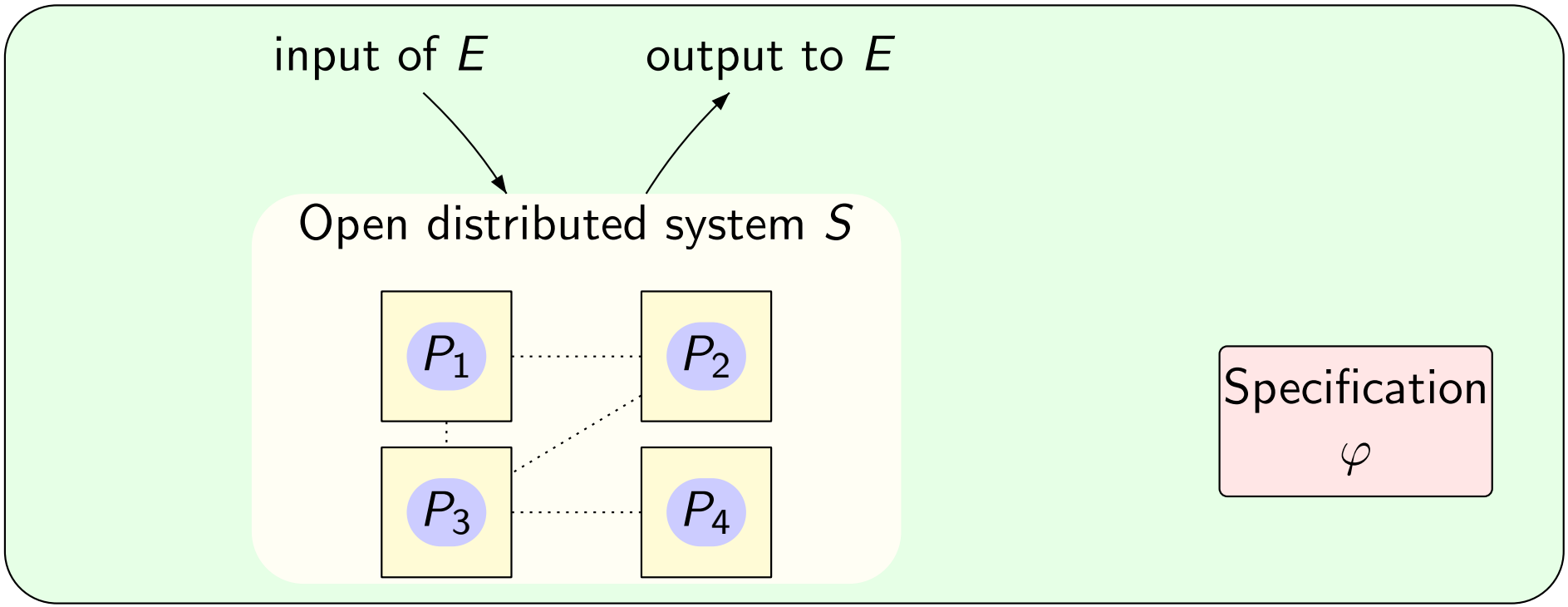

Two problems

- Decide the existence of a distributed program such that their joint behavior $P_1||P_2||P_3||P_4||E$ satisfies φ, for all E.
- Synthesis : If it exists, compute such a distributed program.

Distributed synthesis: Synchronous or asynchronous semantics?

Synchronous semantics

- At each tick of a global clock, all the processes and the environment output their new value
- Introduced in [PnueliRosner90].
- In general undecidable.

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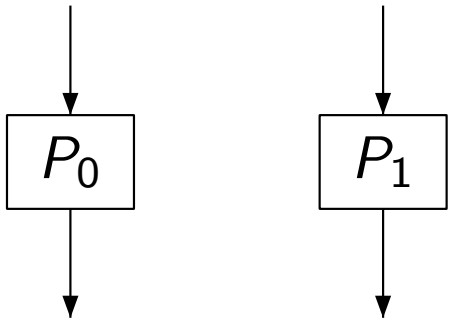

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- Specifications :
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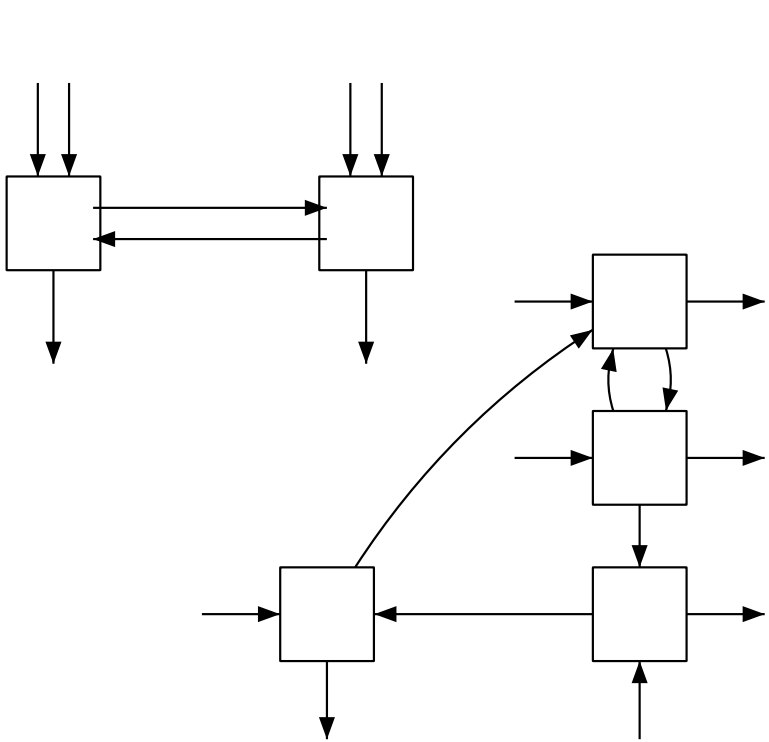
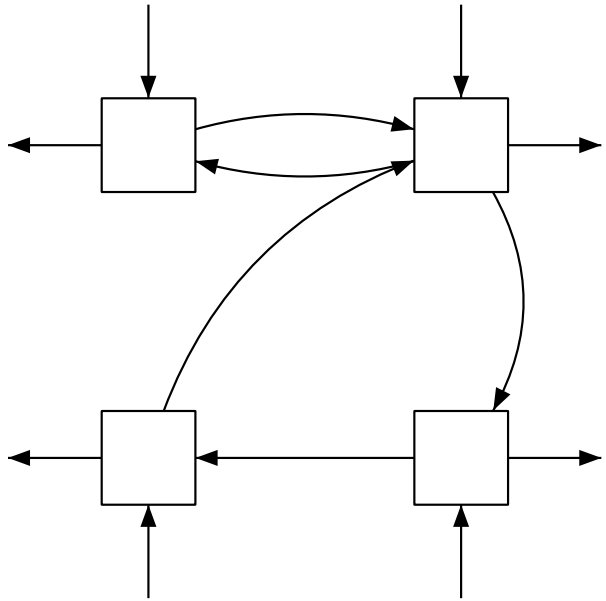
  - will not restrain communication abilities

Decidability Results

Theorem

Synthesis problem is decidable for strongly-connected architectures





Outline

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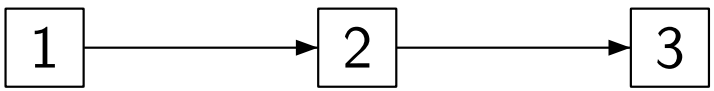
The model

Architectures

- Communication graph $(Proc, E)$



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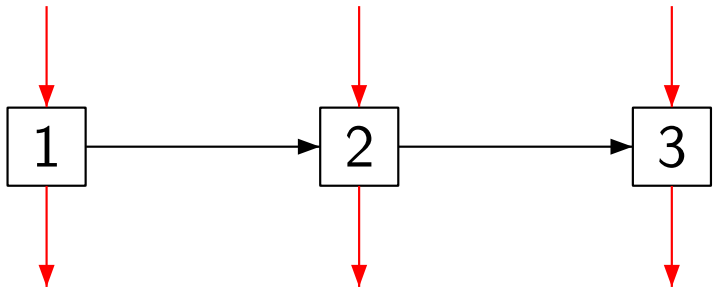

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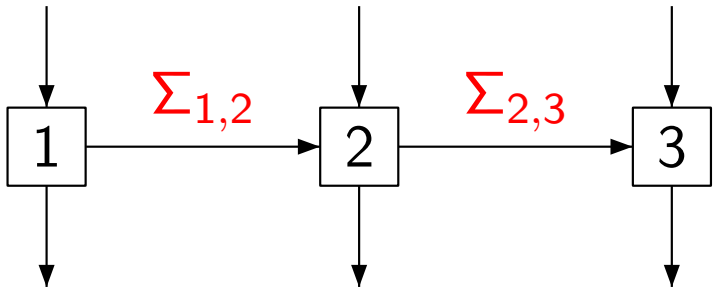

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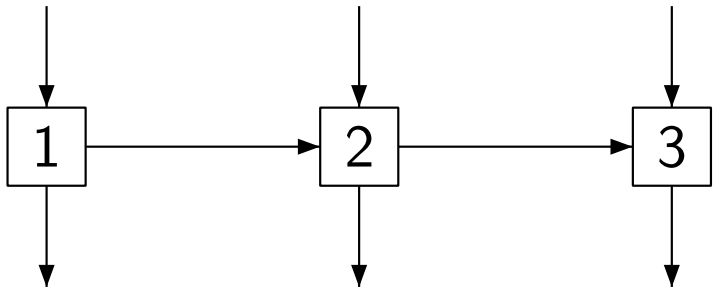

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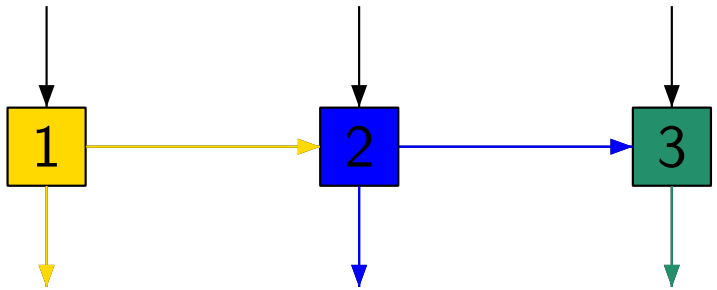
- $\Sigma = \Gamma \cup \bigcup_{(i,j) \in E} \Sigma_{i,j}$
- For each process i, Σ_i is the set of signals it can send or receive, and $\Sigma_i^c = \mathrm{Out}_i \cup \bigcup_{j,(i,j) \in E} \Sigma_{i,j}$



The model: runs

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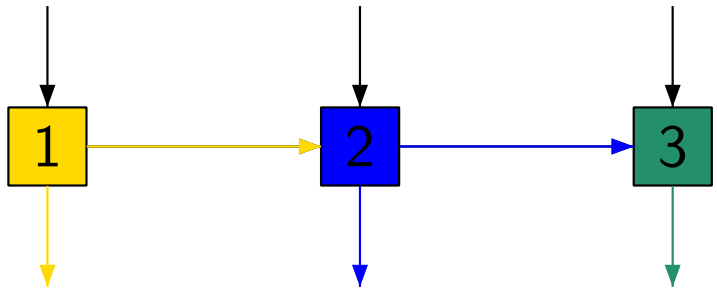
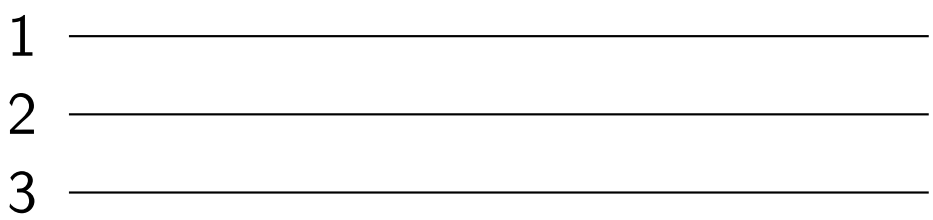
A run is a Mazurkiewicz trace $t = (V, \lambda, \leq)$ over (Σ, D) where aDb if there is a process that takes part both in a and b





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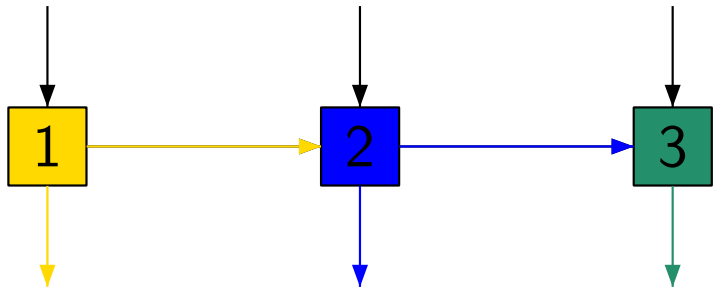

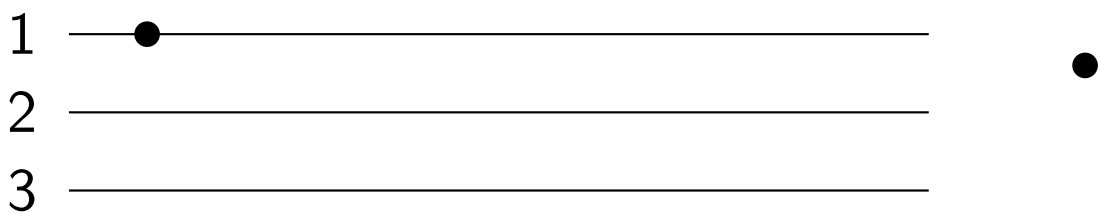

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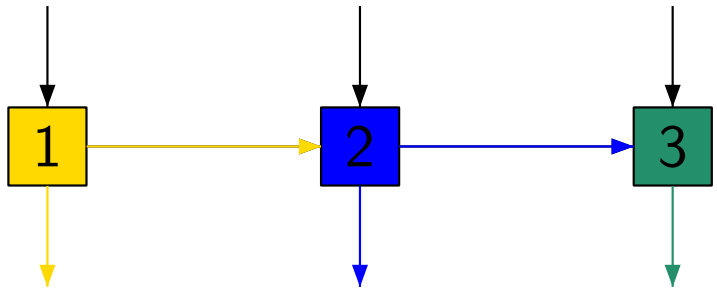

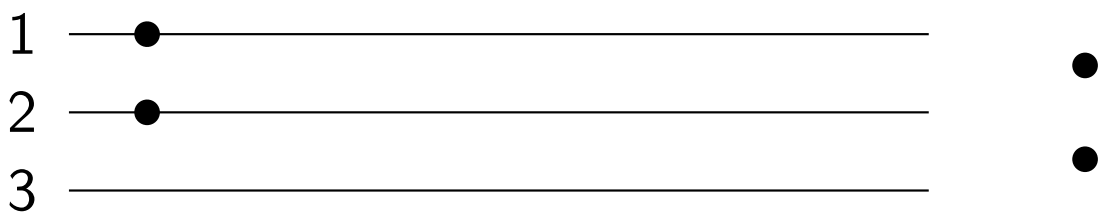

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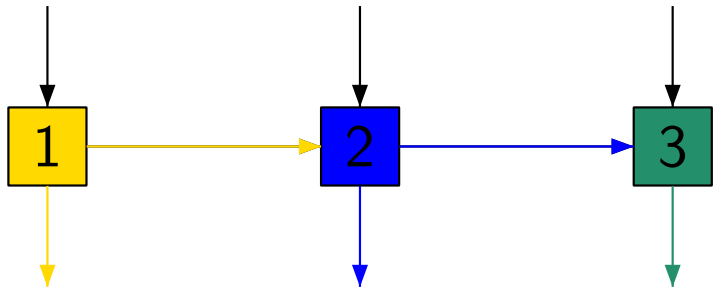

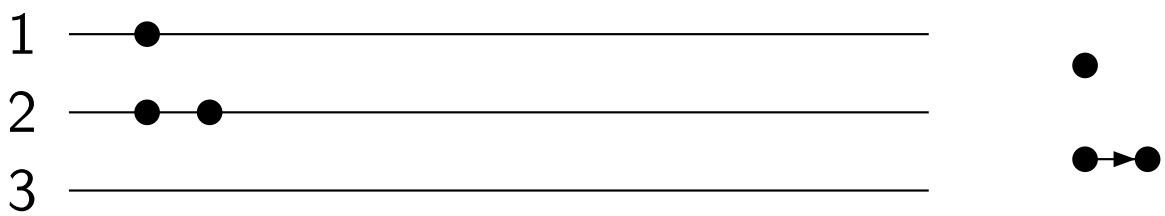

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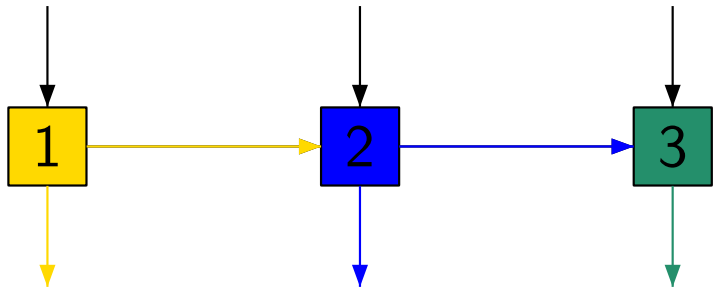

