Synthesizing strategies to avoid deadlocks

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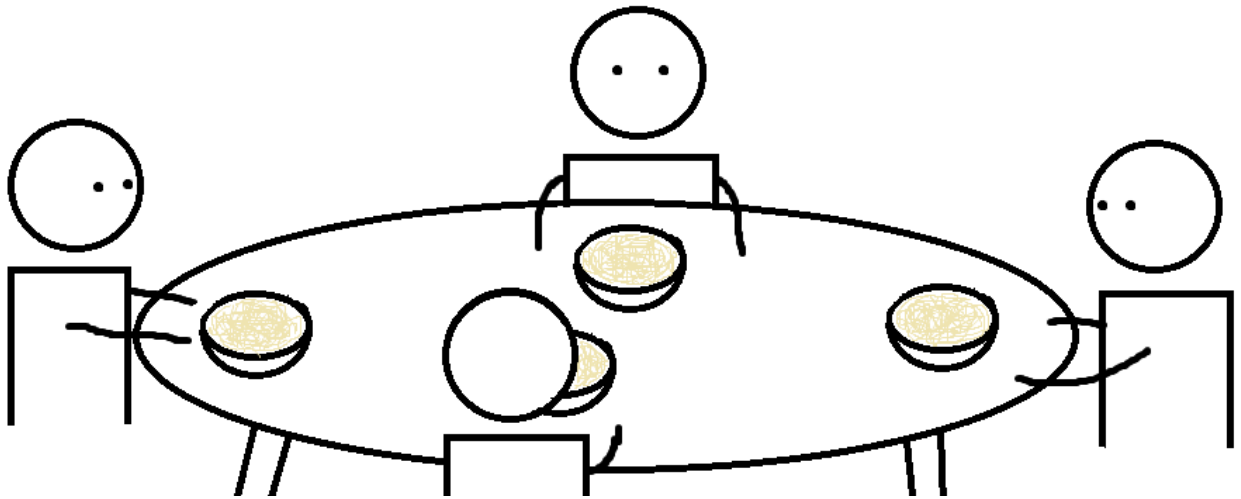
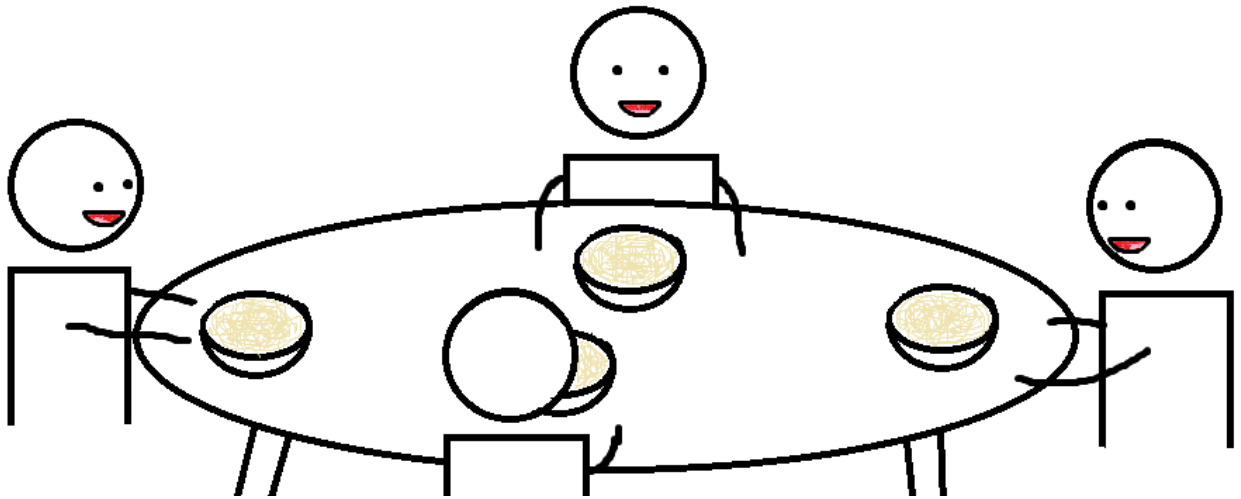
Joint work with Hugo Gimbert, Anca Muscholl and Igor Walukiewicz

RP 2022

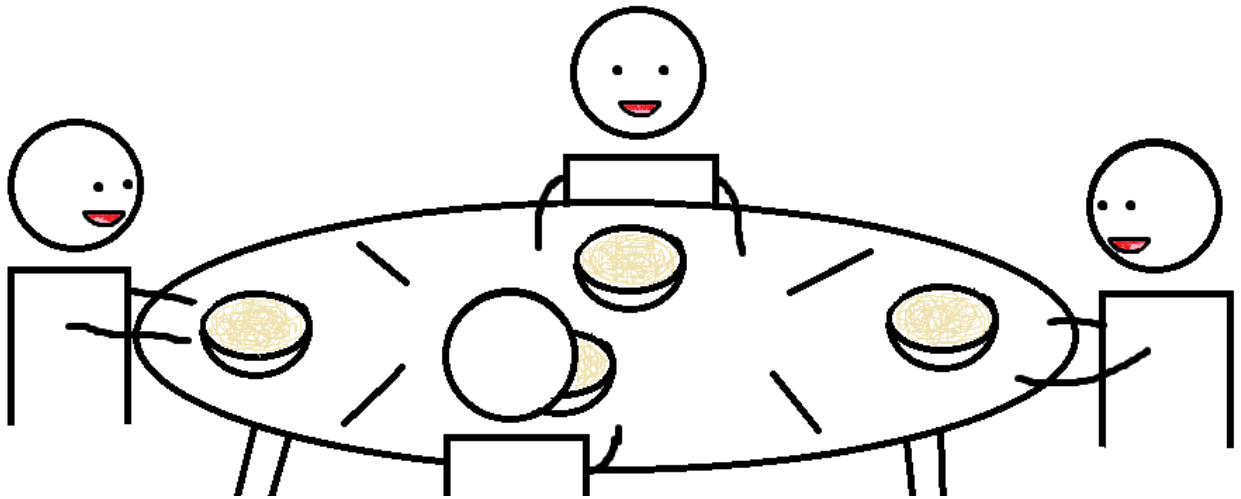
Dining philosophers



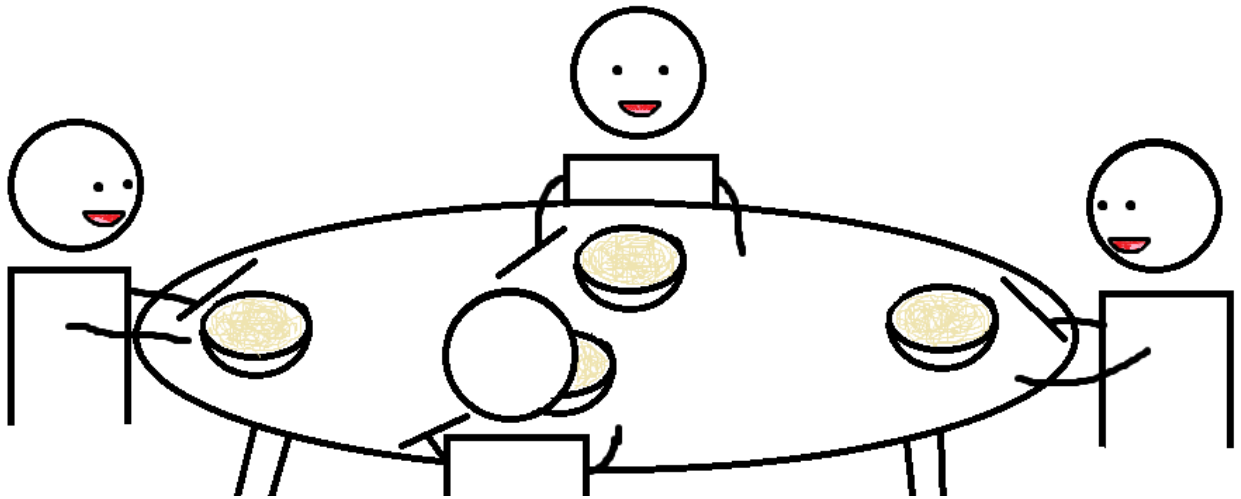
Dining philosophers



Dining philosophers



Dining philosophers



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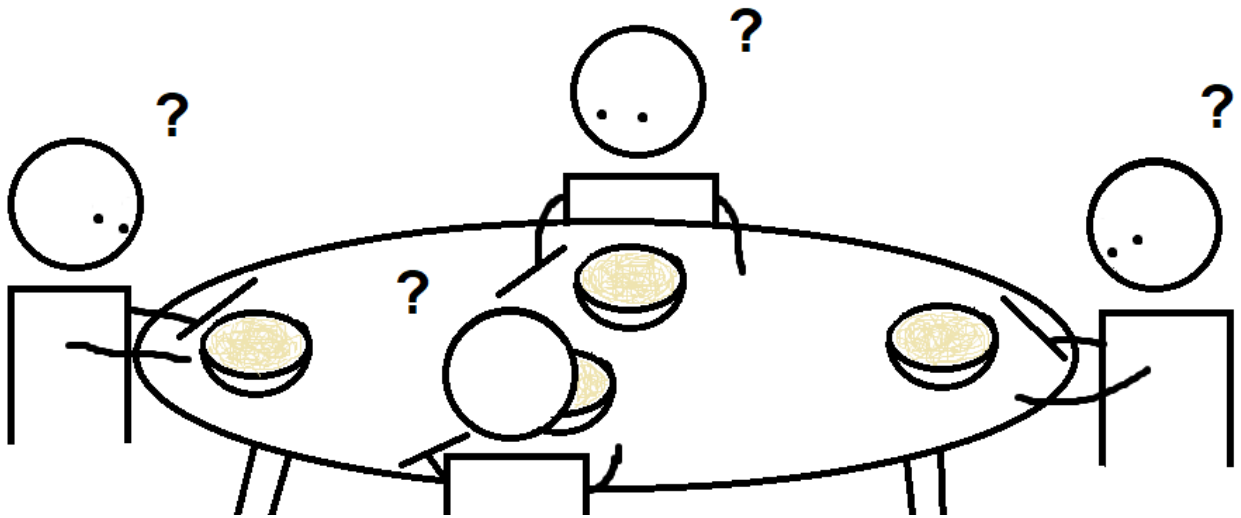
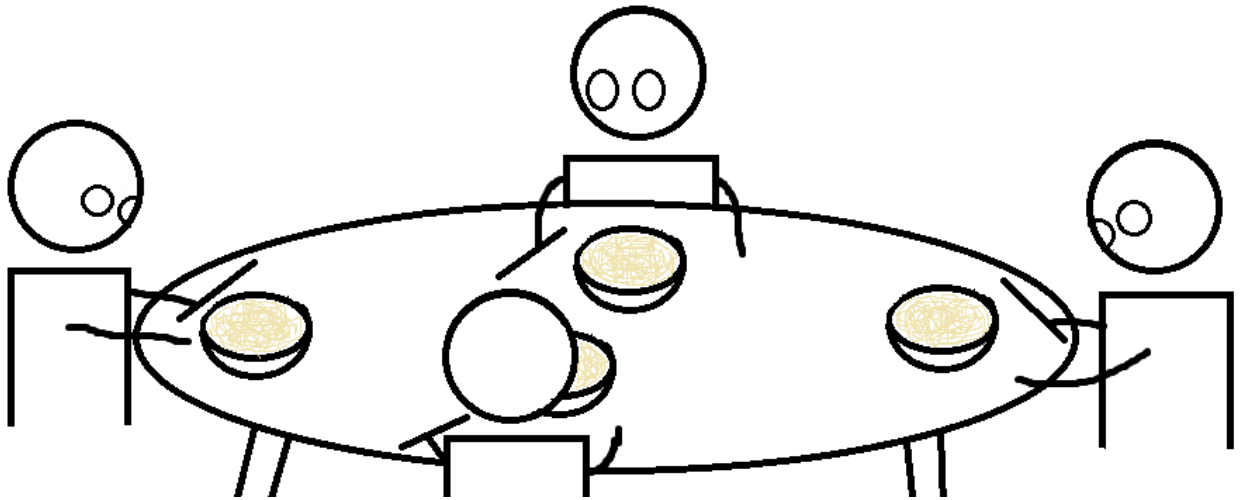
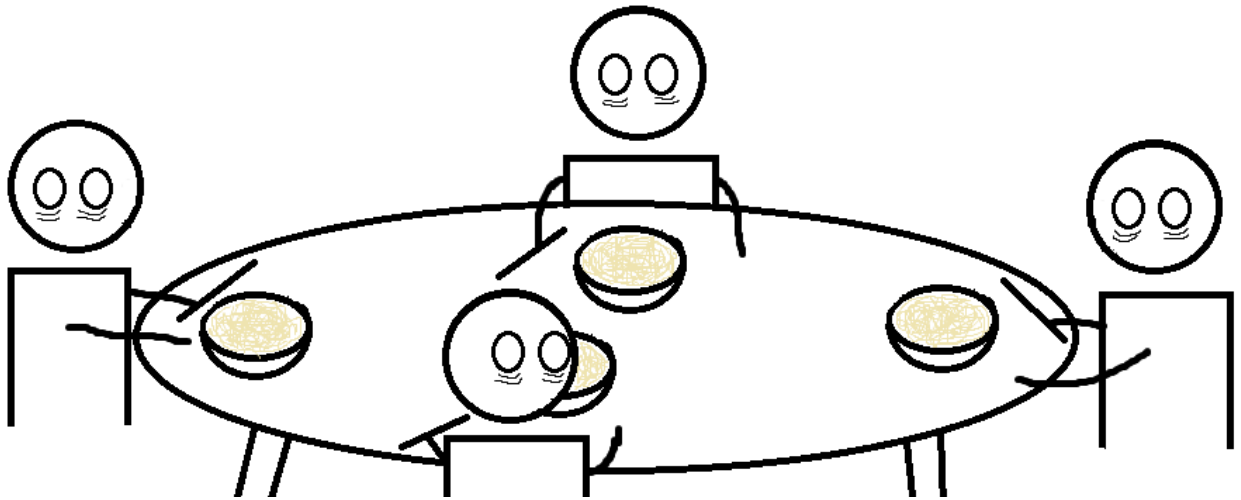


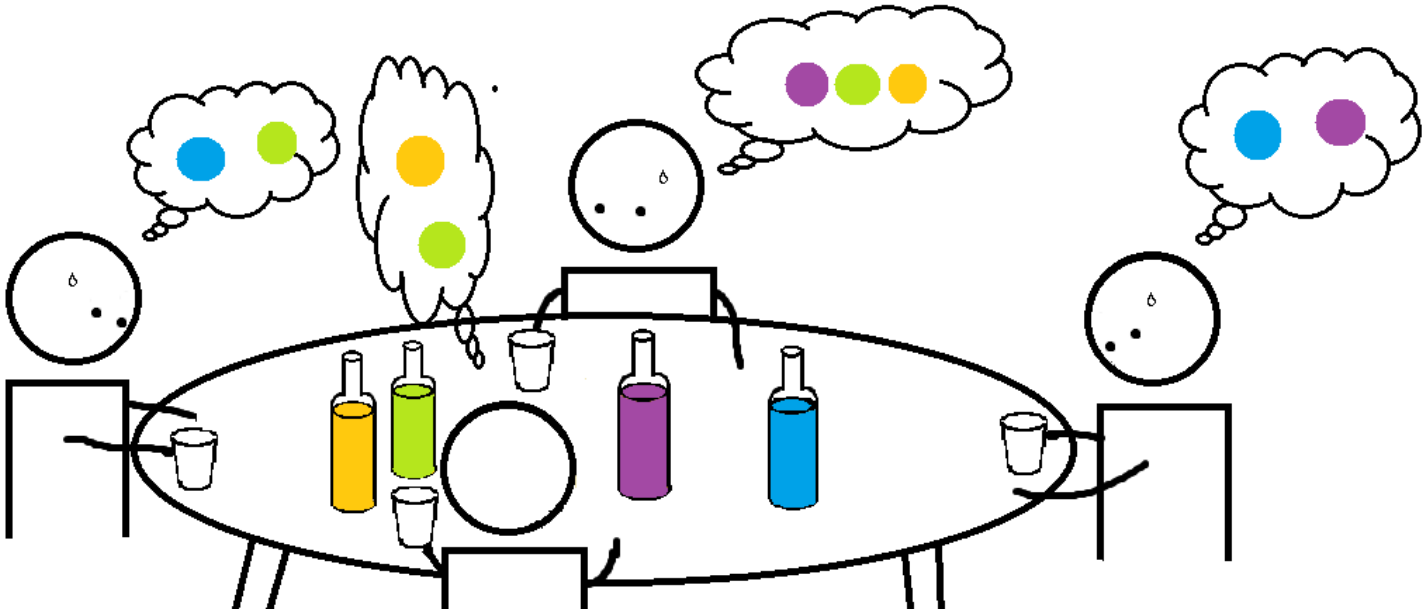
Dining philosophers



Dining philosophers



Drinking philosophers



Lock-sharing systems (LSS)

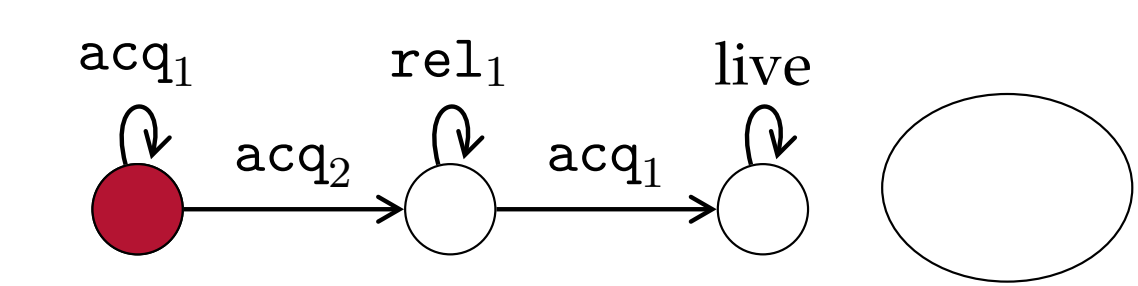
Lock-sharing system

$Proc$: set of processes T: set of locks .

Lock-sharing system: $\mathcal{A}_p = (S_p, \Sigma_p, \delta_p, init_p)$ for each $p \in Proc$.

Transitions include operations on locks :
$\delta_p : S_p \times \Sigma_p \to Op_T \times S_p$ with $Op_T = \{acq_t, rel_t \mid t \in T\} \cup \{nop\}$.

Semantics



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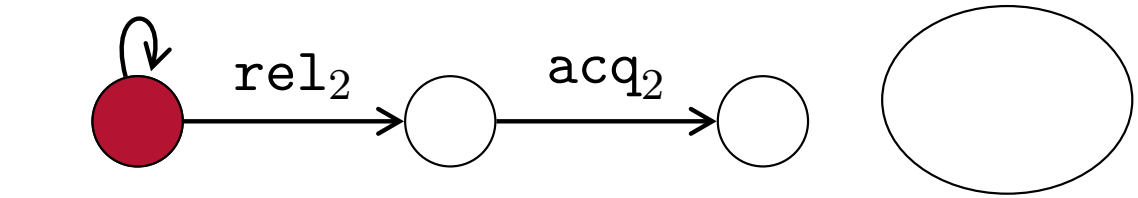