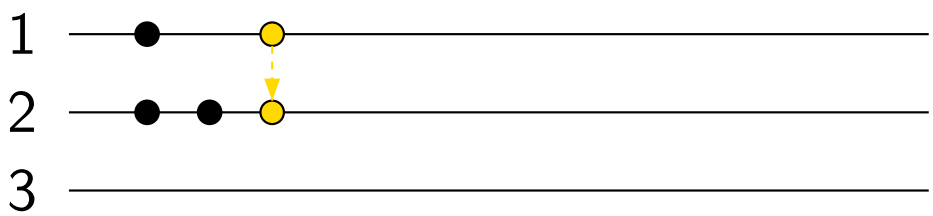

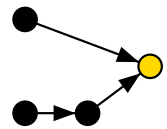

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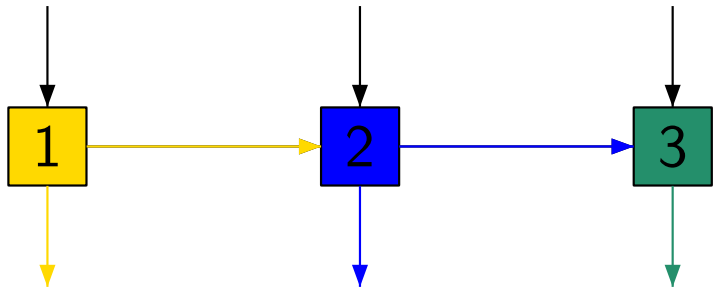

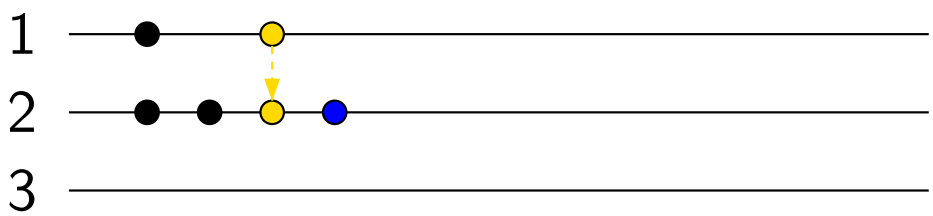

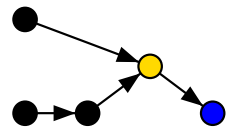

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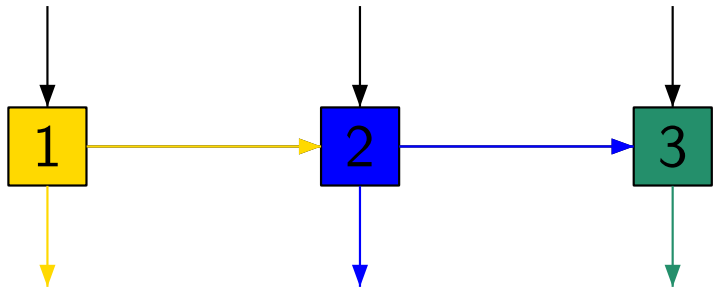

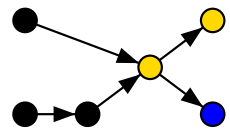

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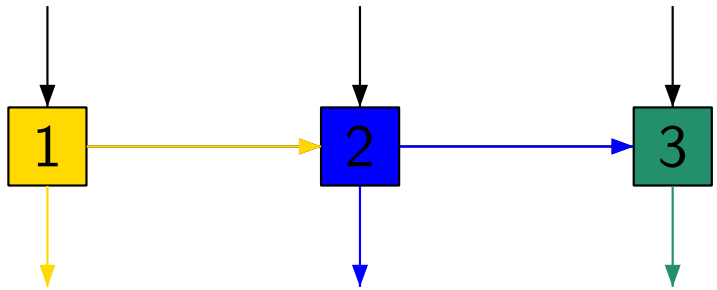

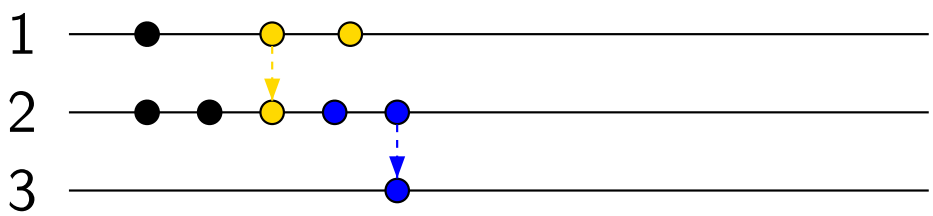

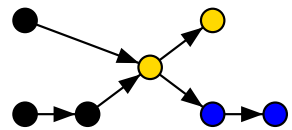

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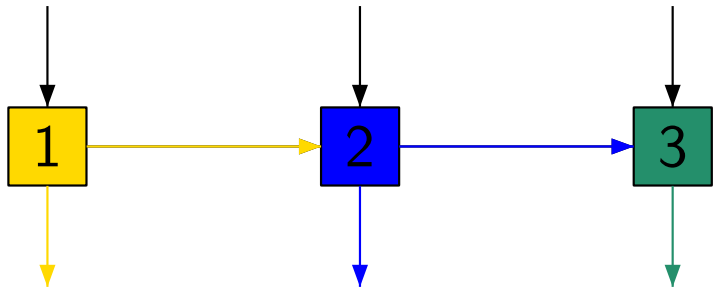

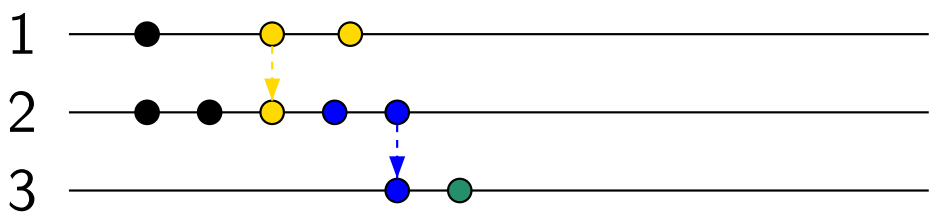

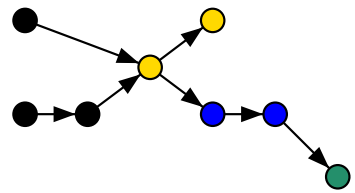

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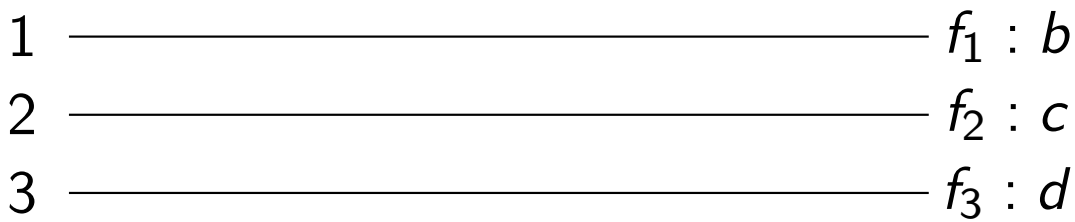

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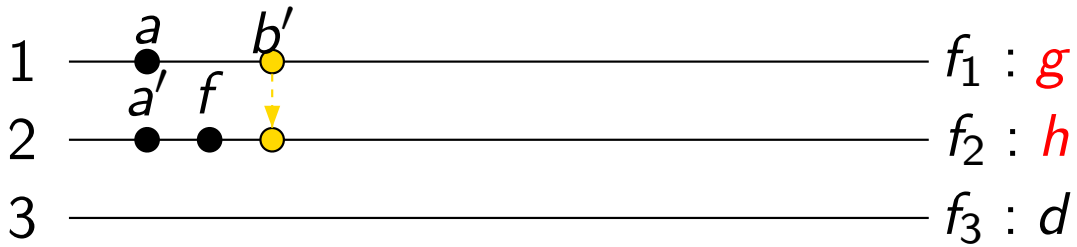

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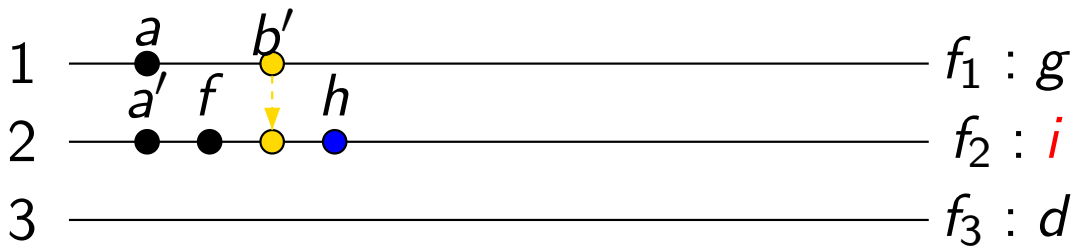

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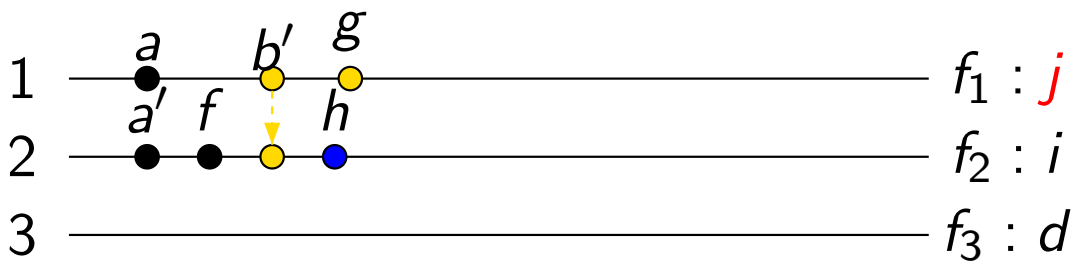

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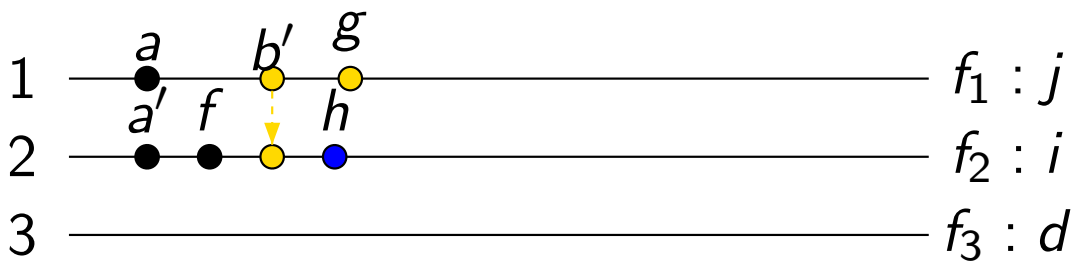

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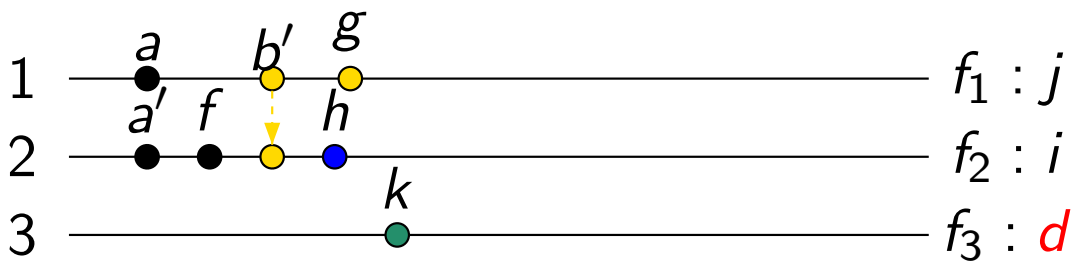

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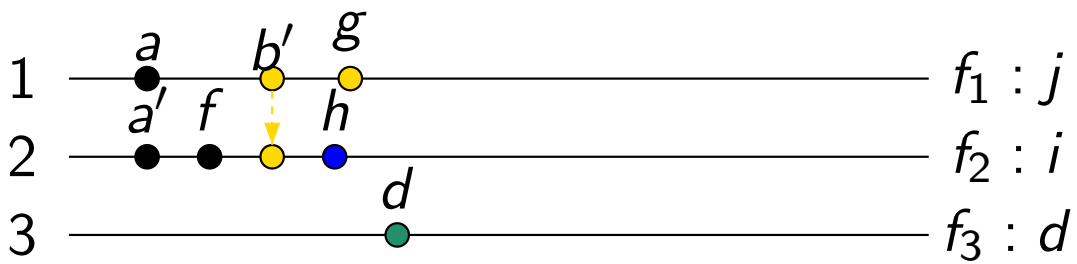

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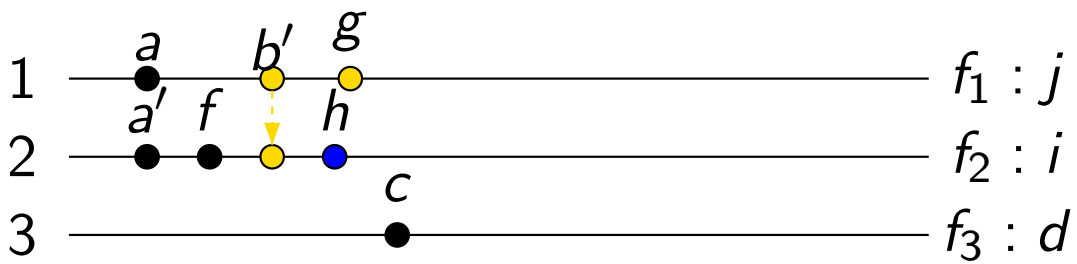

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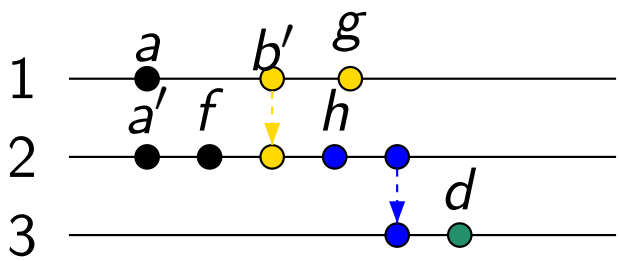

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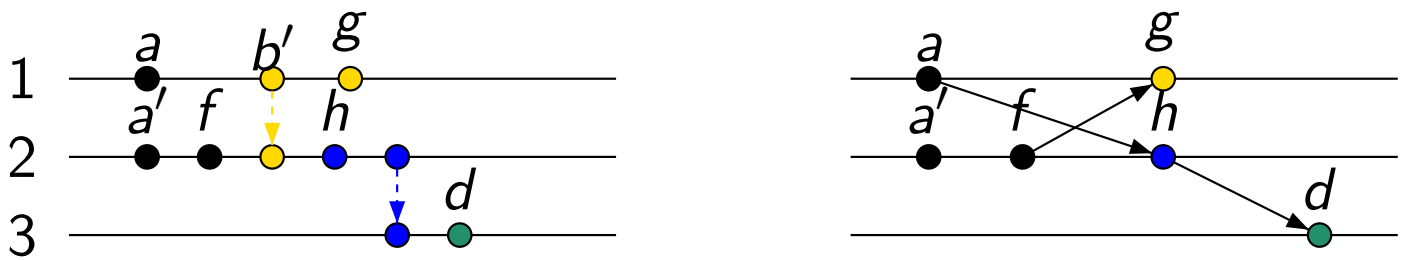

The synthesis problem

Given

- $\mathcal{A} = (\mathrm{Proc}, E, \Gamma)$
- φ a specification over Γ-labelled partial orders (observable runs)

Do there exist

- sets $\Sigma_{i,j}$ for each $(i,j) \in E$
- and strategies $f_i : \Sigma_i^* \to \Sigma_i^c$ for each $i \in \mathrm{Proc}$

such that every $(f_i)_{i \in \mathrm{Proc}}$-run t is such that $\pi_\Gamma(t) \models \varphi$? If so, compute them

Specifications

Communication induces order relation

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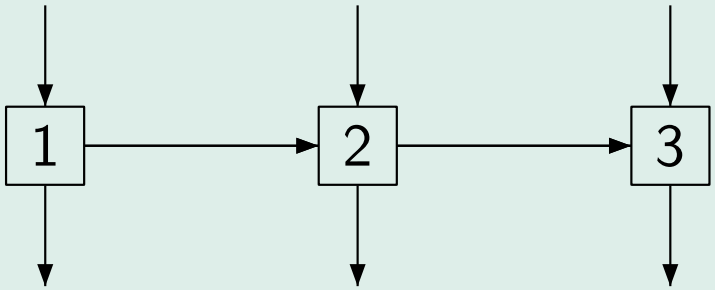

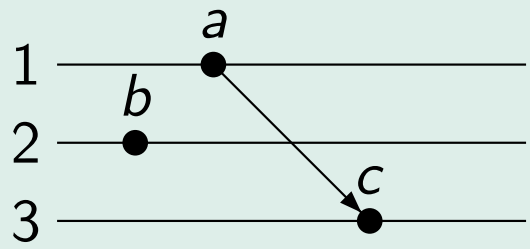

Specifications

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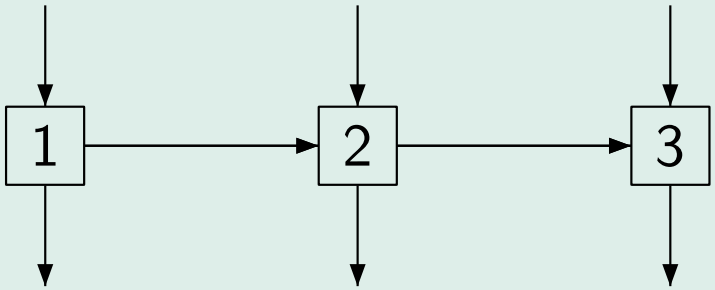