p_2

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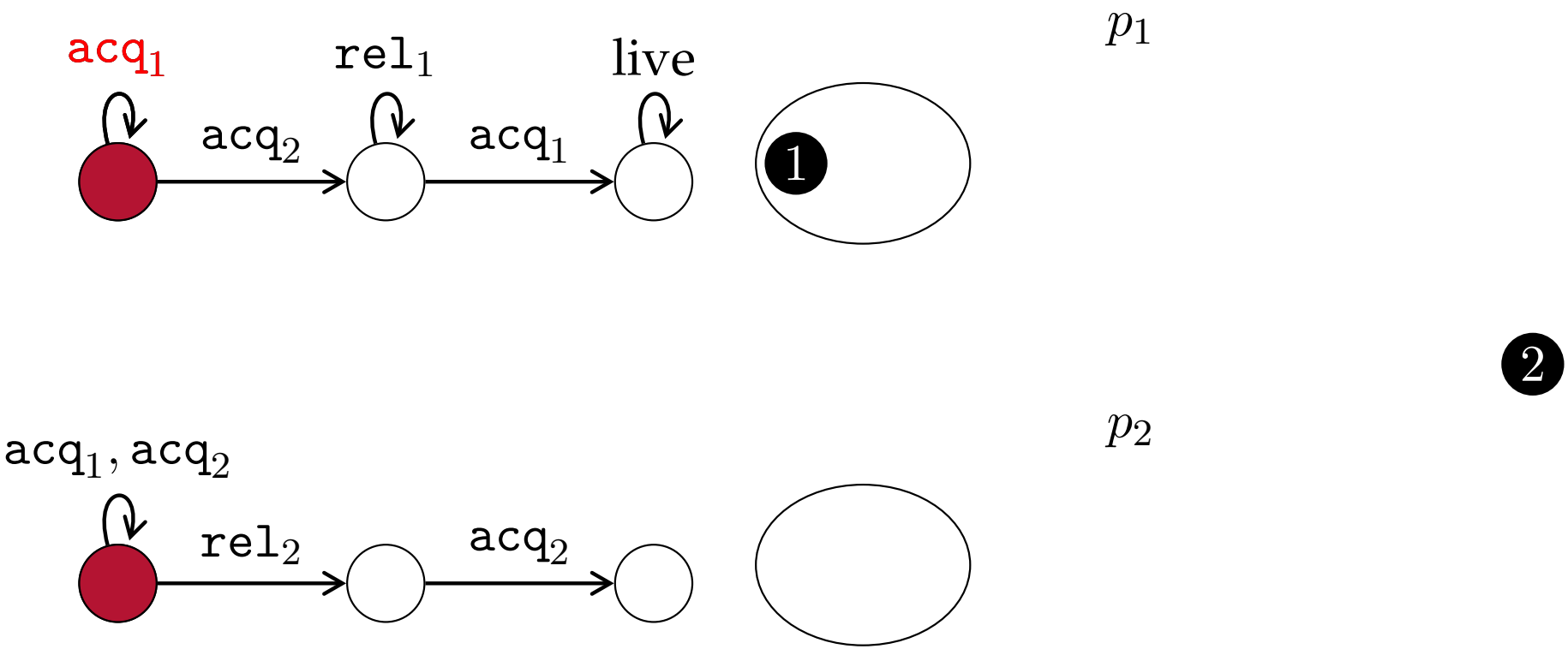
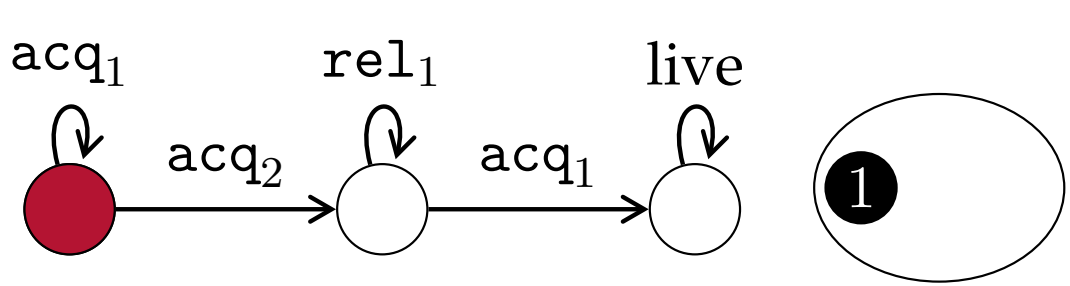
Semantics


$\mathtt{acq}_1$
$\mathtt{rel}_1$
live
$\mathtt{acq}_2$
$\mathtt{acq}_1$
1
p_1
2
$\mathtt{acq}_1, \mathtt{acq}_2$
$\mathtt{rel}_2$
$\mathtt{acq}_2$
p_2

Semantics



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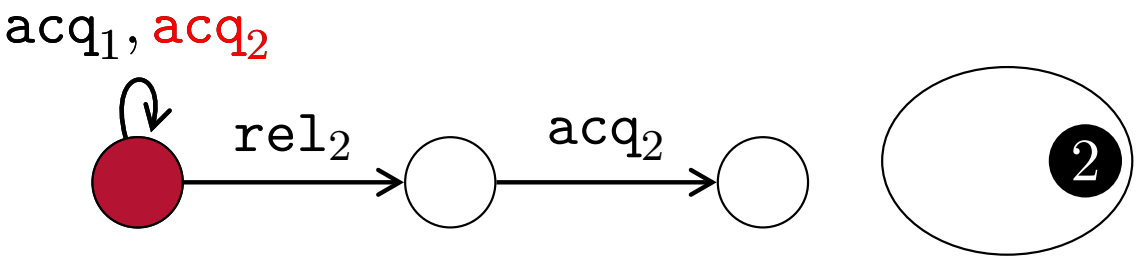
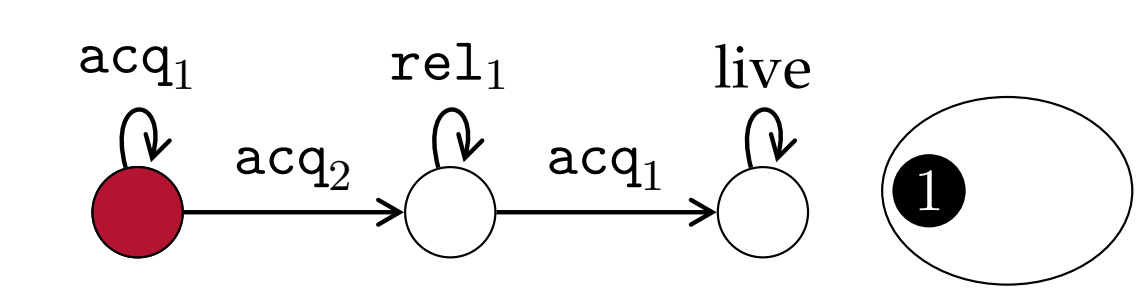


p_2

Semantics



p_1

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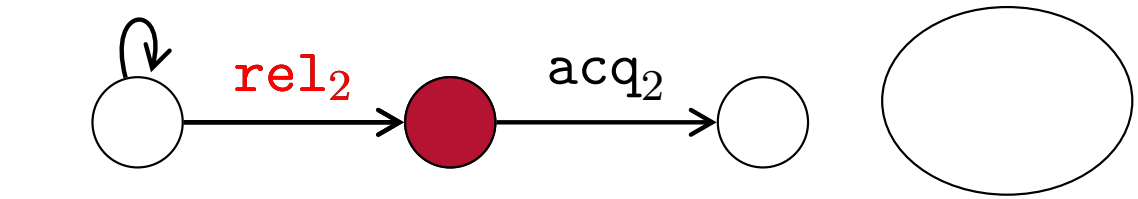
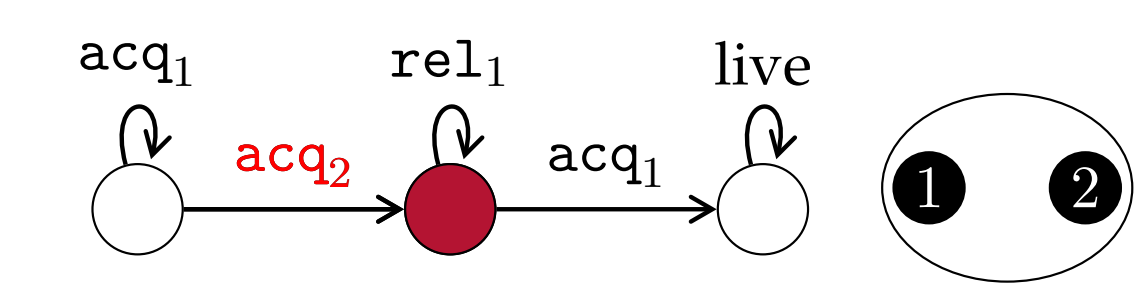
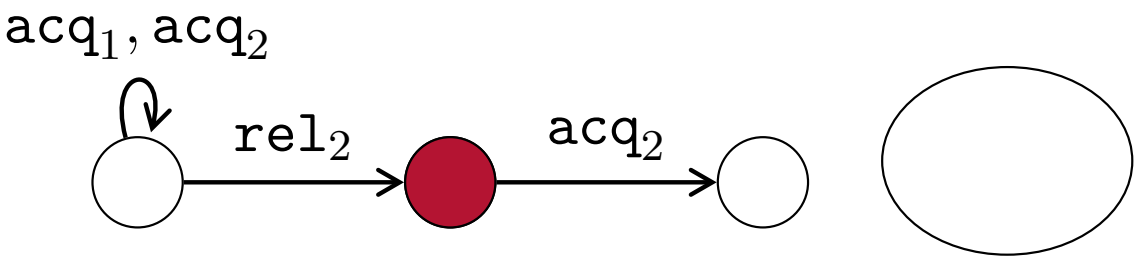
p_2



Semantics



p_1



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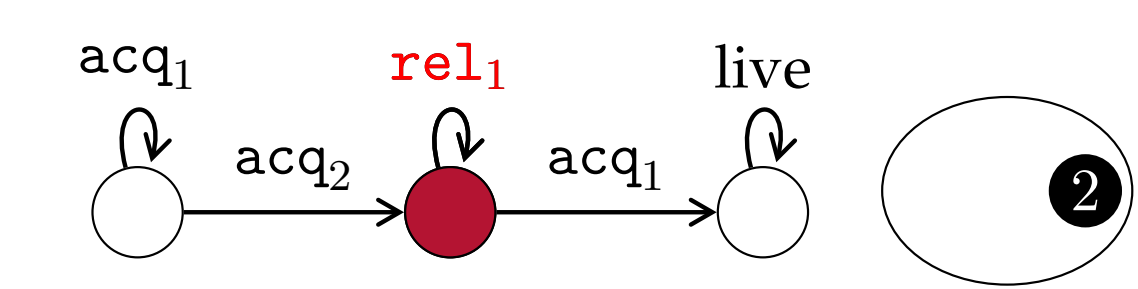
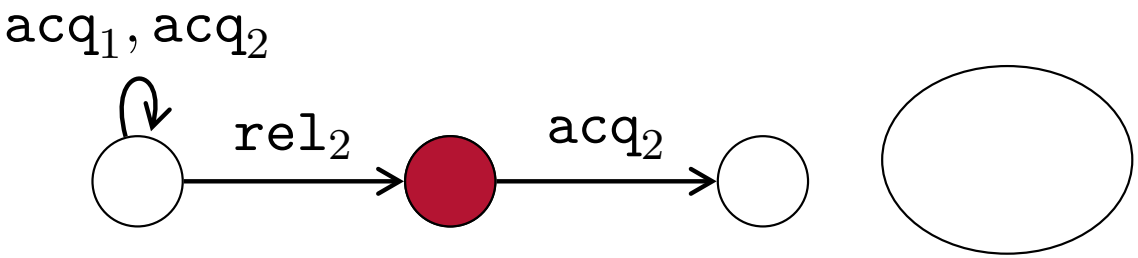
Semantics



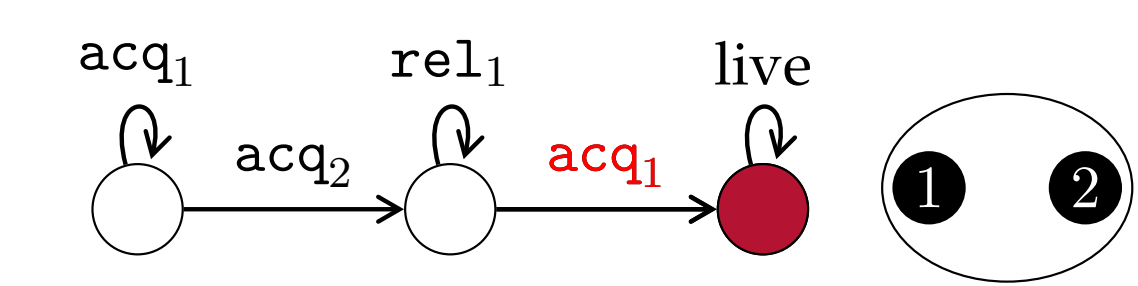
p_1

1

p_2



Semantics



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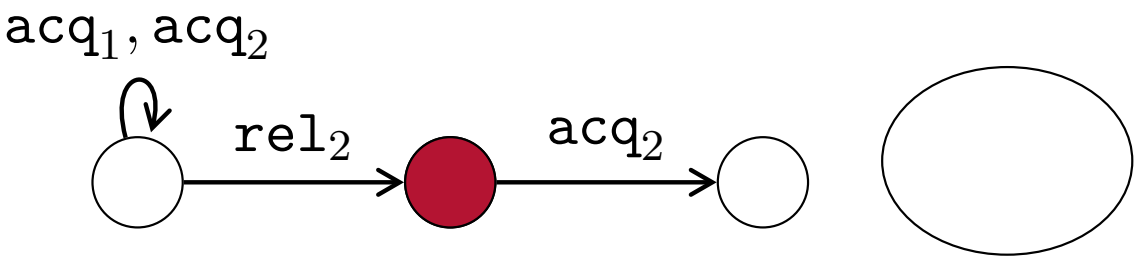


p_2

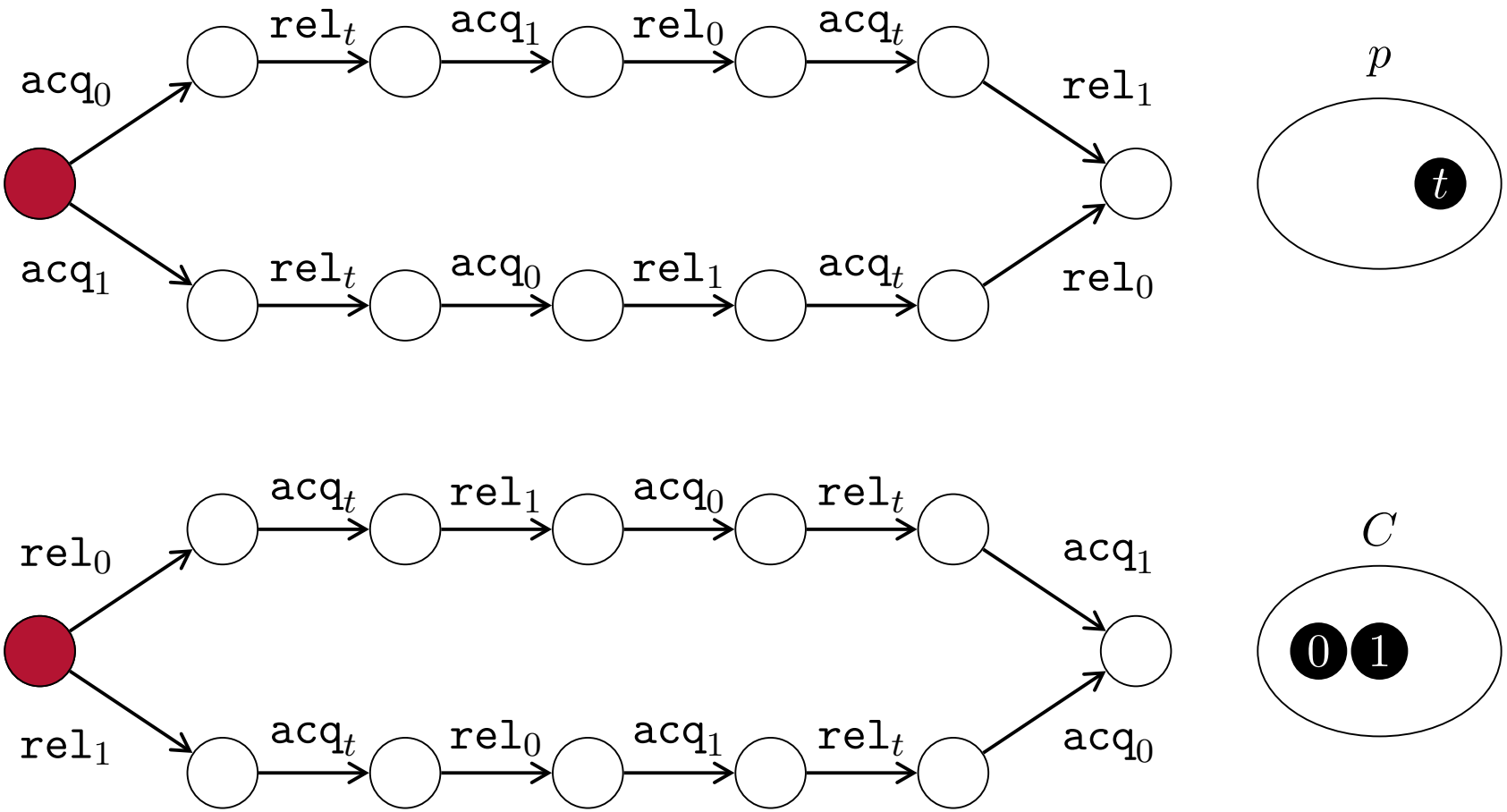
A problem

Model-checking problem

Input: A set of processes $Proc$, a set of locks T, an LSS $(\mathcal{A}_p)_{p \in Proc}$, a property $\mathcal{P}$ (for instance $\mathcal{P}$ =“the run ends in a deadlock”)

Output: Is there a run satisfying $\mathcal{P}$?

Passing information



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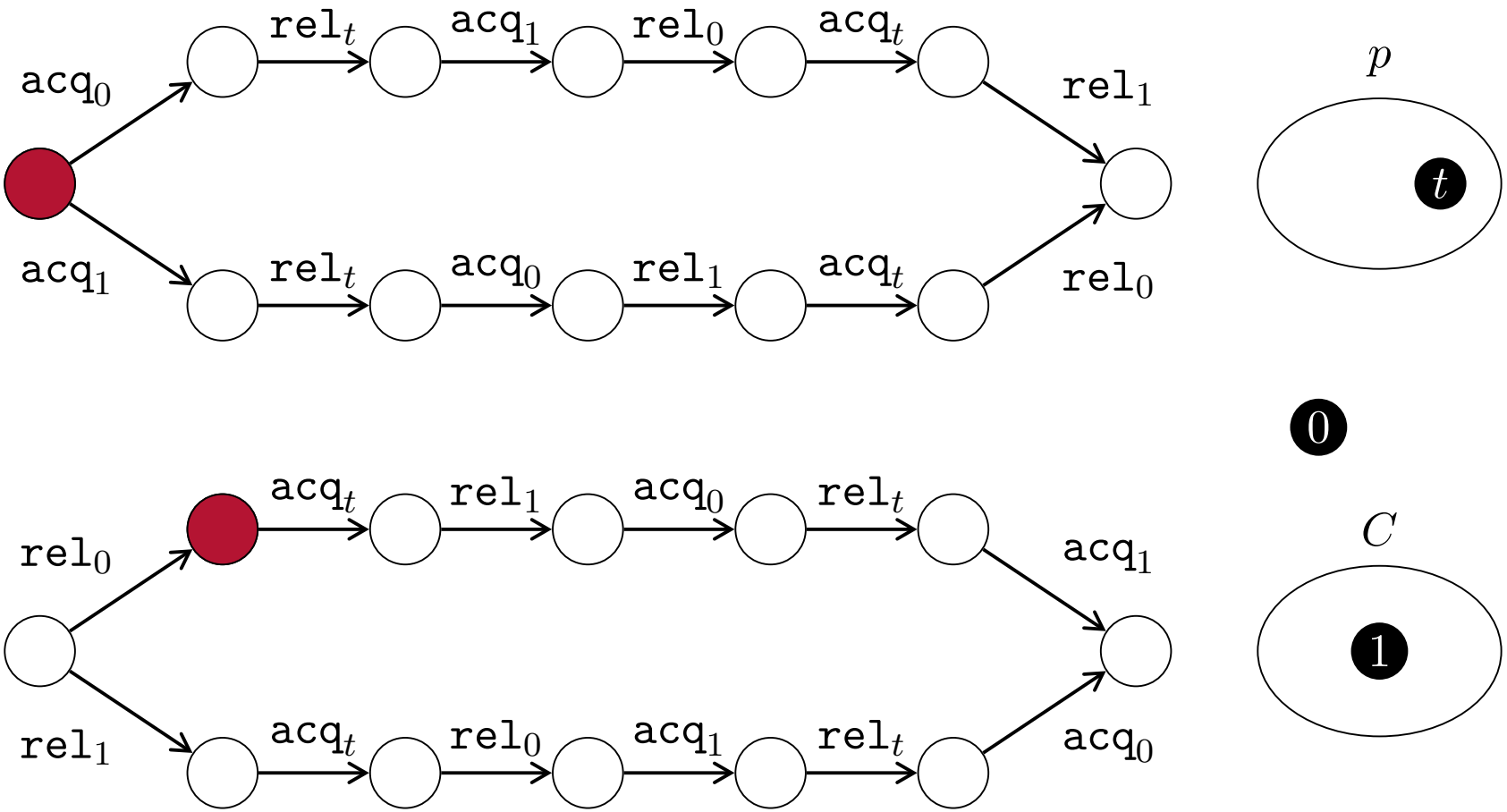