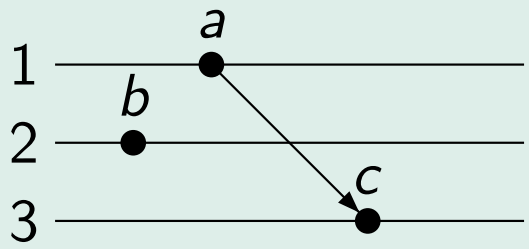

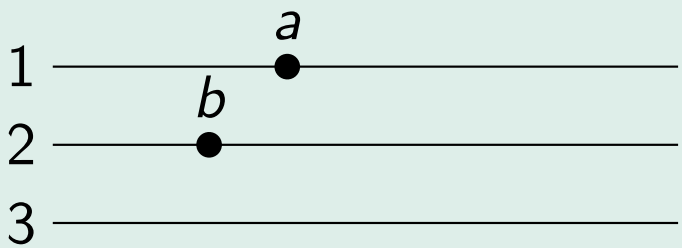

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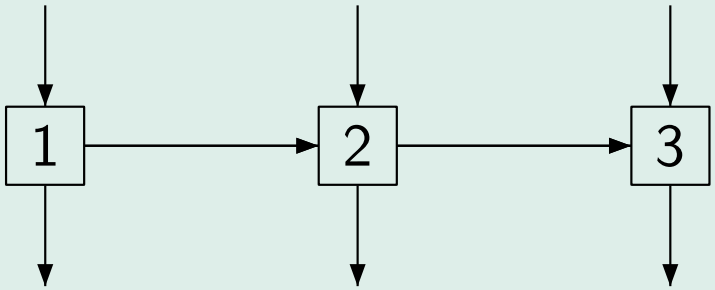

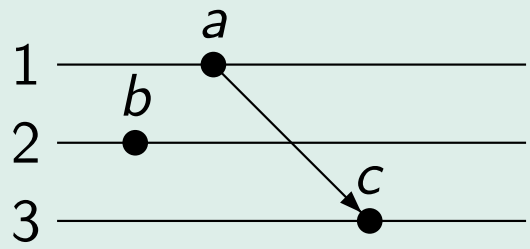

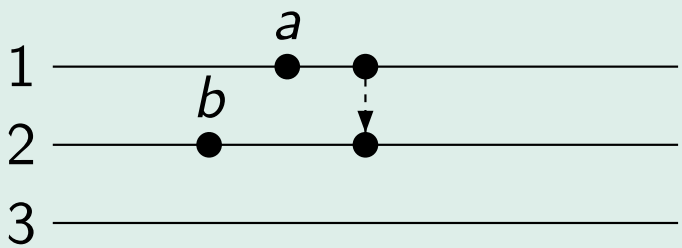

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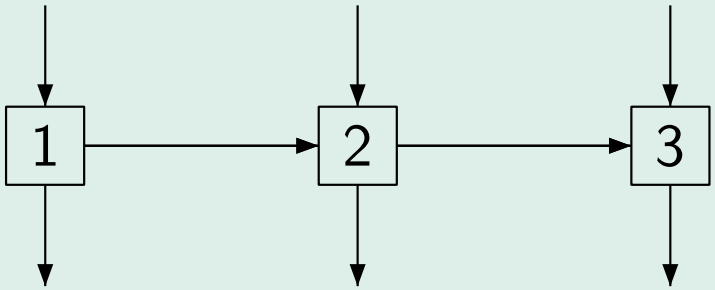

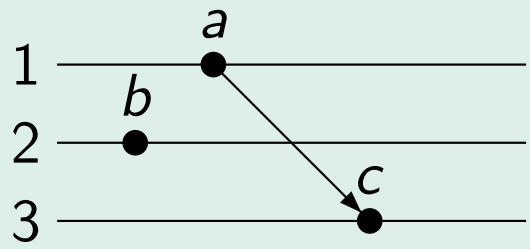

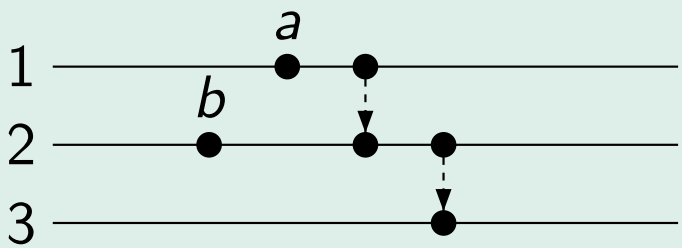

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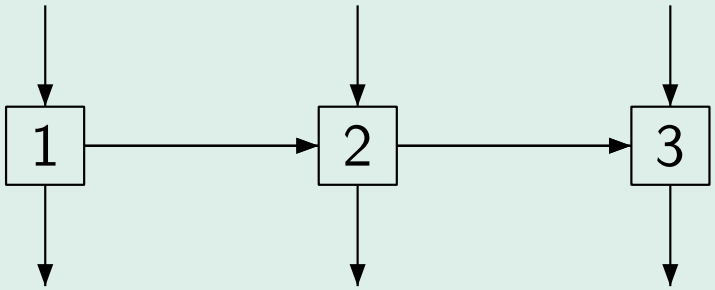

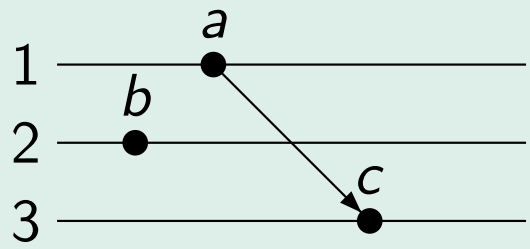

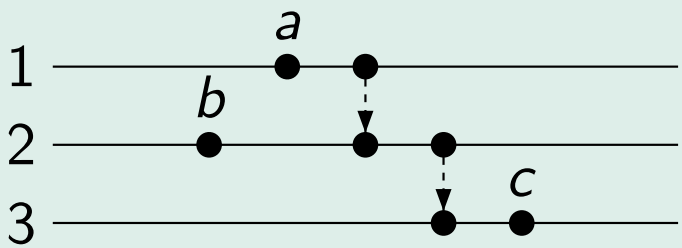

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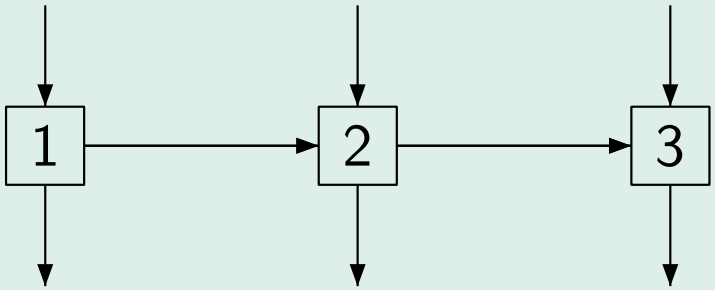

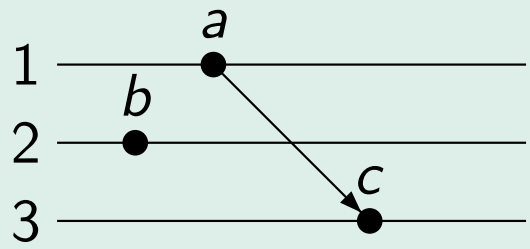

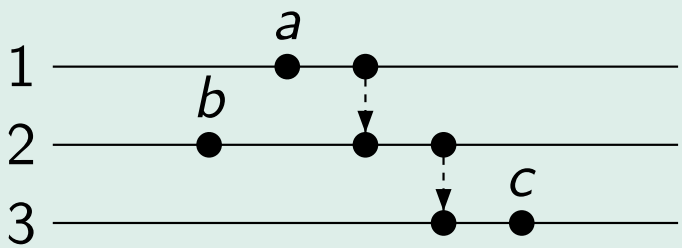

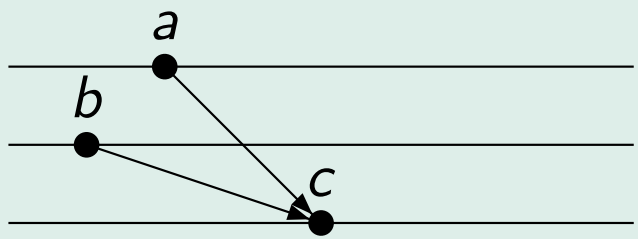

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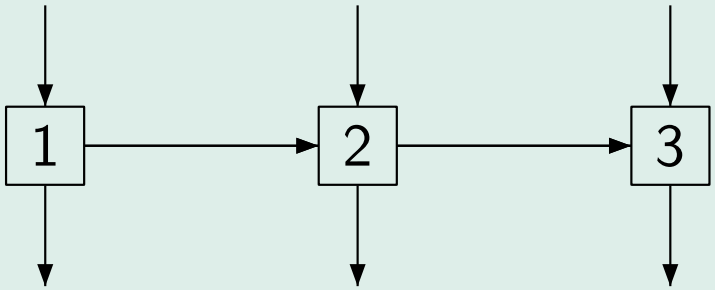

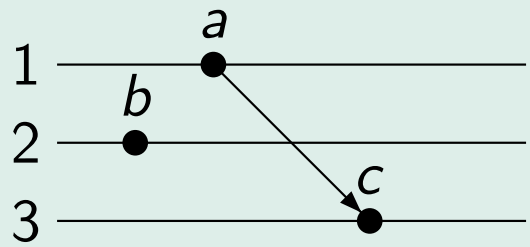

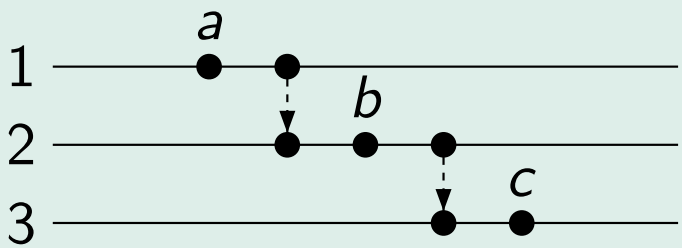

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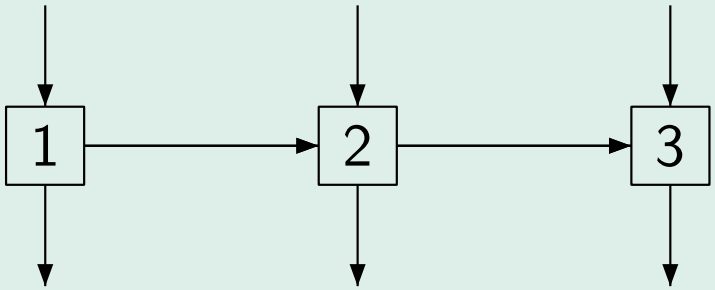

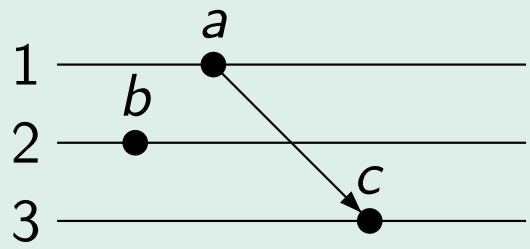

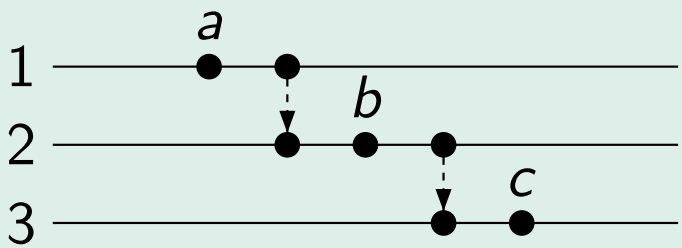

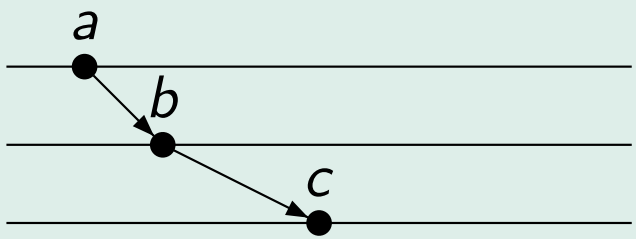

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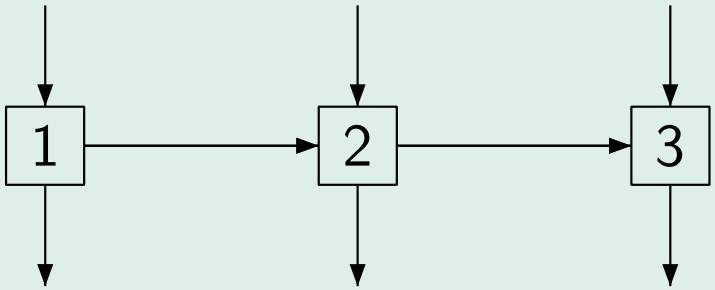

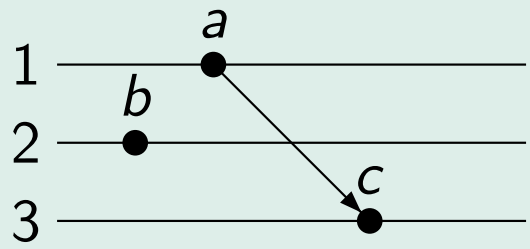

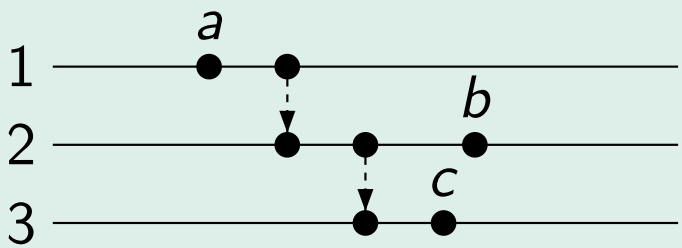

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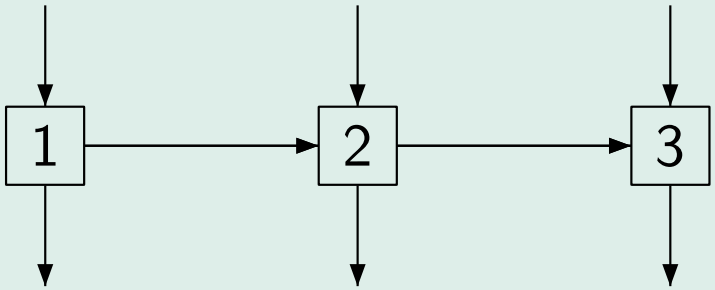

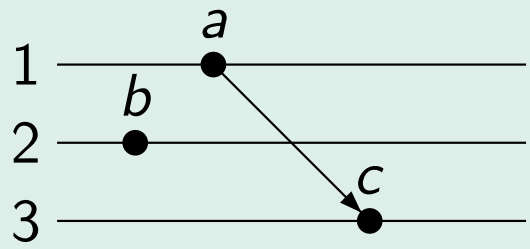

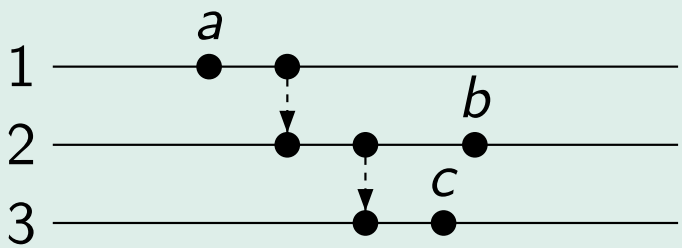

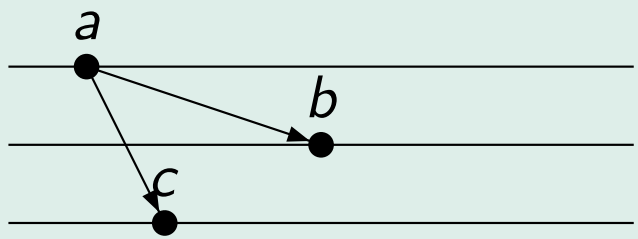

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Restrictions on specifications

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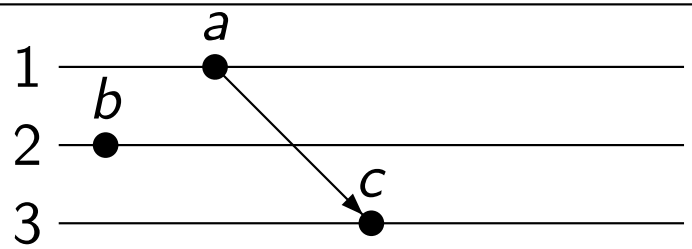

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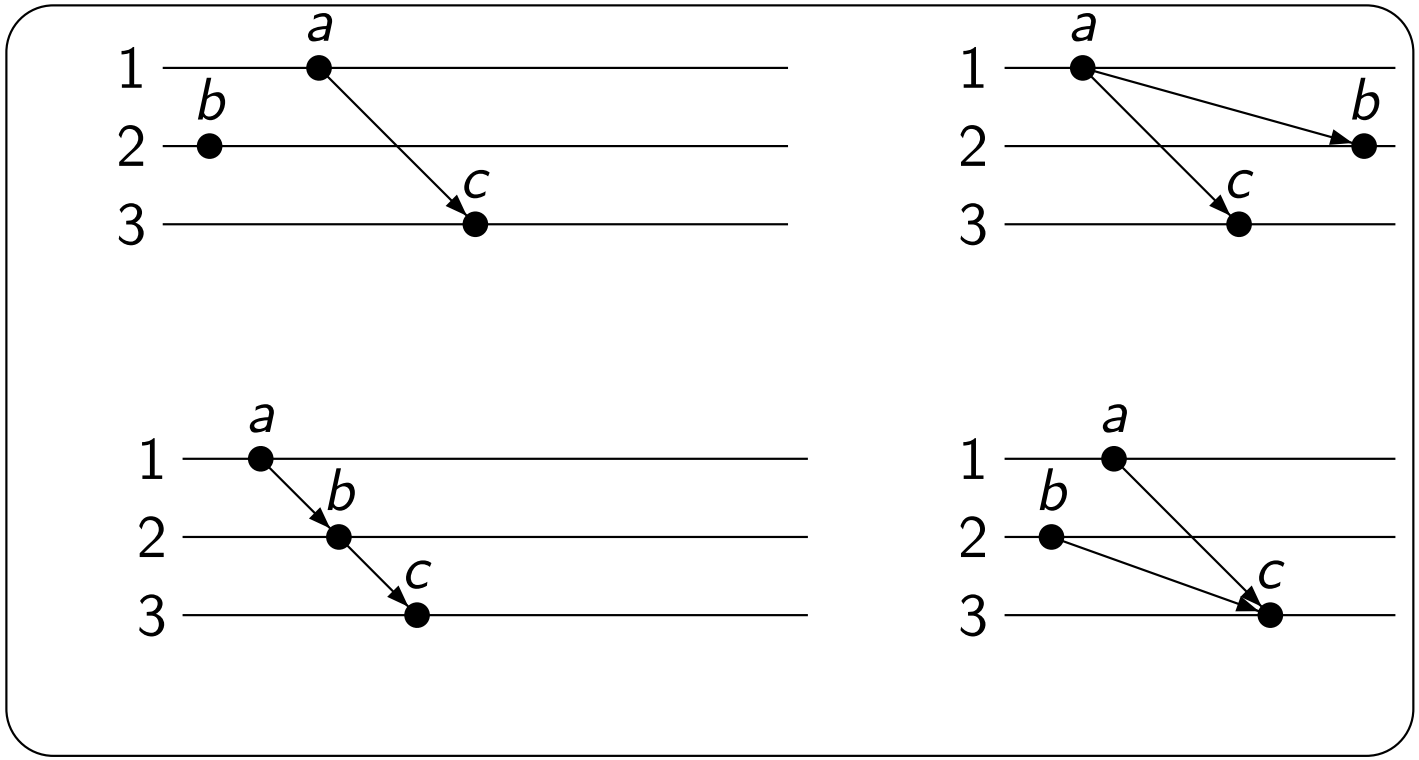

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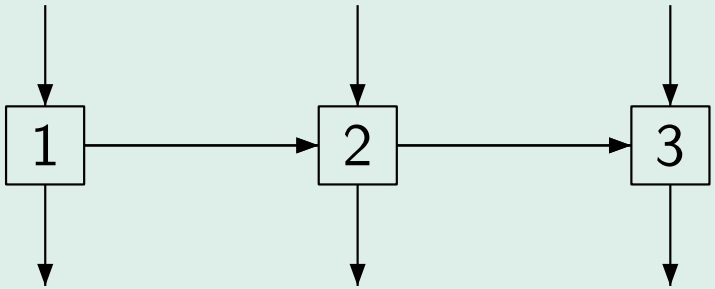

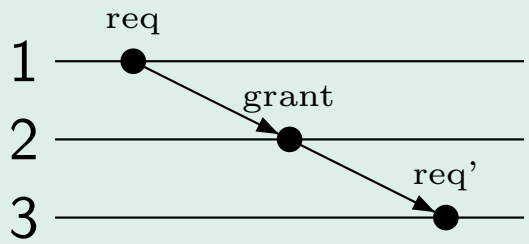

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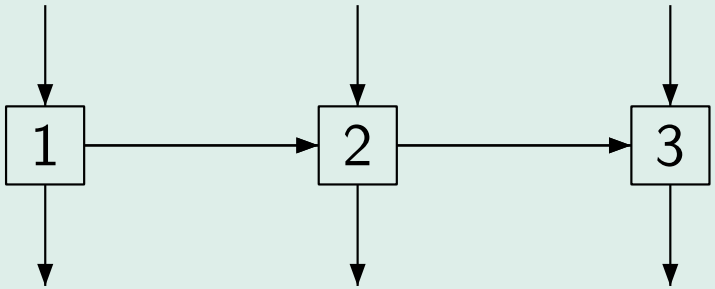

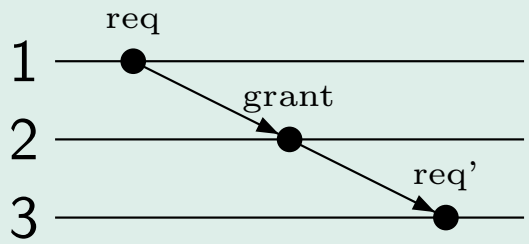

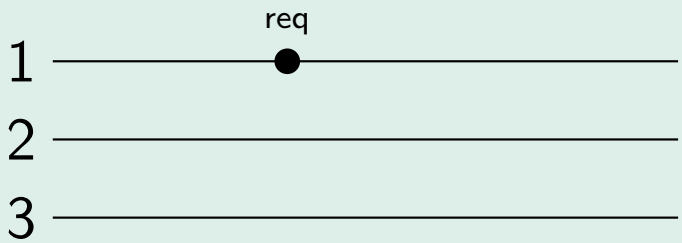

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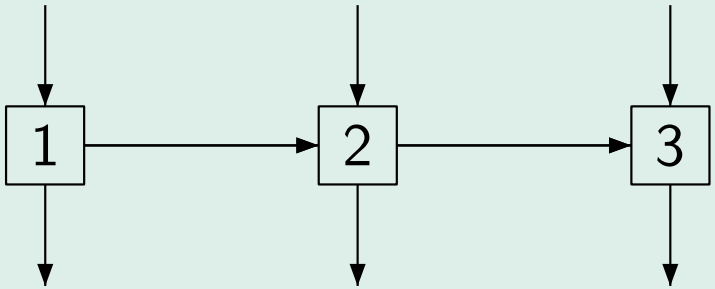

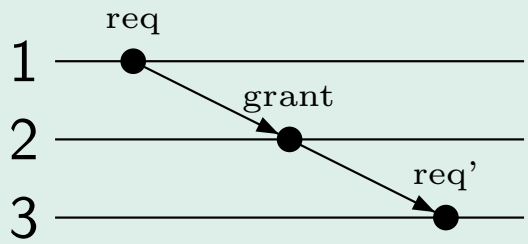

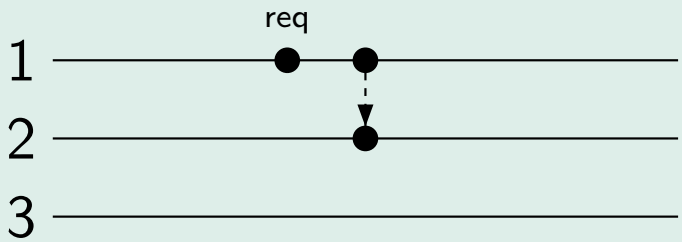

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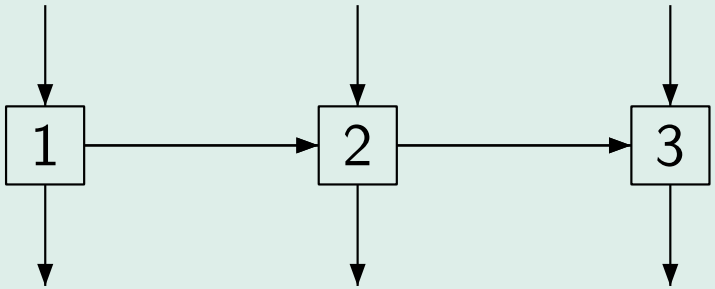

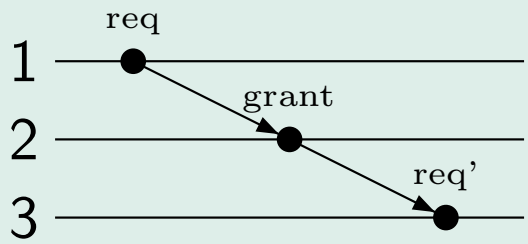

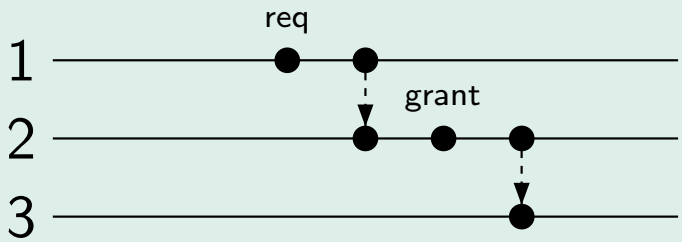

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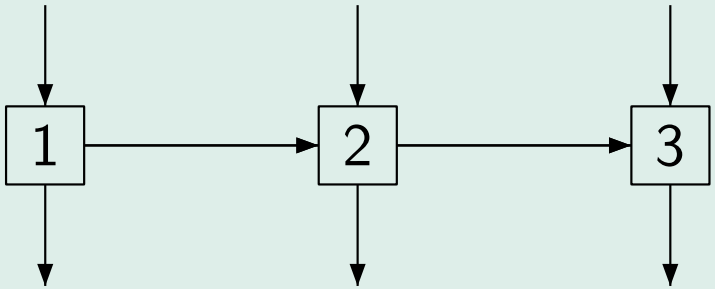

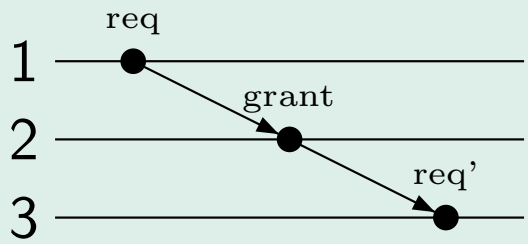

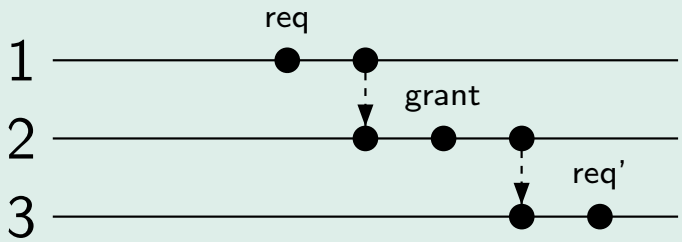

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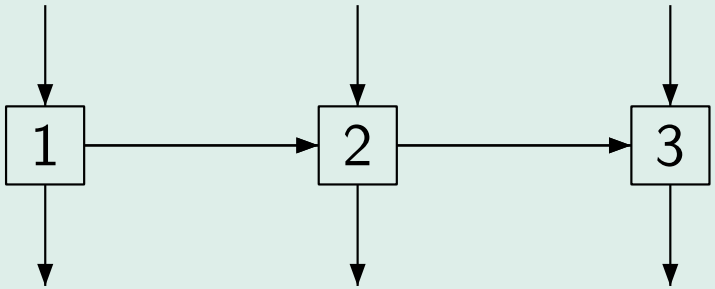

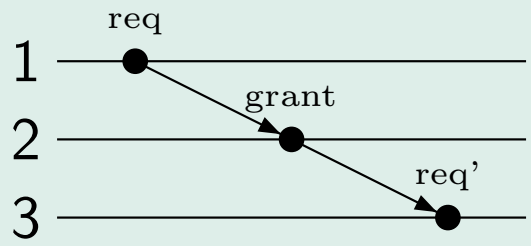

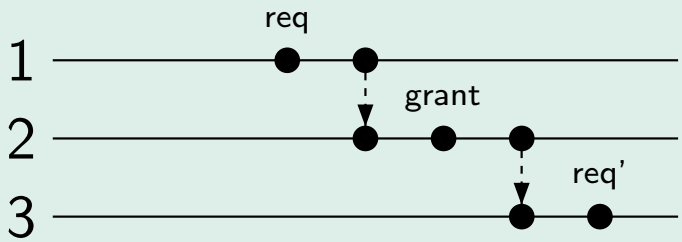

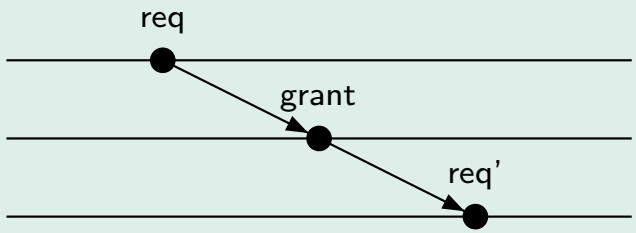

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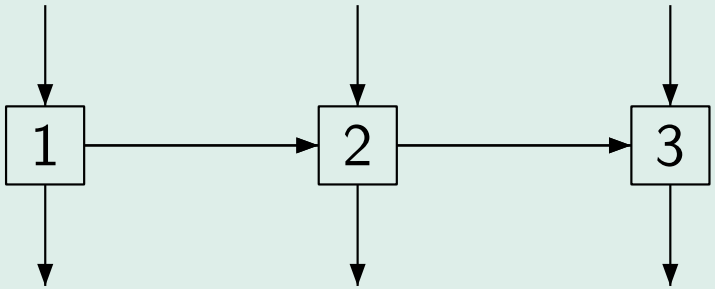

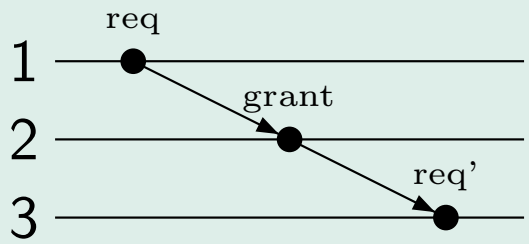

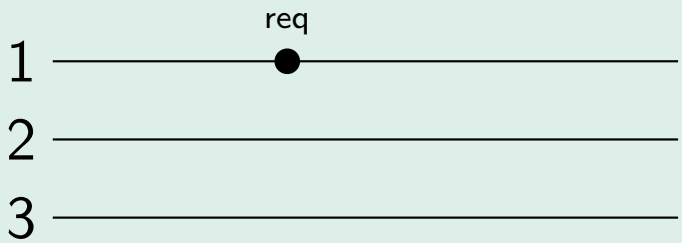

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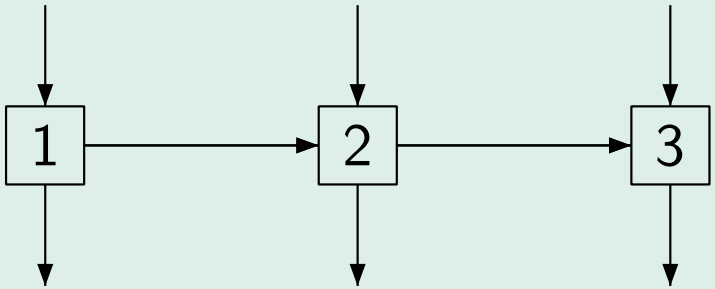

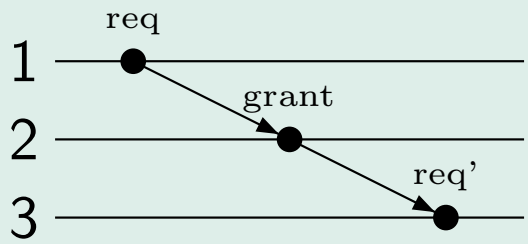

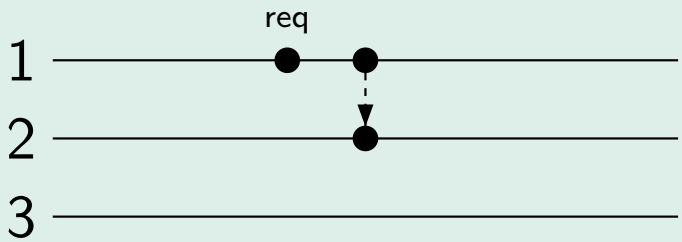

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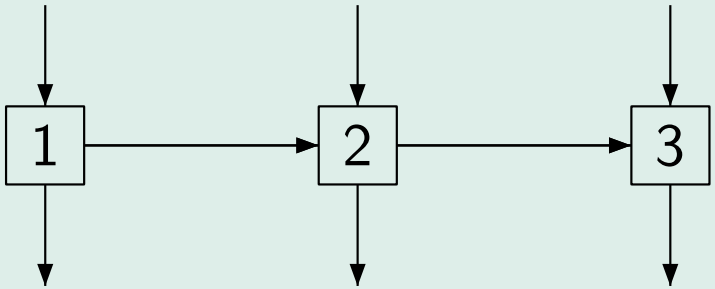
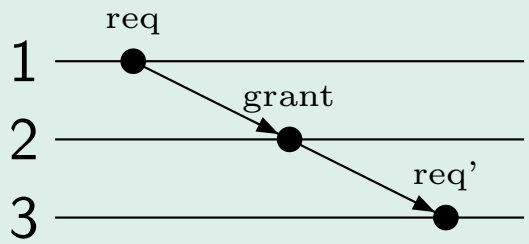
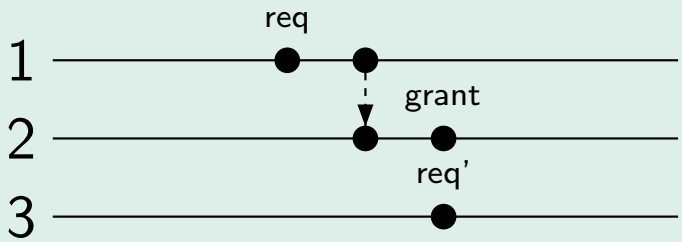
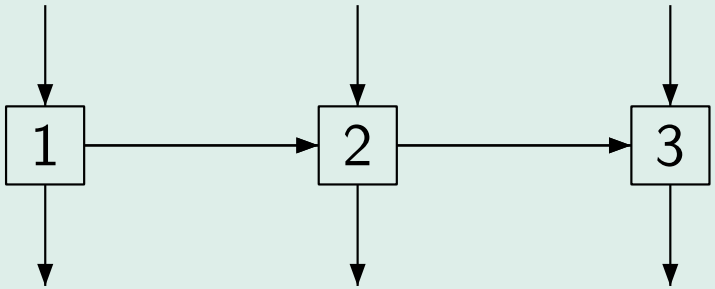