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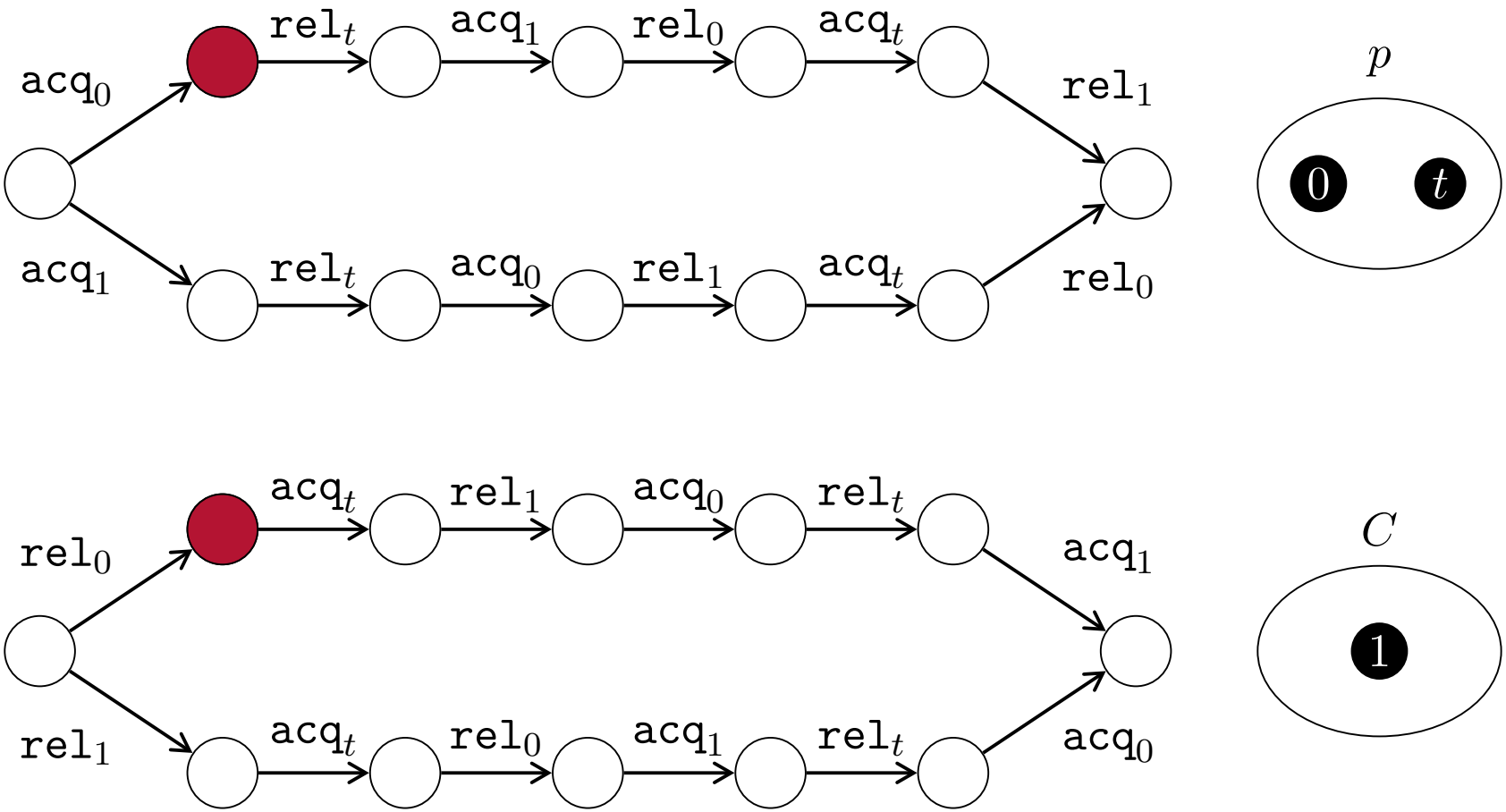

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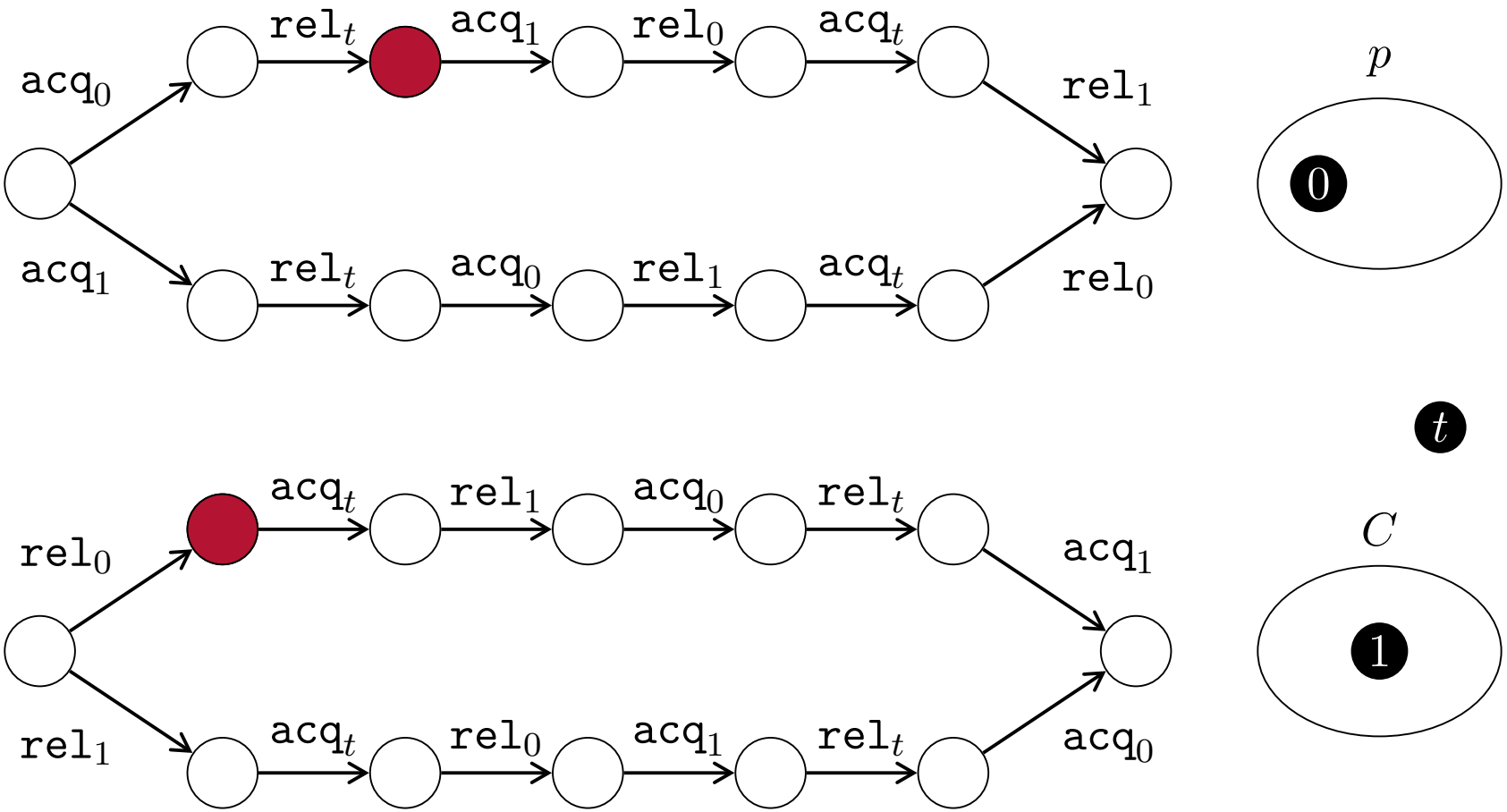

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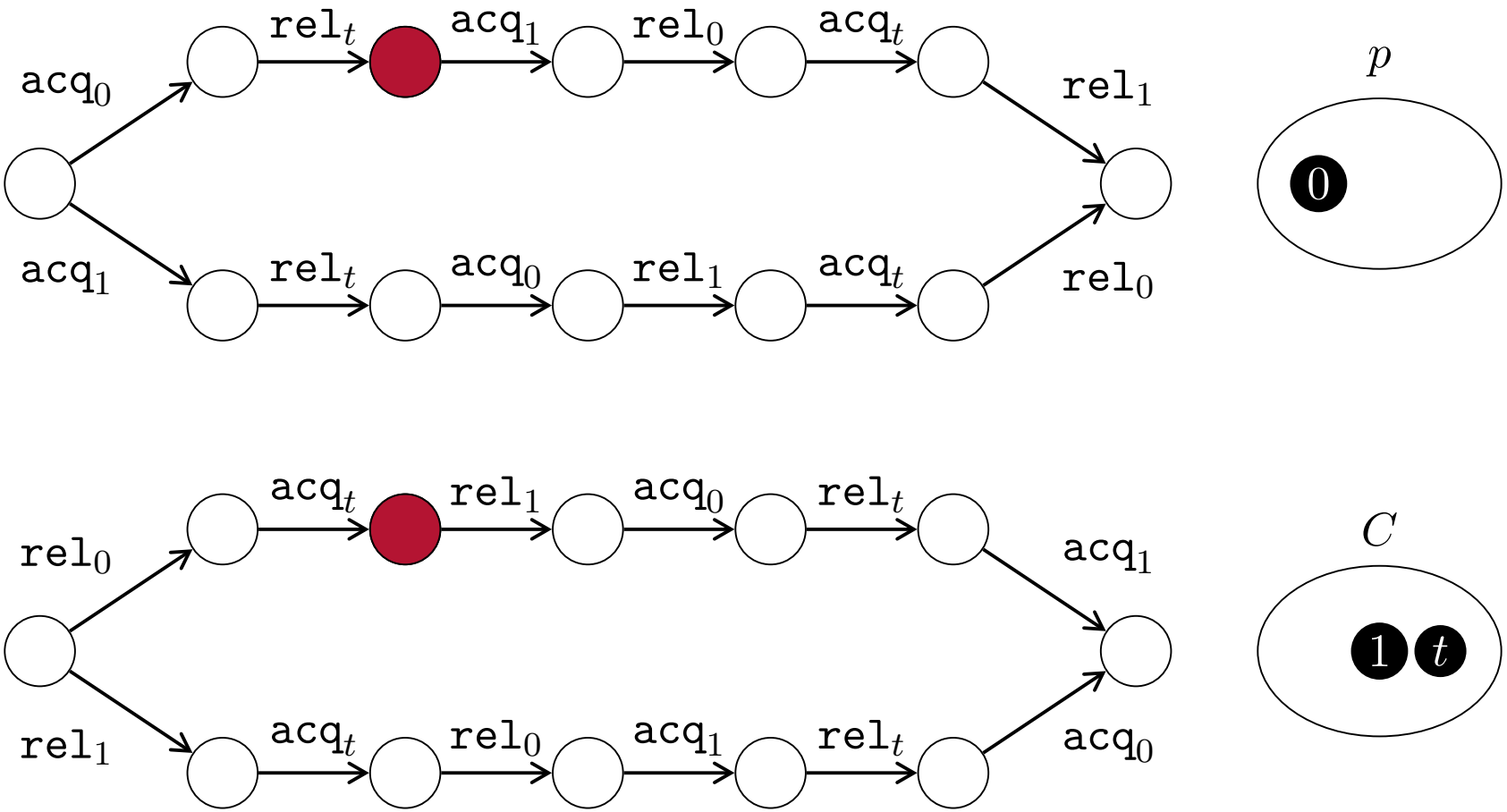