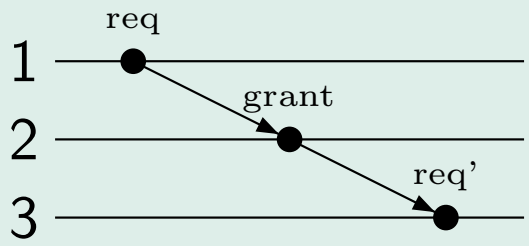


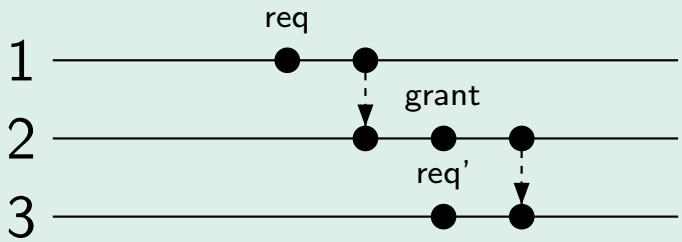


Specifications

Input events are not controllable by processes







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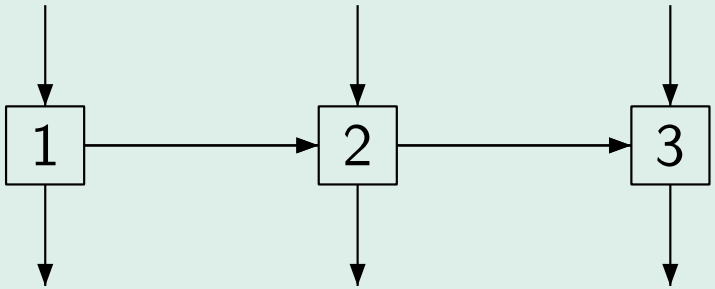

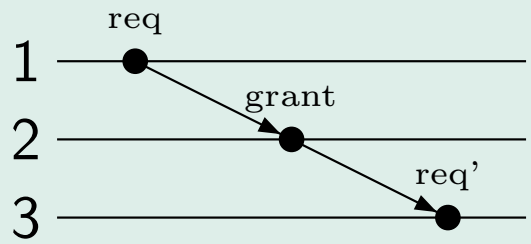

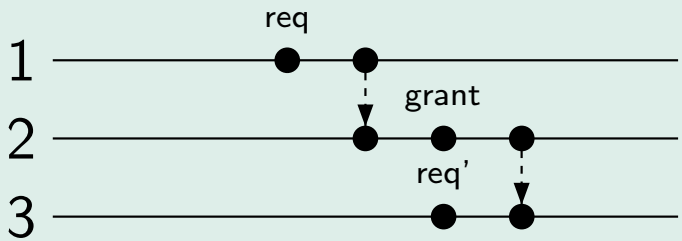

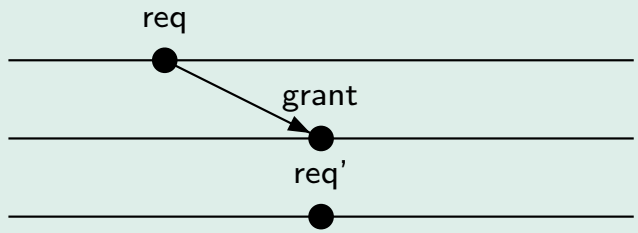

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Restrictions on specifications

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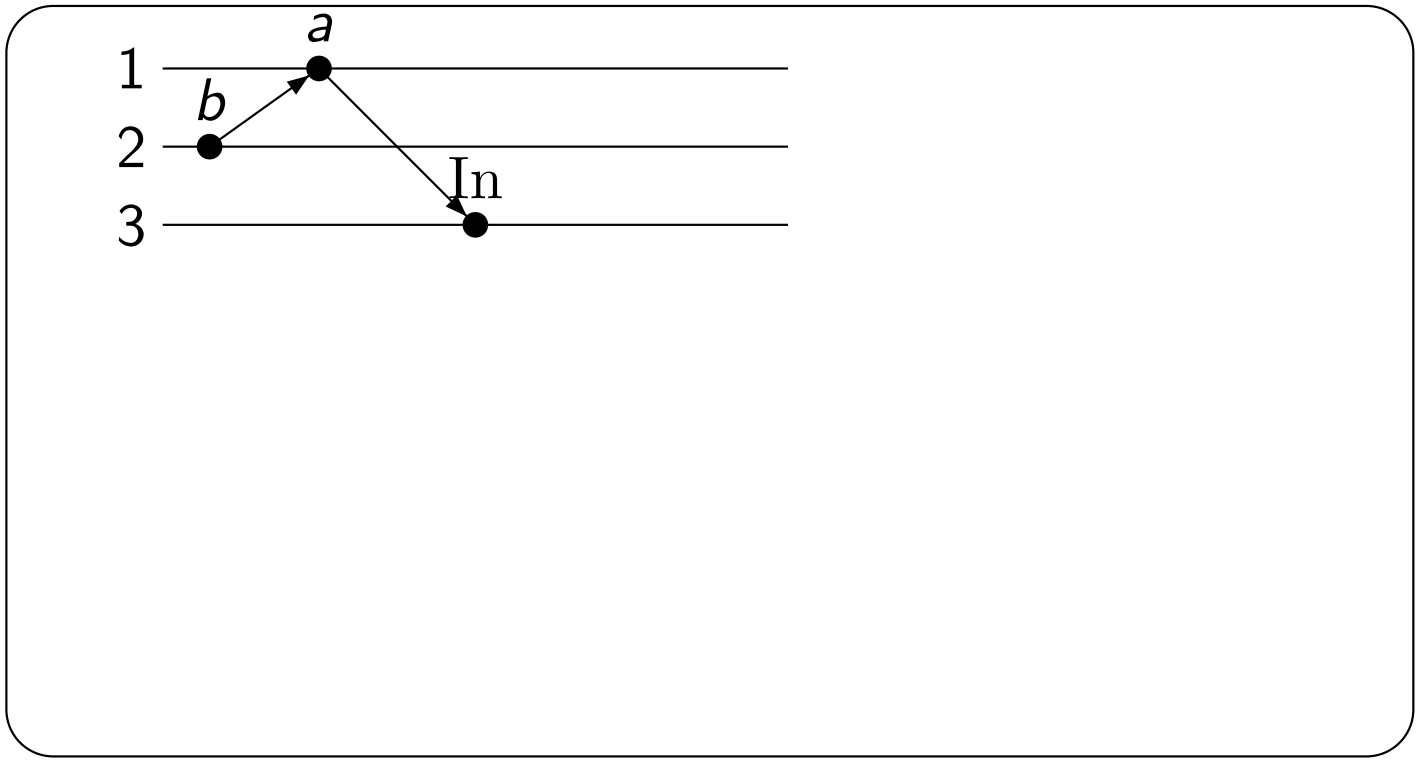

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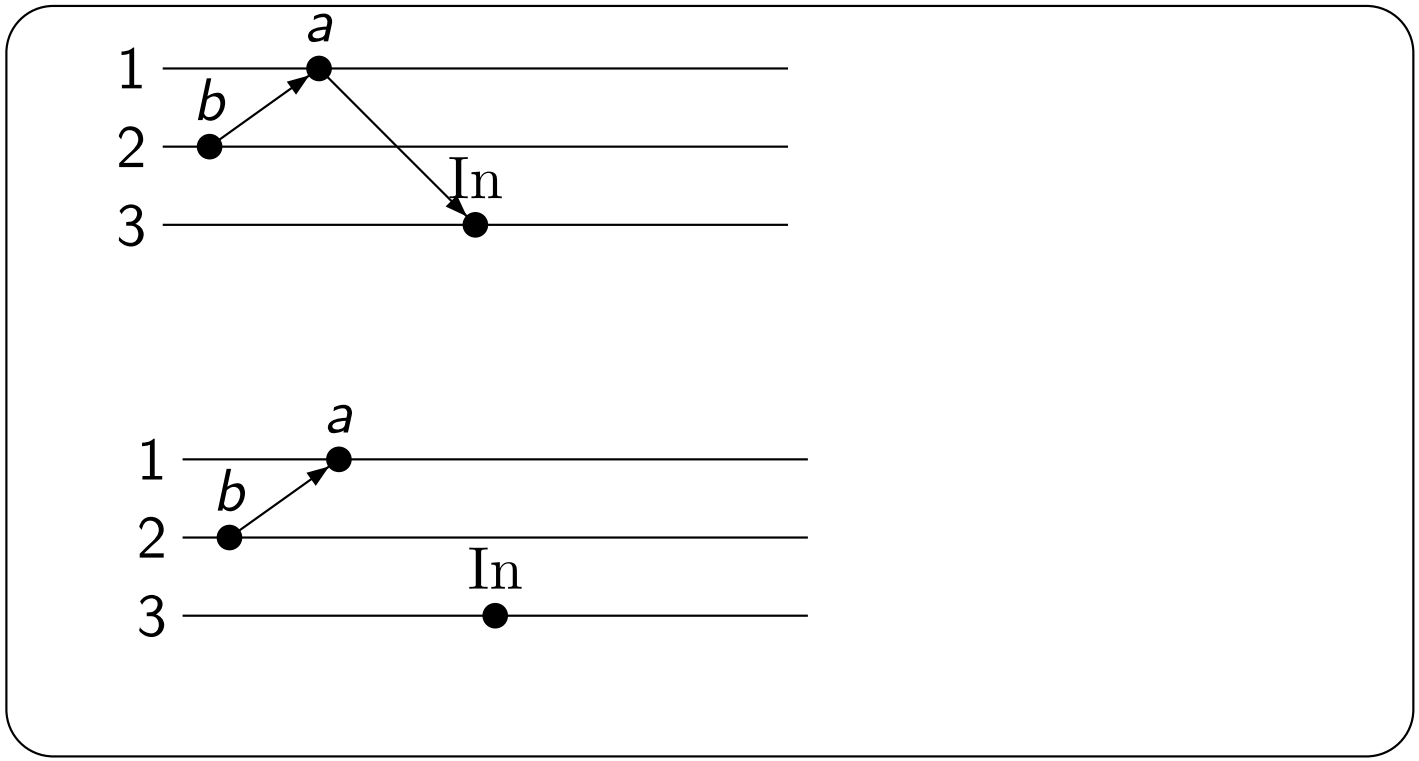

Outline

Decidability Results

Theorem

The synthesis problem over singleton architectures is decidable for regular specifications.

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The distributed synthesis problem over strongly connected architectures is decidable for acceptable specifications.

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The distributed synthesis problem over strongly connected architectures is decidable for acceptable specifications.

Proof

By reduction to the singleton case.

Strongly connected architectures

Proposition

If there is a winning strategy over the singleton architecture then one can define internal signals sets and a distributed winning strategy for the strongly connected one.

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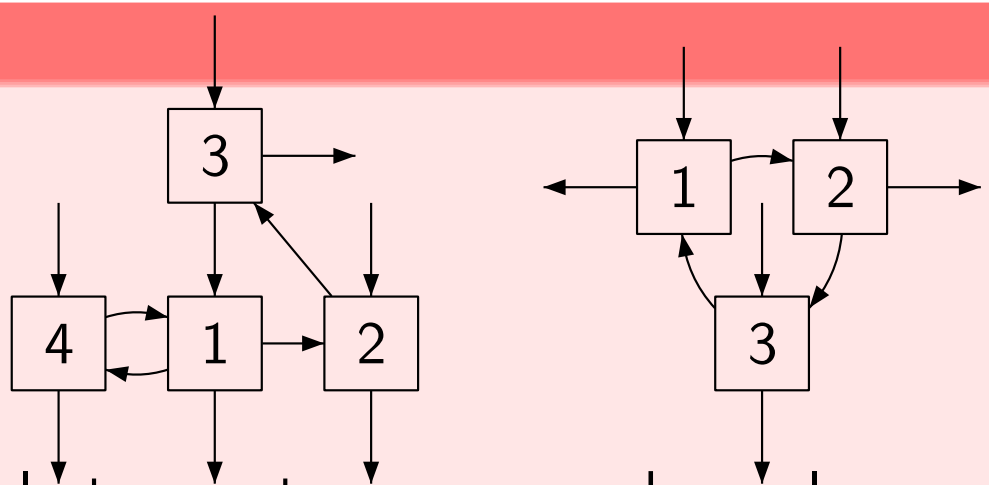

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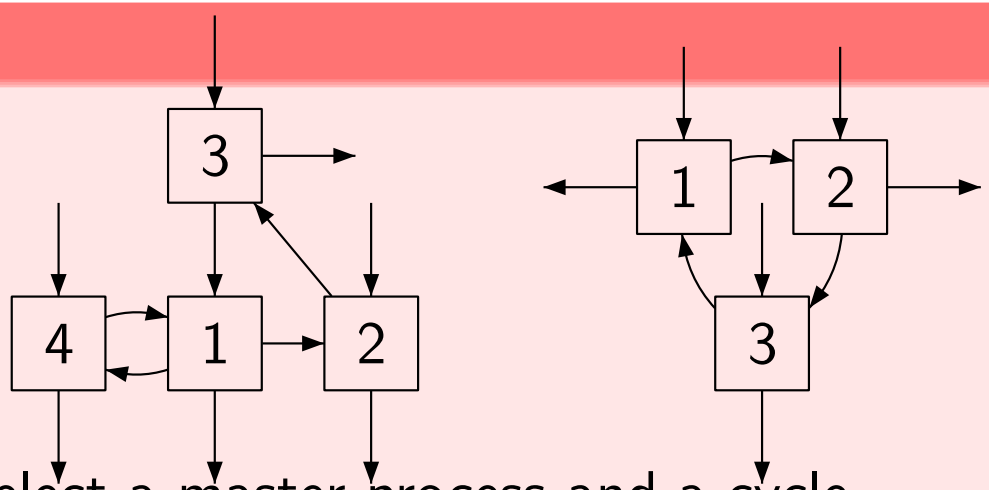

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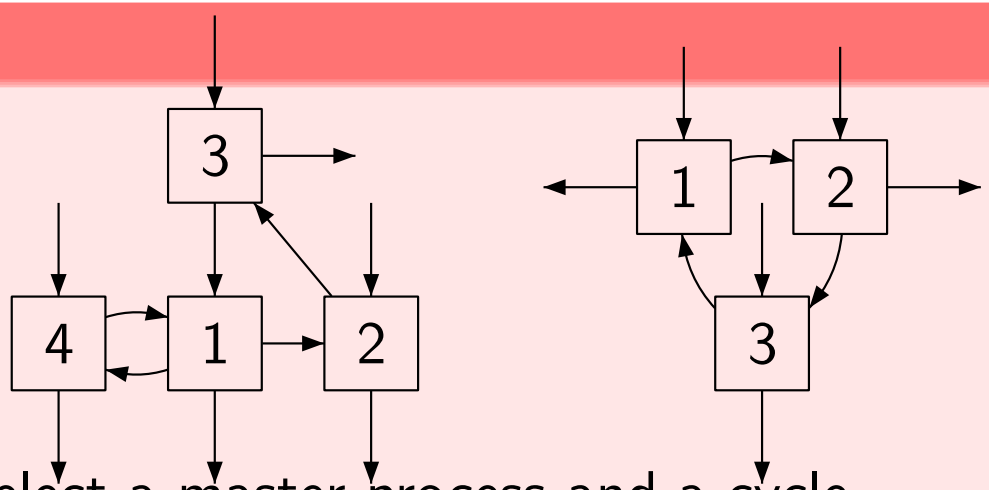

- We select a master process and a cycle.
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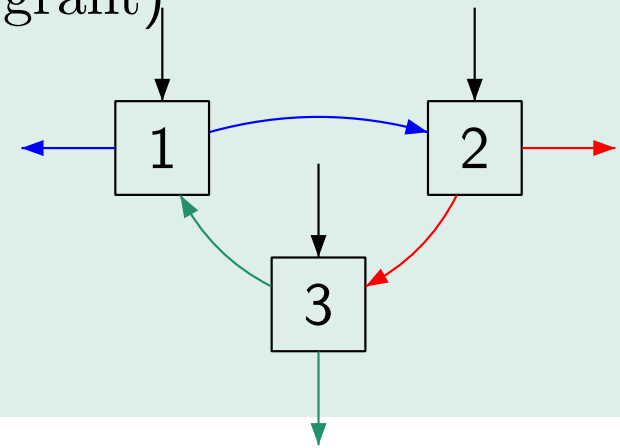
Centralize information

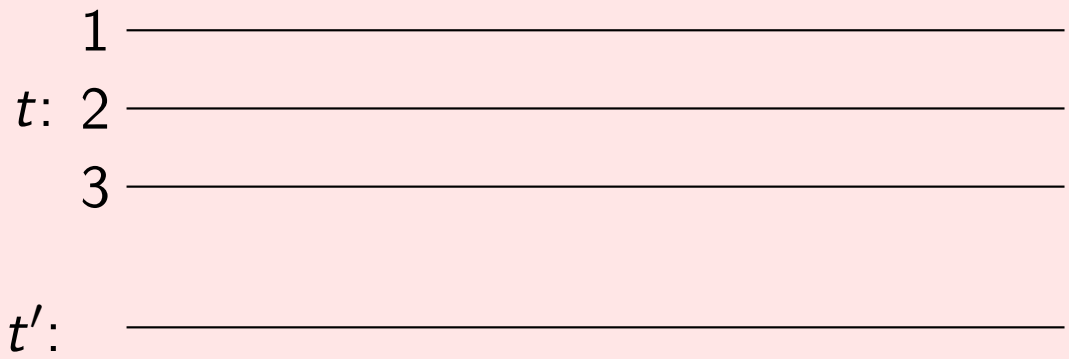
Example

$$\mathrm{req}_3 \rightarrow \mathsf{F}_{32}(\neg\, \mathsf{Y}_2\, \mathrm{alert} \leftrightarrow \mathrm{grant})$$



$f(\sigma) = \mathrm{grant}$ iff σ contains req_3 and no alert

Master collect information by sending a signal Msg through the cycle



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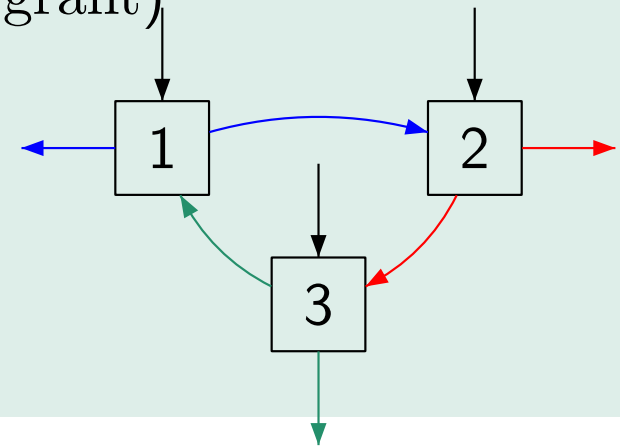

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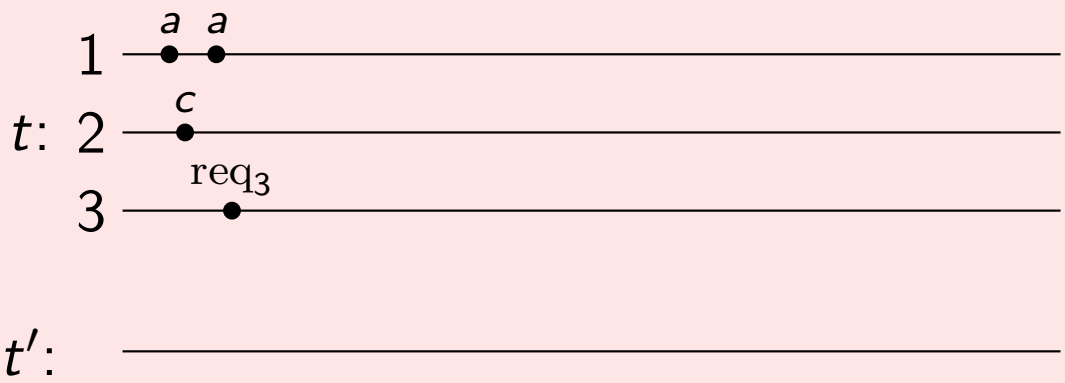

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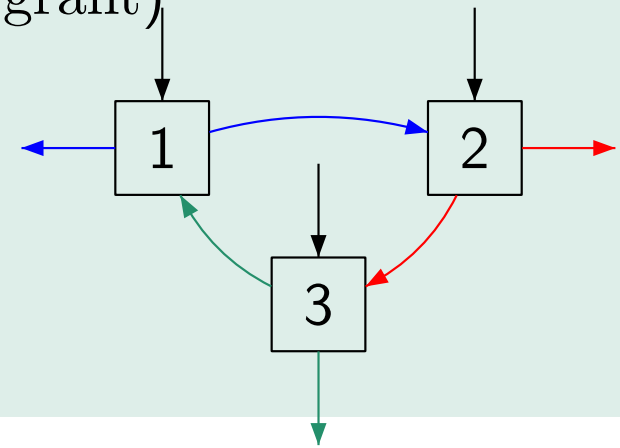

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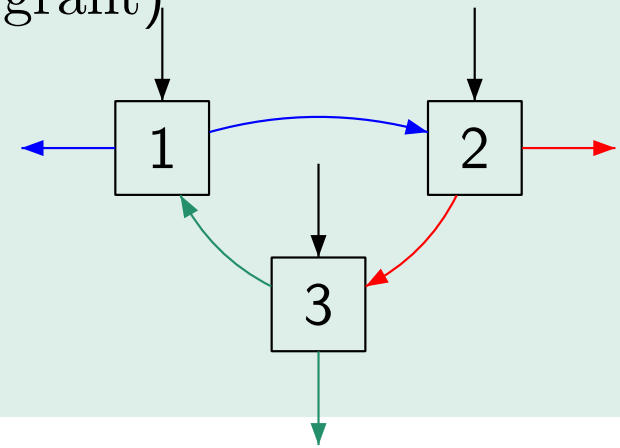

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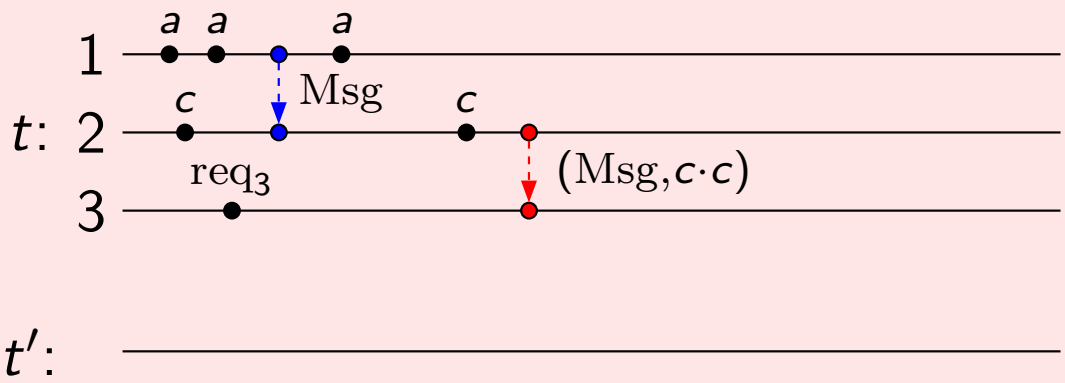

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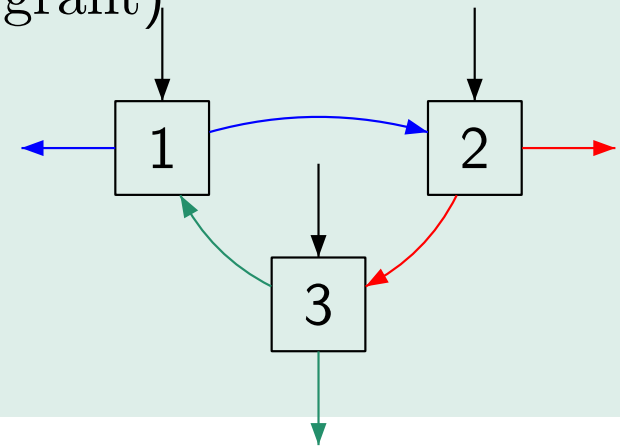

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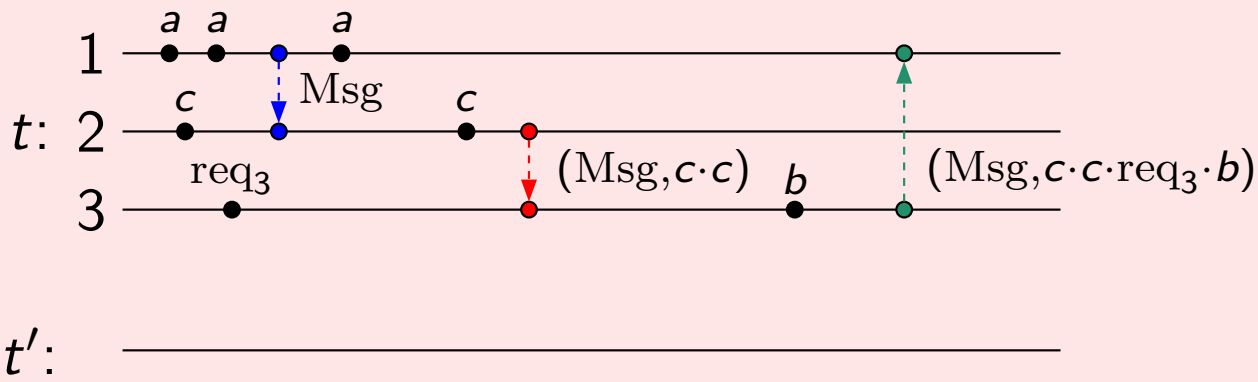

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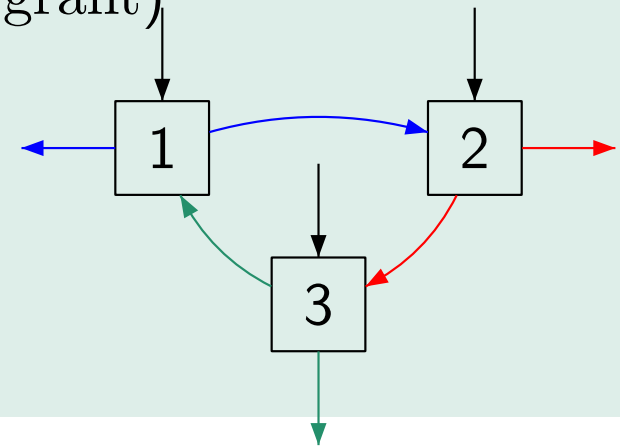

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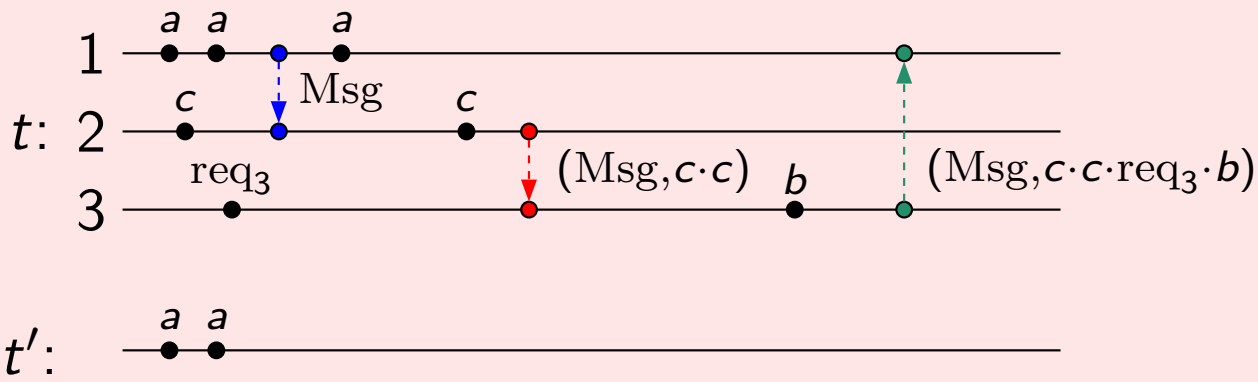

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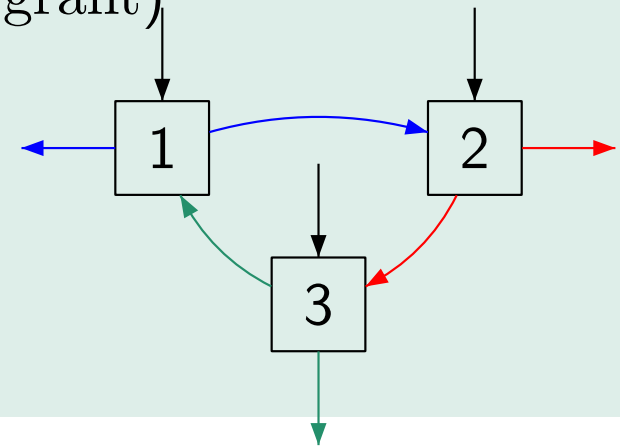

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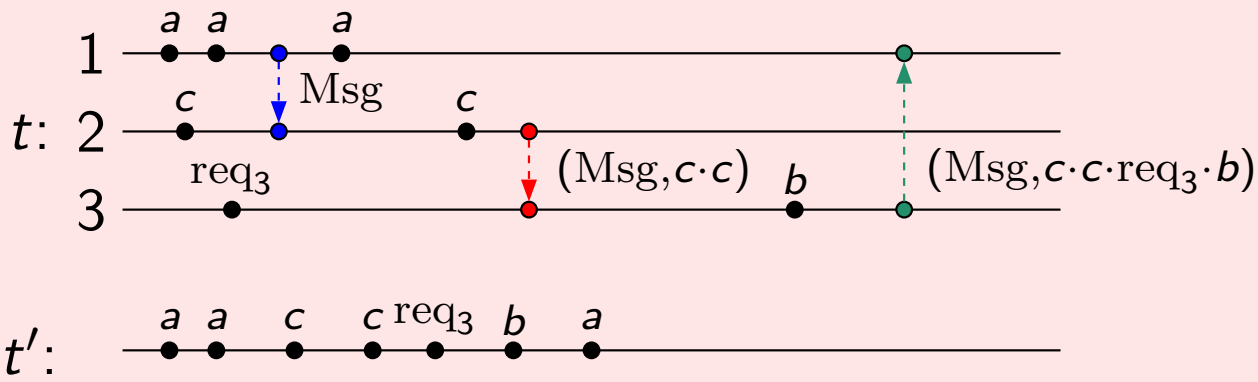

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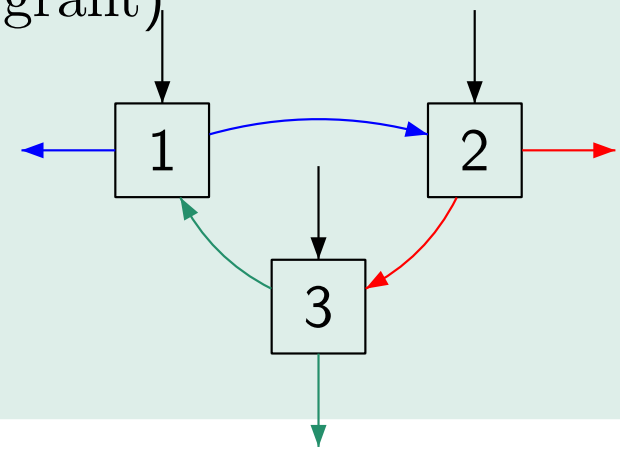

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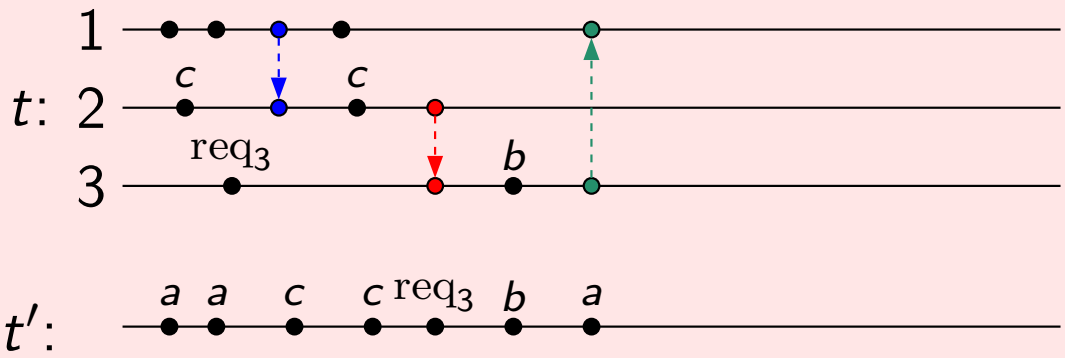