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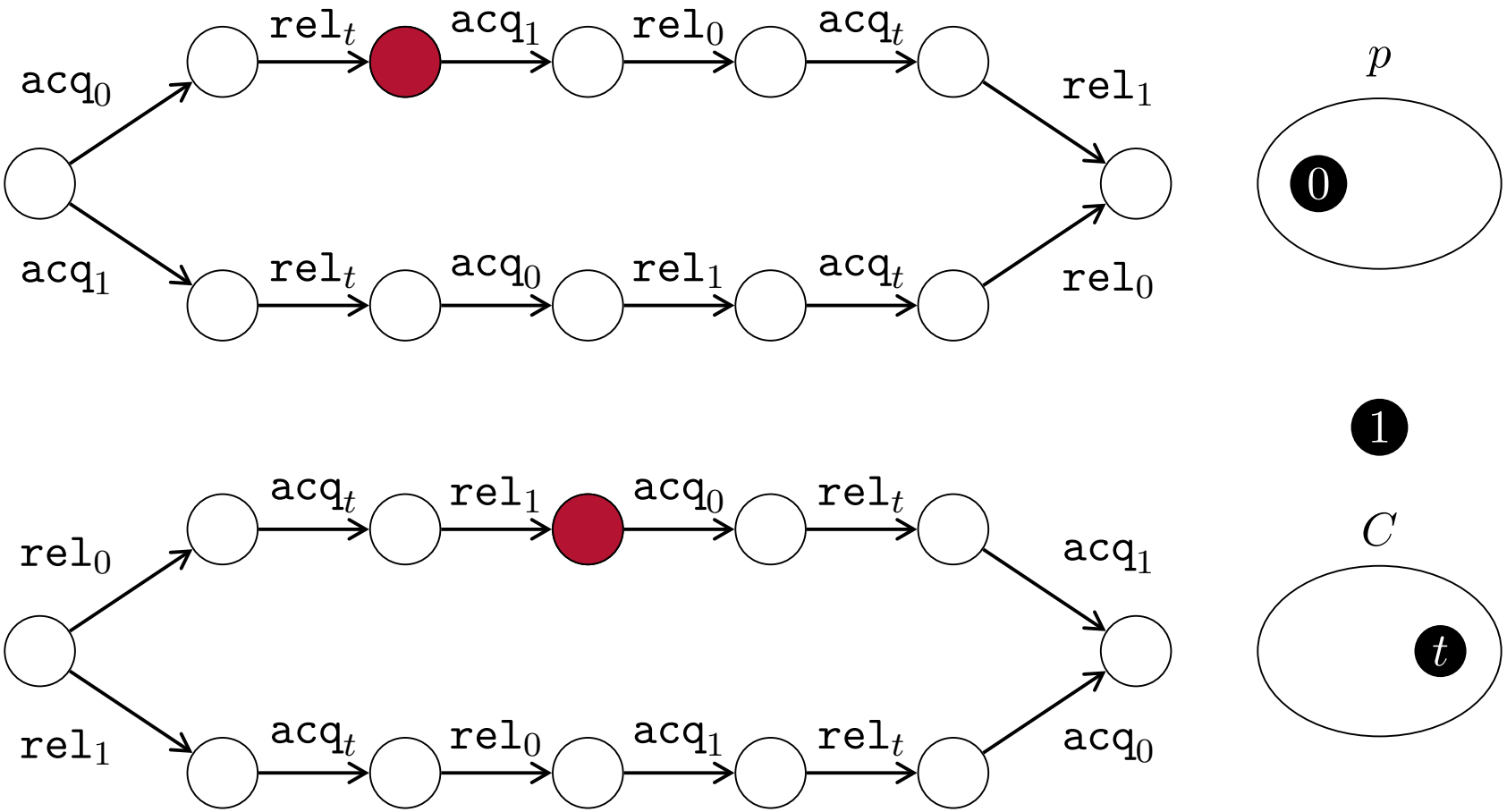

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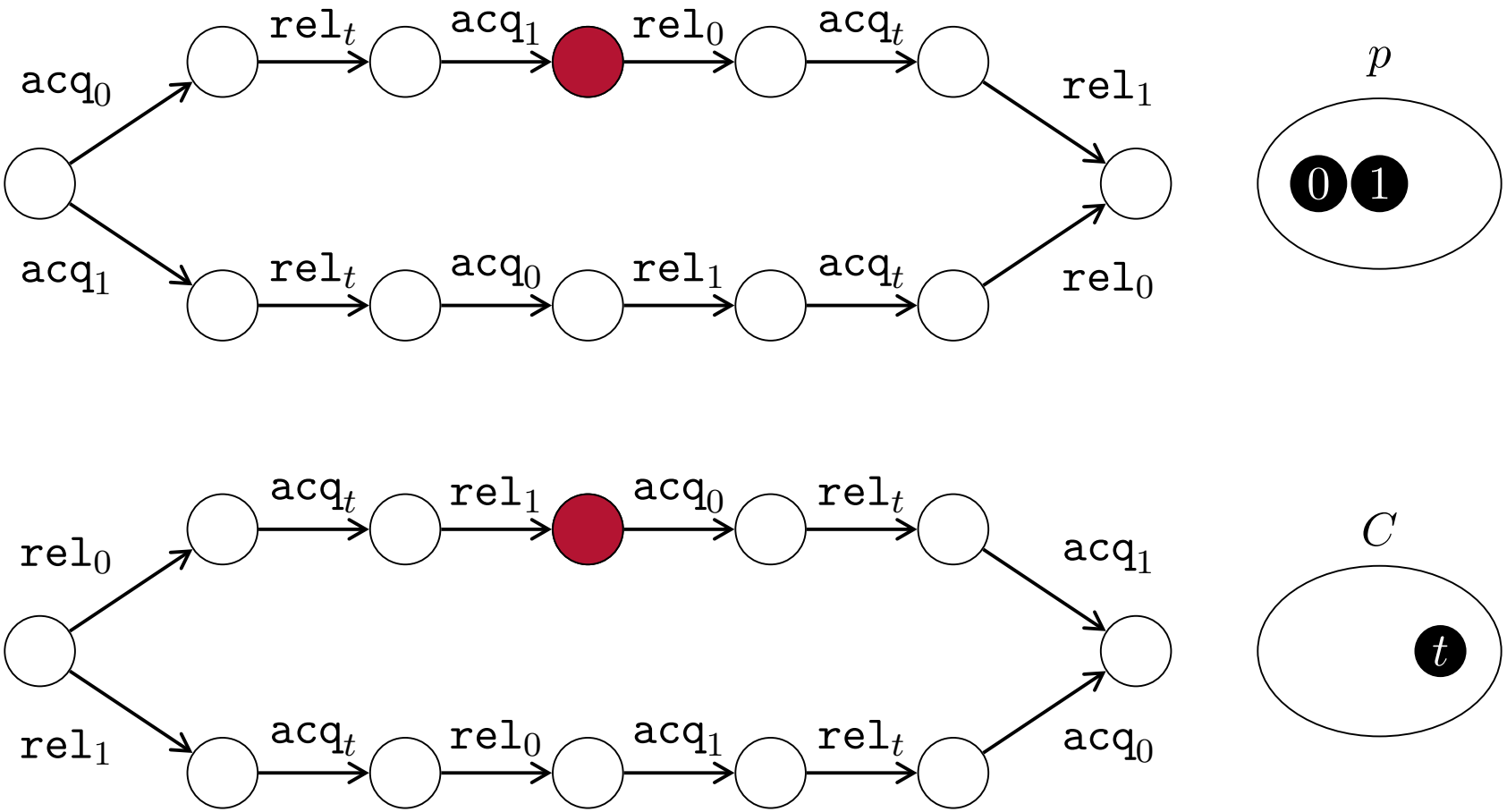

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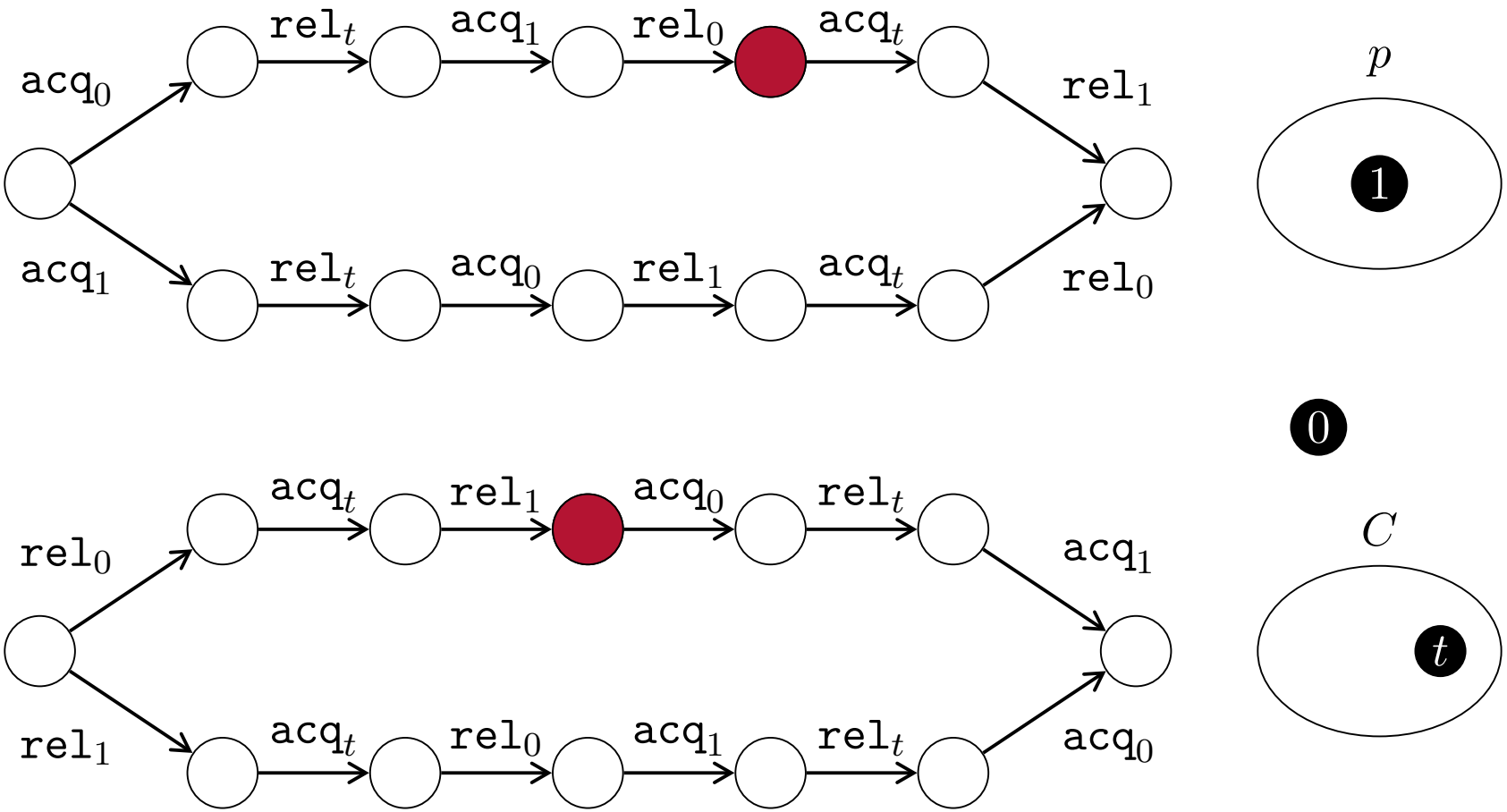

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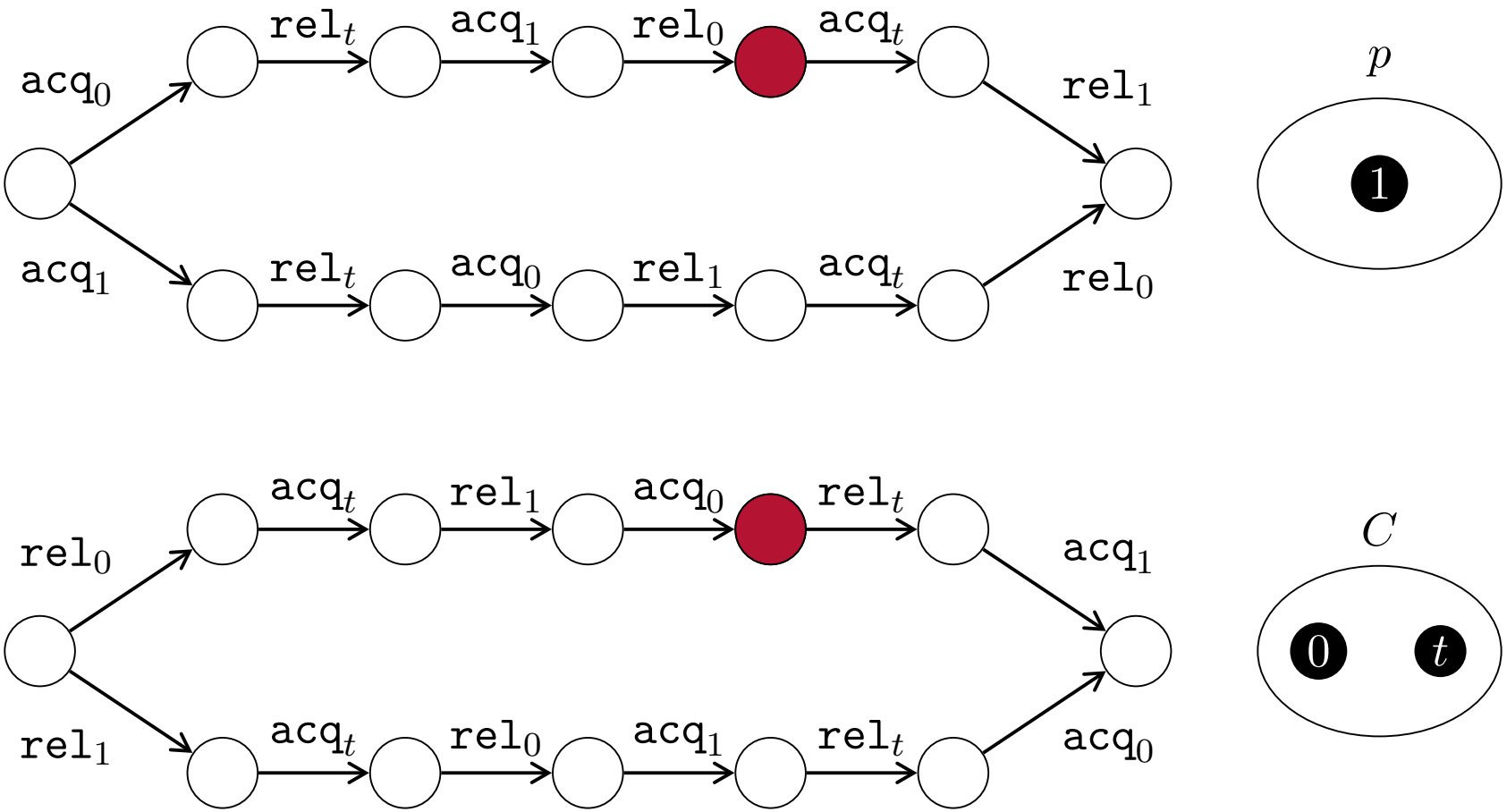

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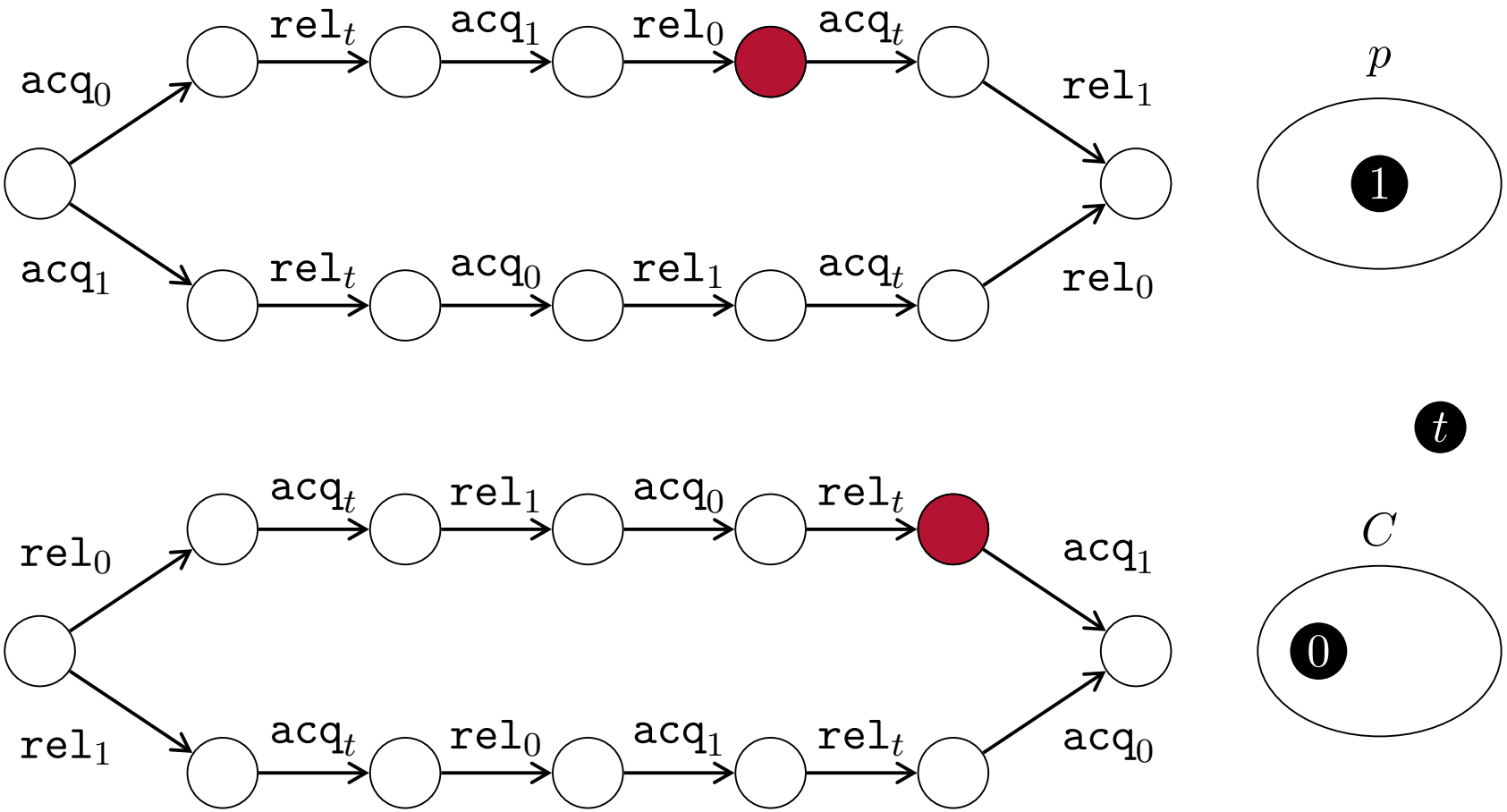

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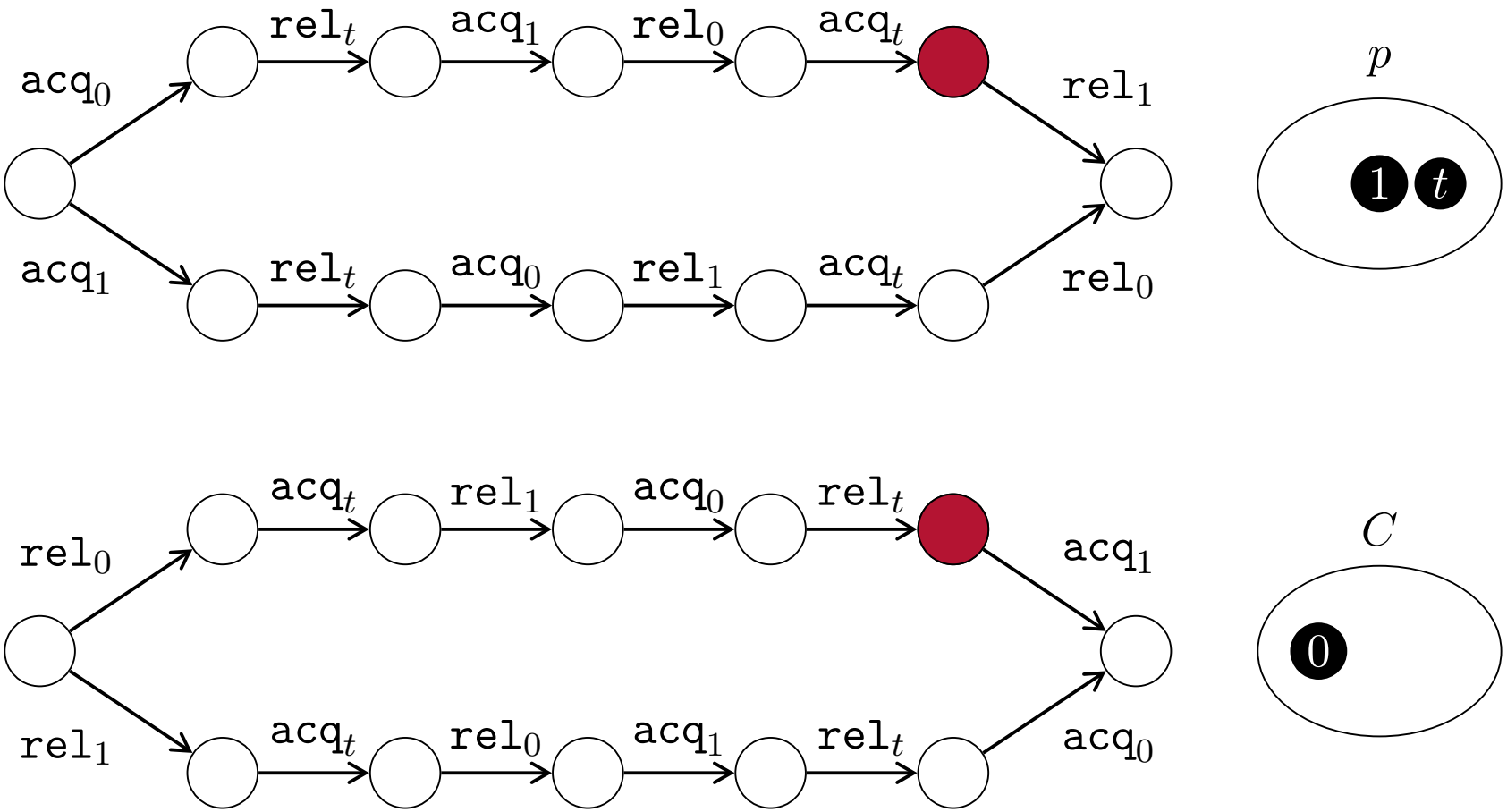