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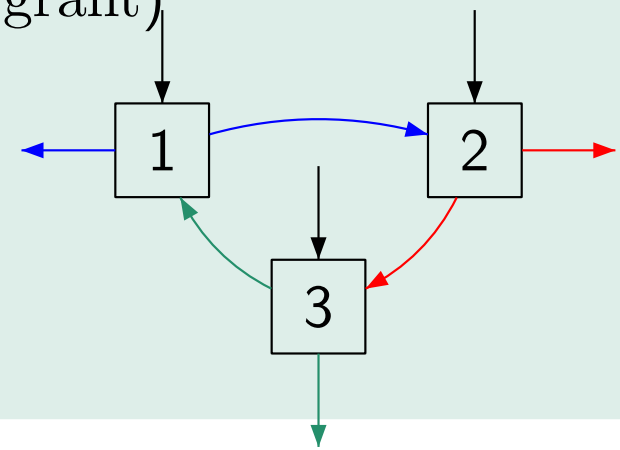

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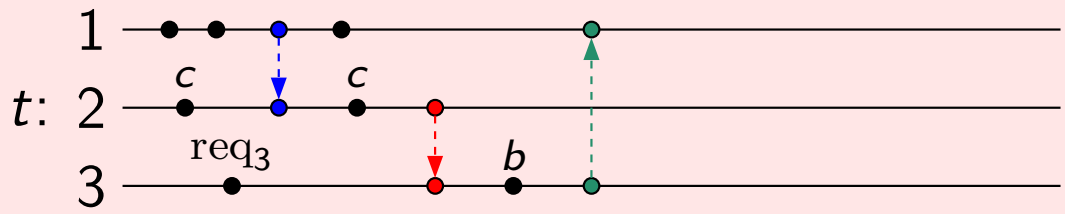

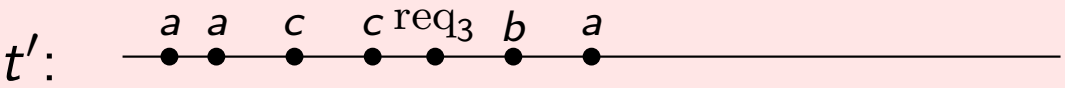

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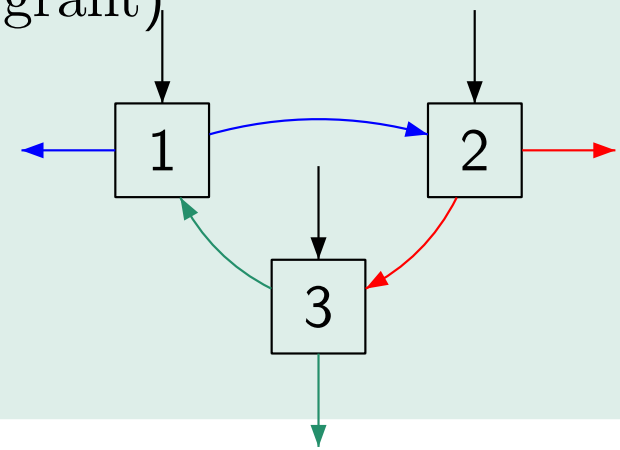

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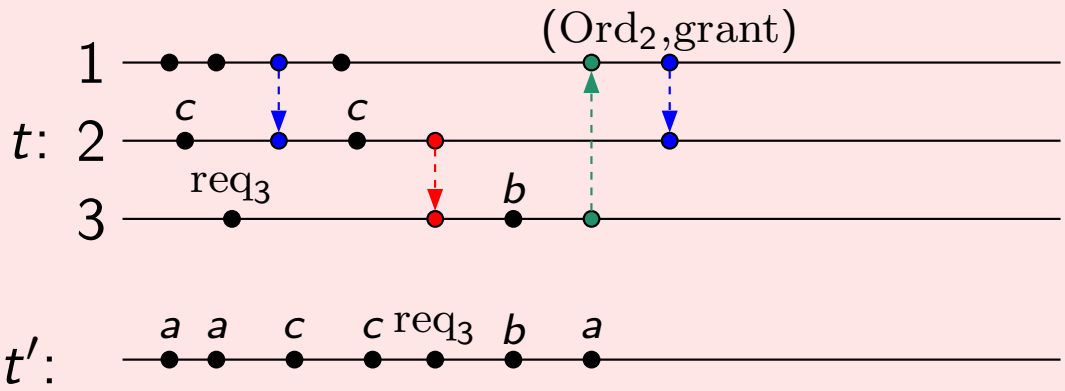

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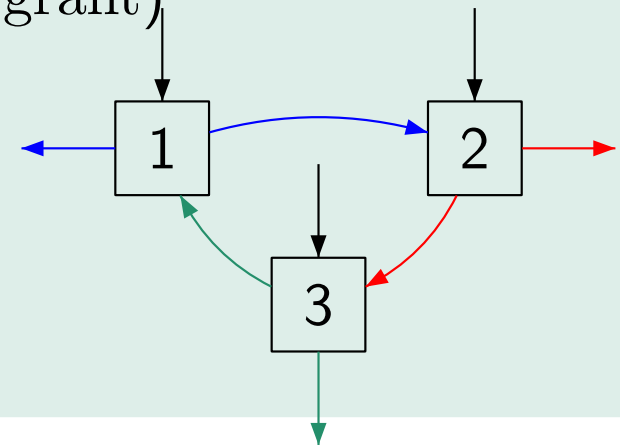

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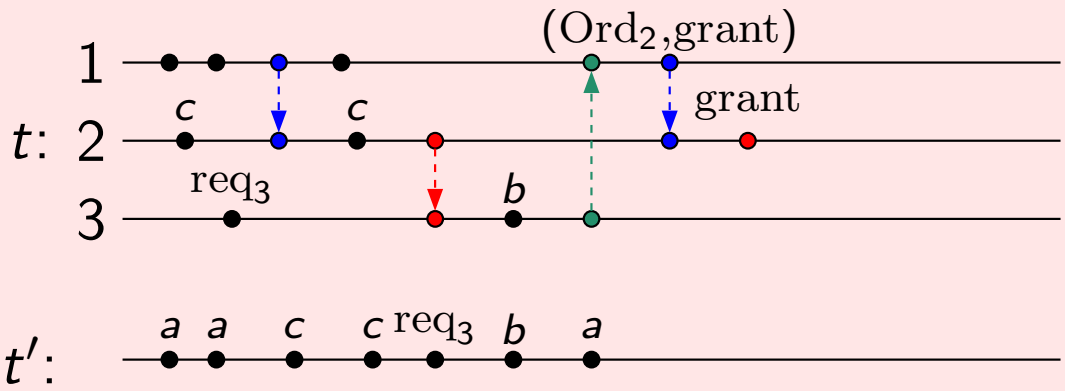

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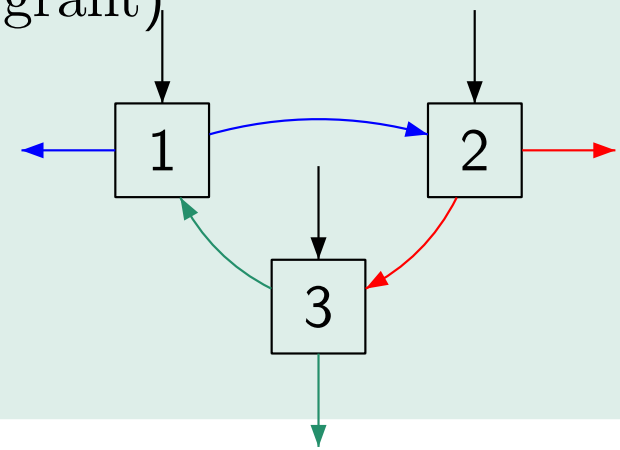

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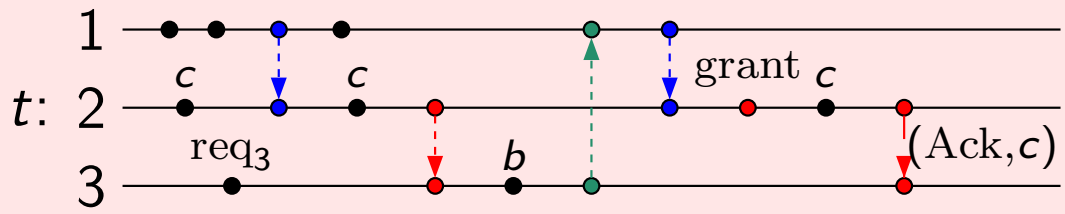

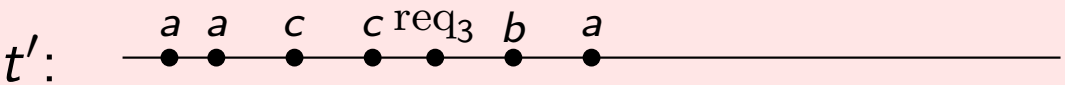

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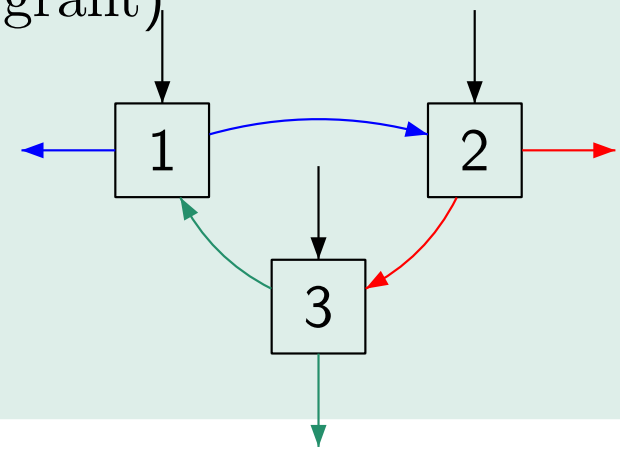

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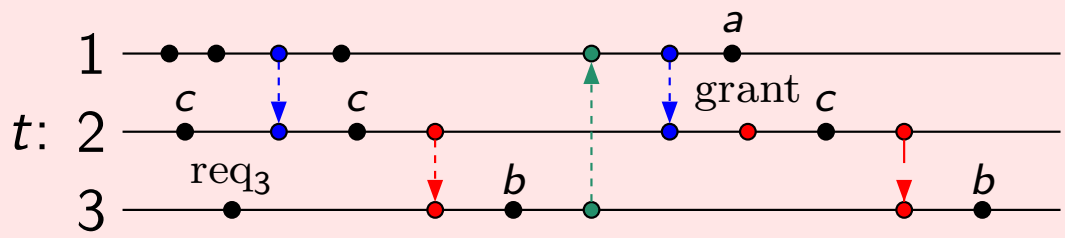

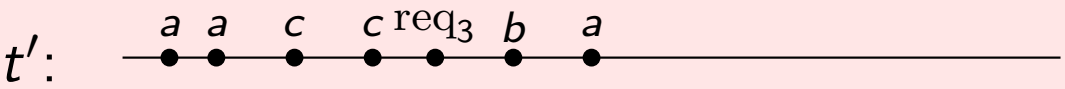

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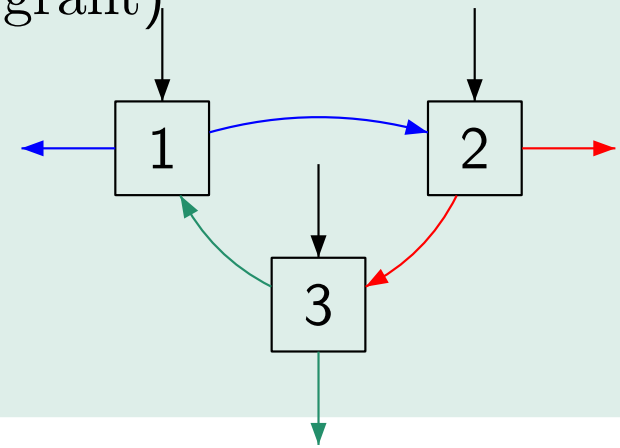

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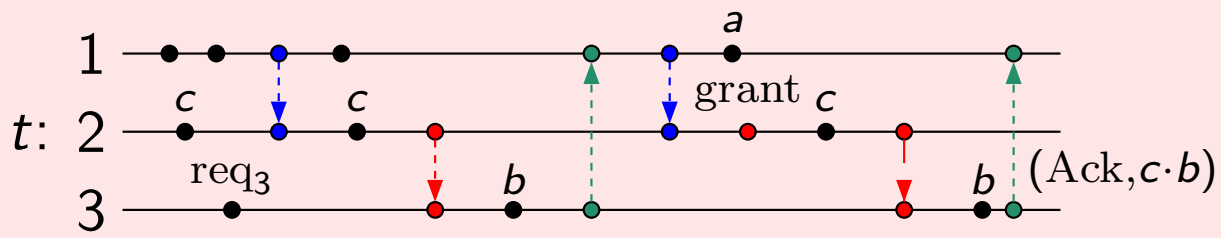

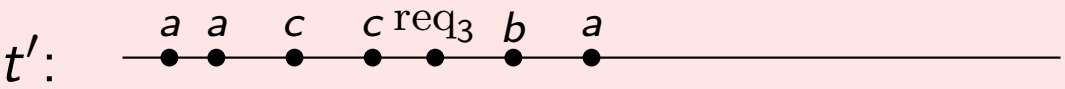

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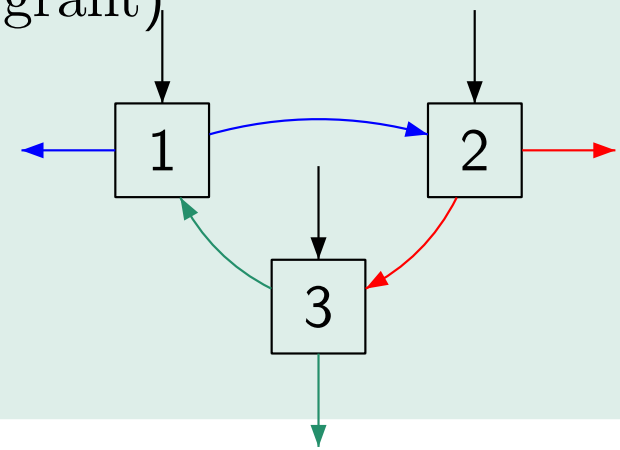

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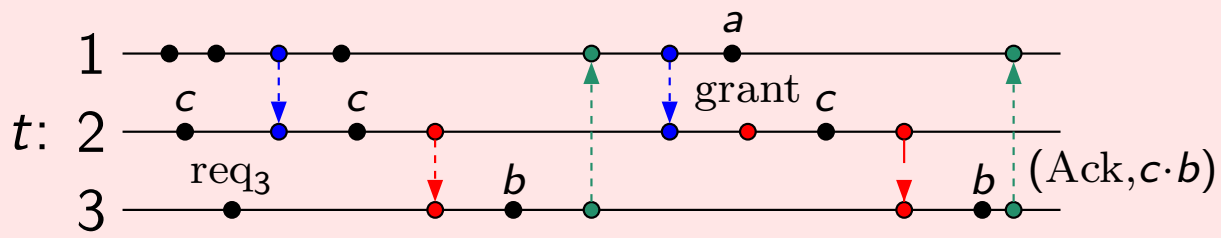

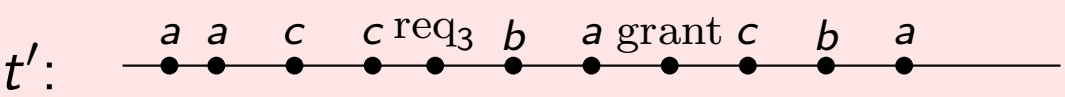

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Tell processes what to ouptut (2)

Example

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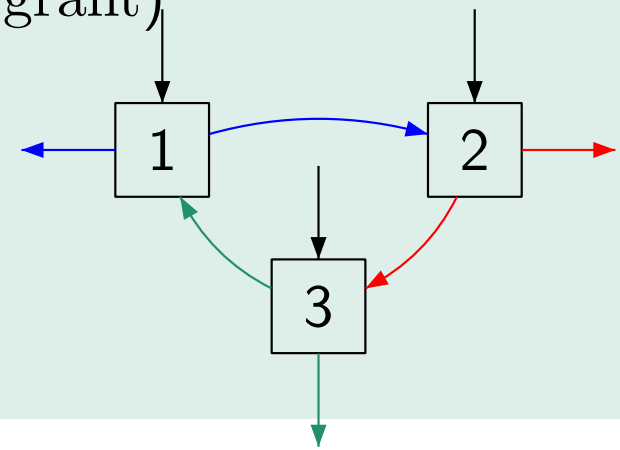

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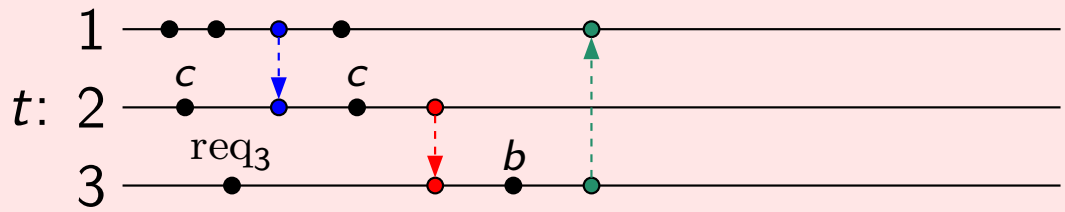

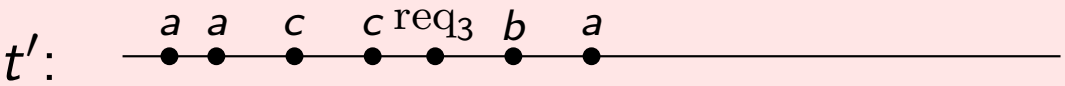

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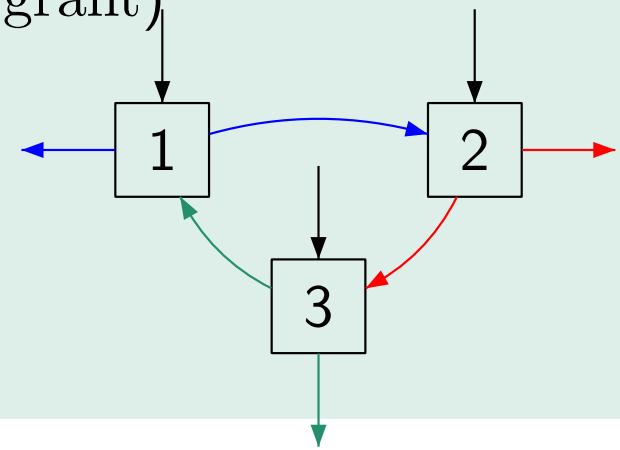

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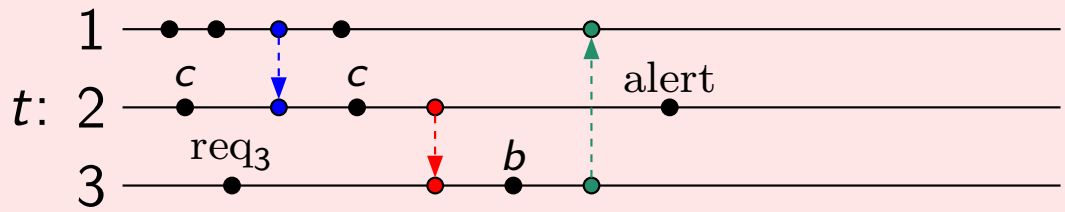

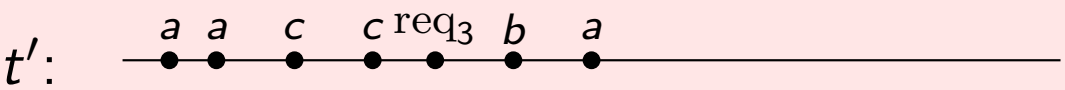

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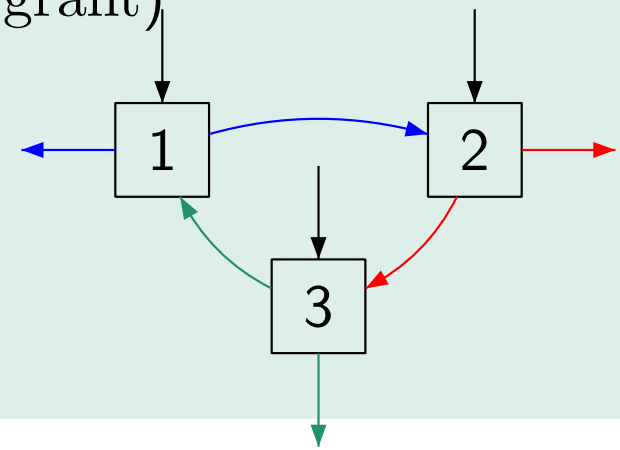

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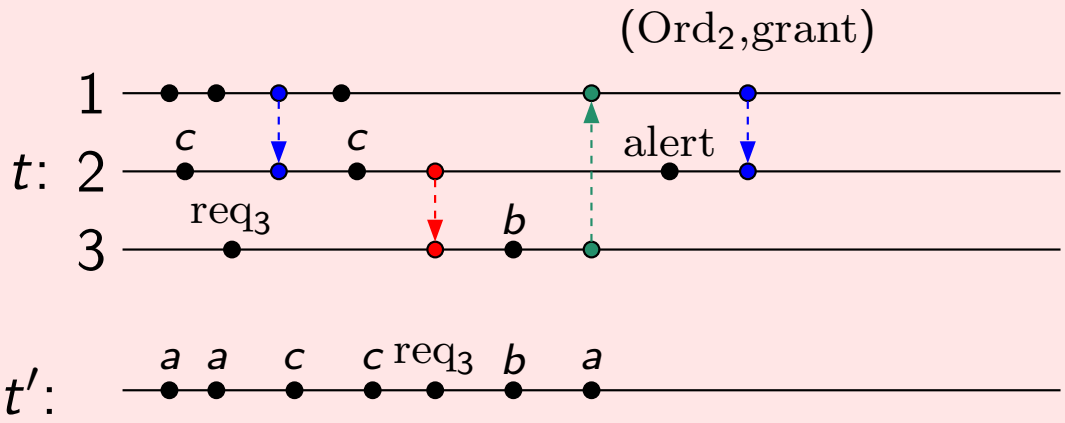

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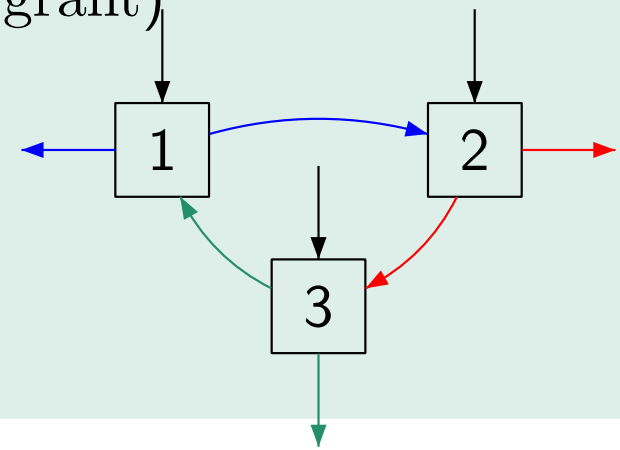

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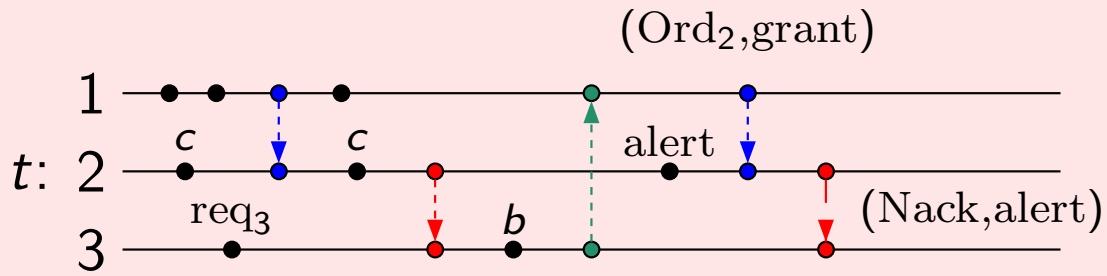

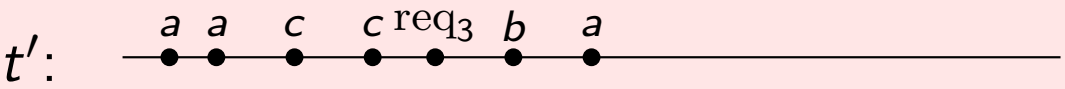

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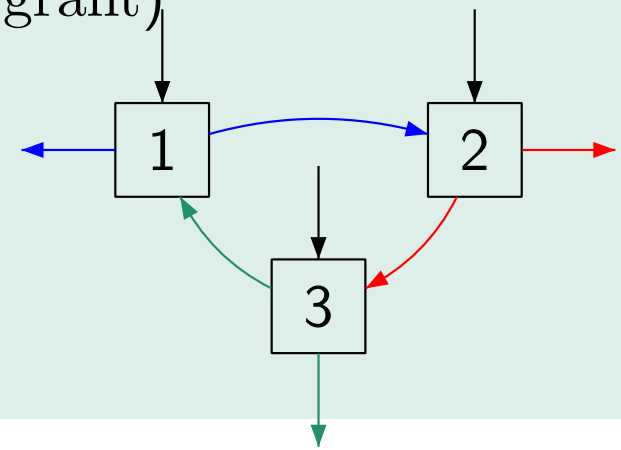

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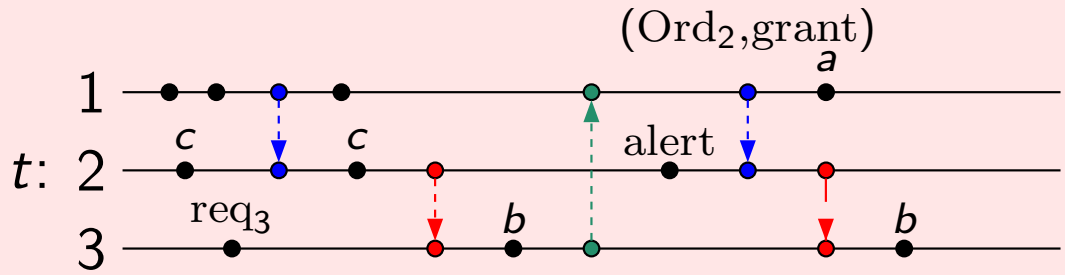

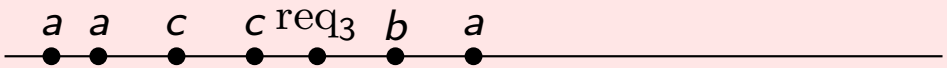

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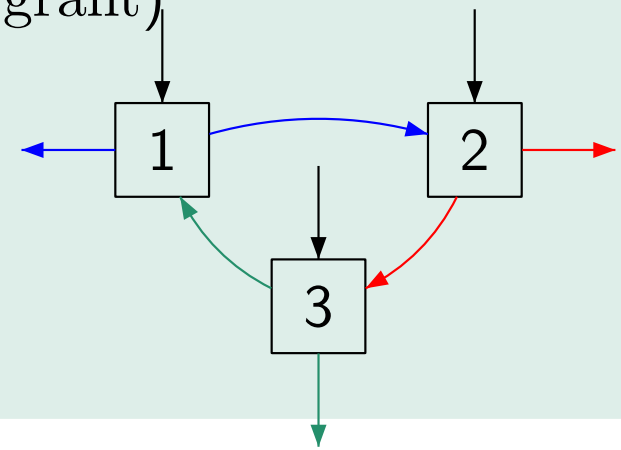

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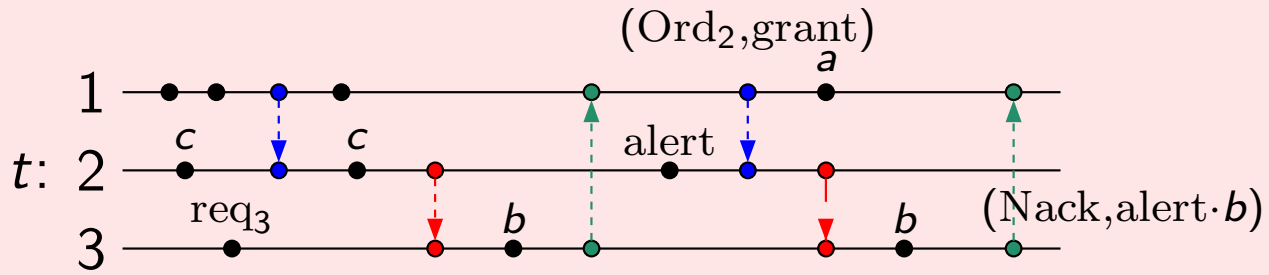

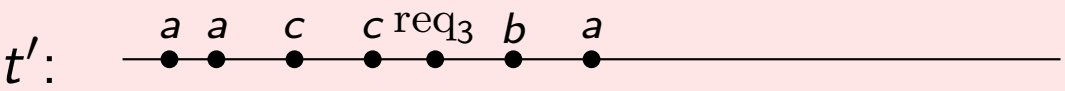

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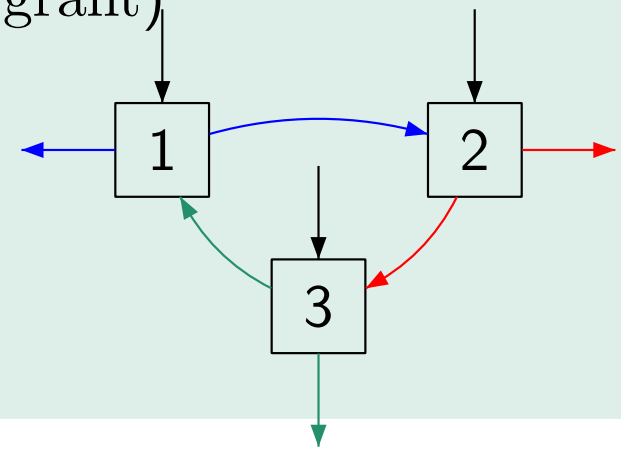

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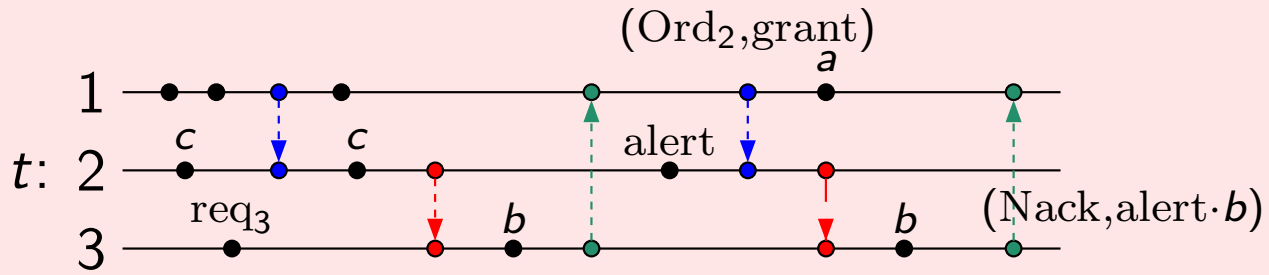

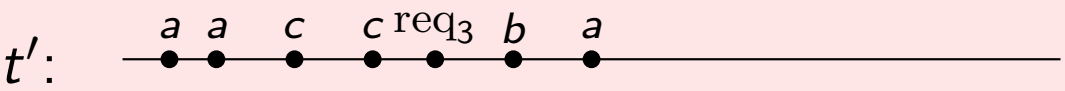

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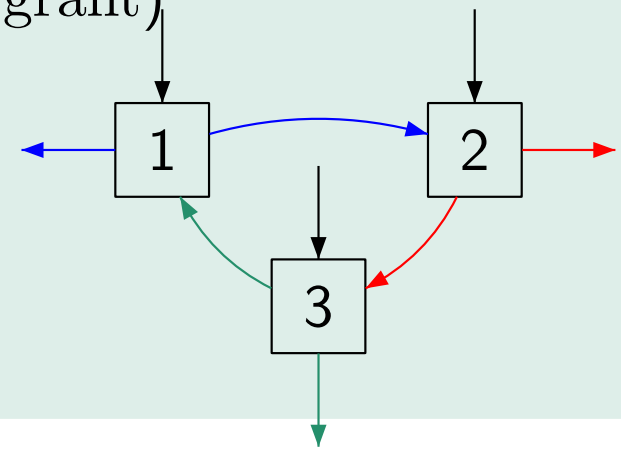

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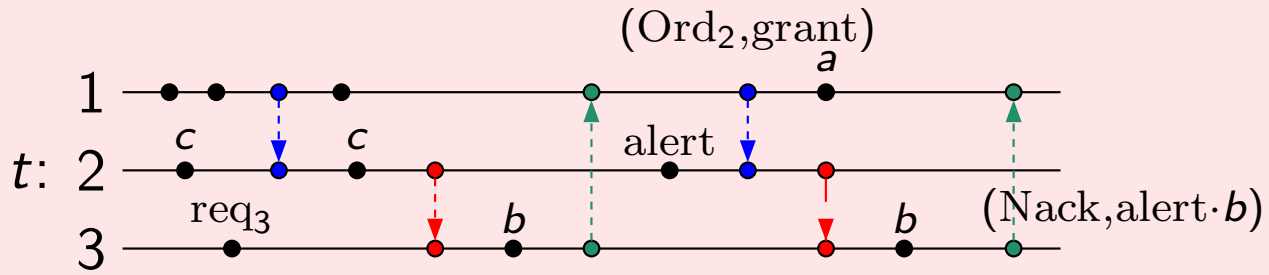

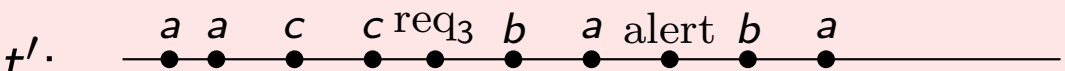

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Proof - end

Lemma

t' is an f-run.

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$\pi_\Gamma(t)$ is a weakening of t'.

Conclusion

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Then $t' \models \varphi$ and, by closure property $\pi_\Gamma(t) \models \varphi$.

Proposition

If there are communication sets $\Sigma_{i,j}$ for $(i,j) \in E$ and a winning distributed strategy on the strongly connected architecture, then there is a winning strategy on the singleton.

Proof

Easier.

Conclusion

- Asynchrony removes undecidability causes
- We have defined a new model of communication
- We have identified a class of decidable architectures
- Hopefully, many more to come!