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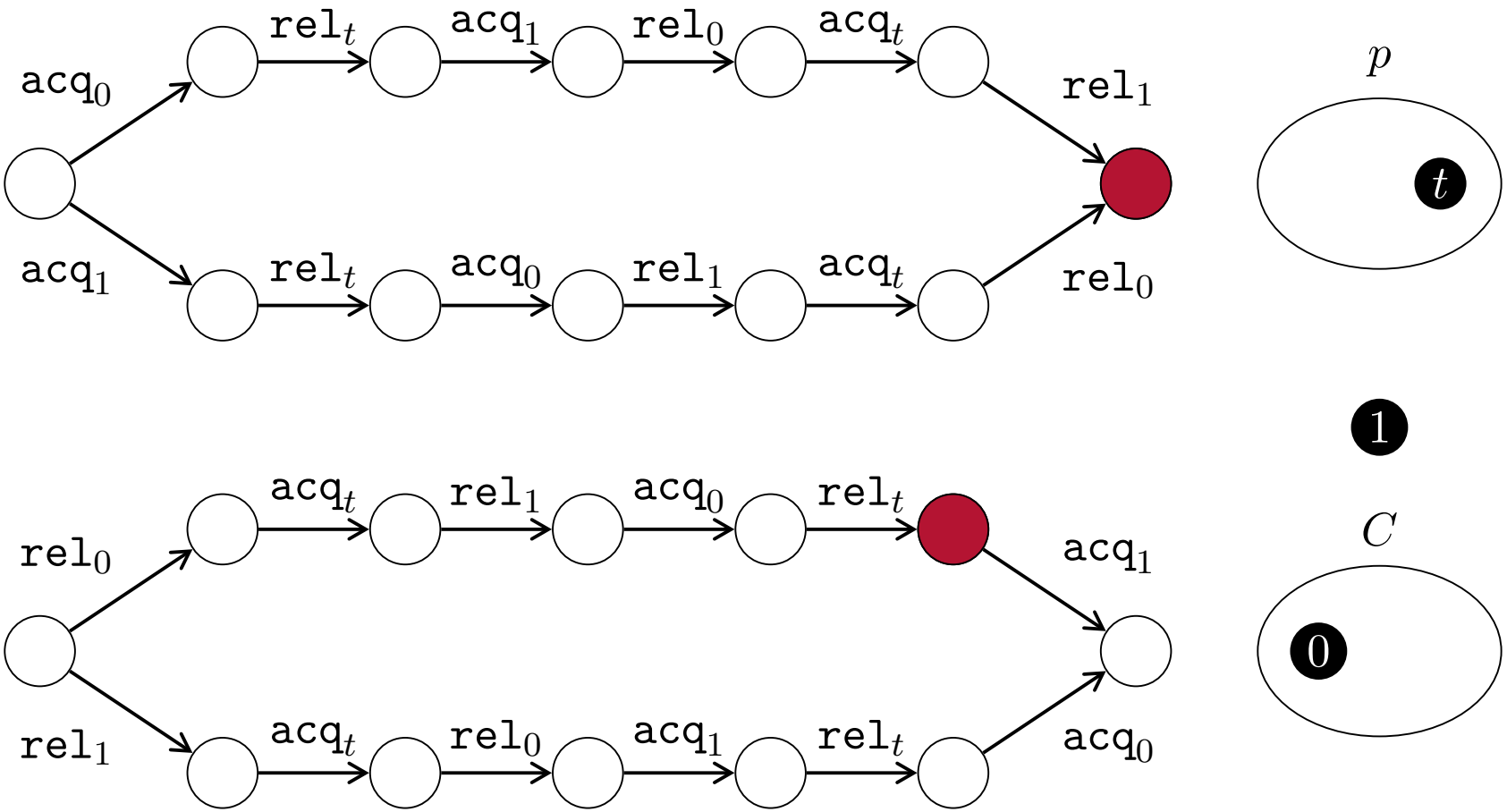

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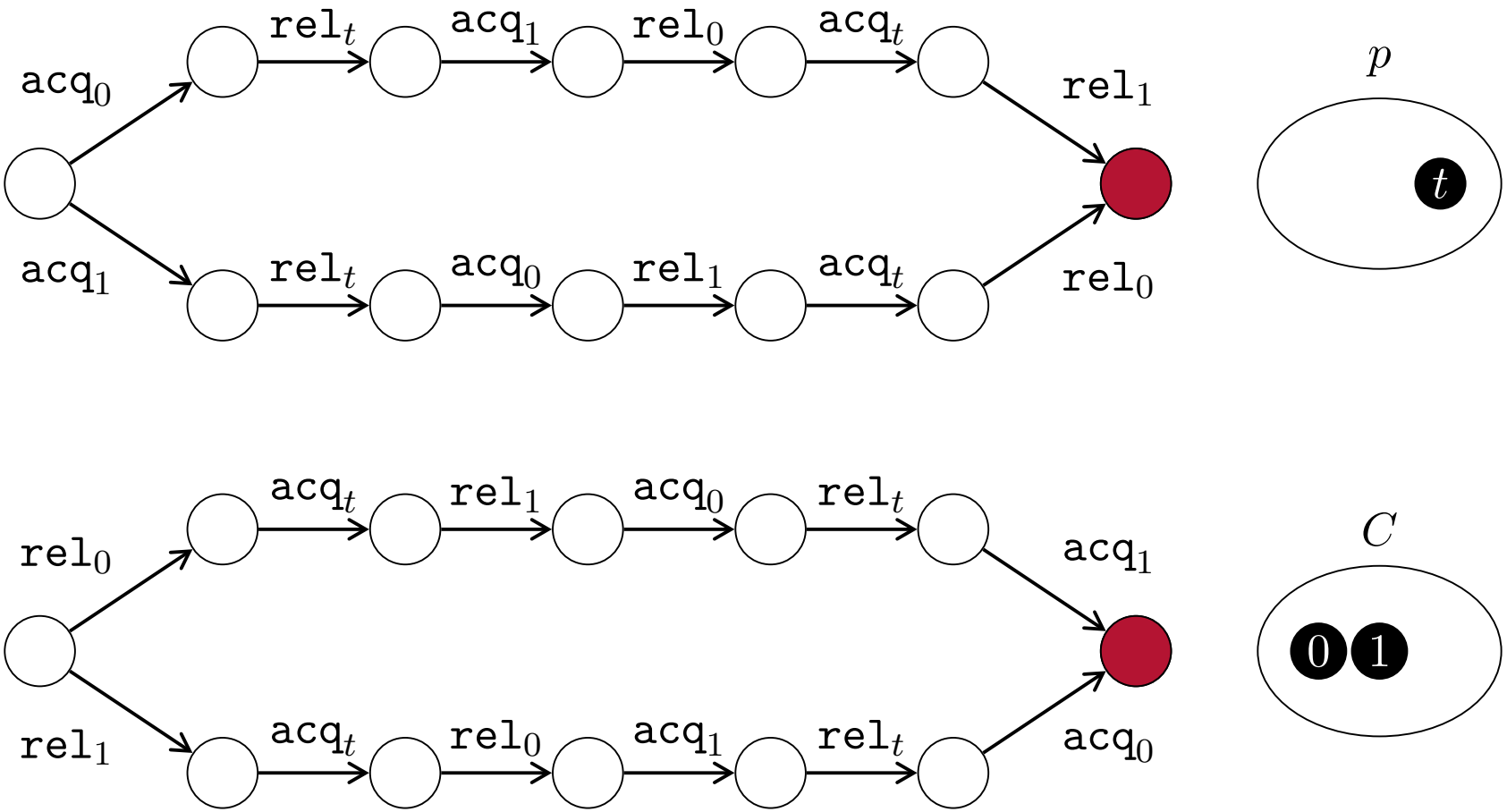

Useful restrictions

If we can pass unlimited information, **PSPACE-complete**

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2LSS

Each process accesses **at most two** different locks.

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Nested LSS

All processes acquire and release locks in a **stack-like order**, i.e., a process can only release the lock it acquired the latest.

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2LSS

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All processes acquire and release locks in a **stack-like order**, i.e., a process can only release the lock it acquired the latest.

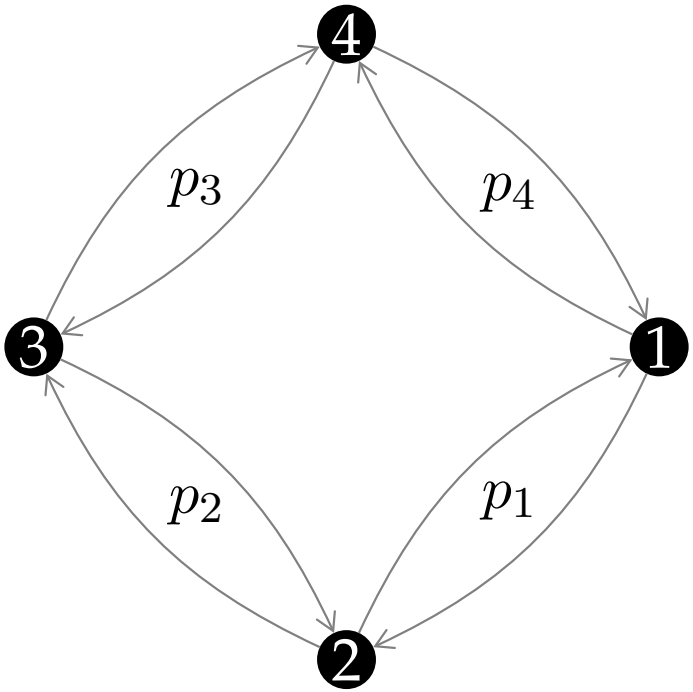
Those cases are generally **NP-complete**

Key property

We summarize runs as short patterns .

Patterns tell us if some local runs can be interleaved into a global run leading to a deadlock.

Solving the dining philosophers



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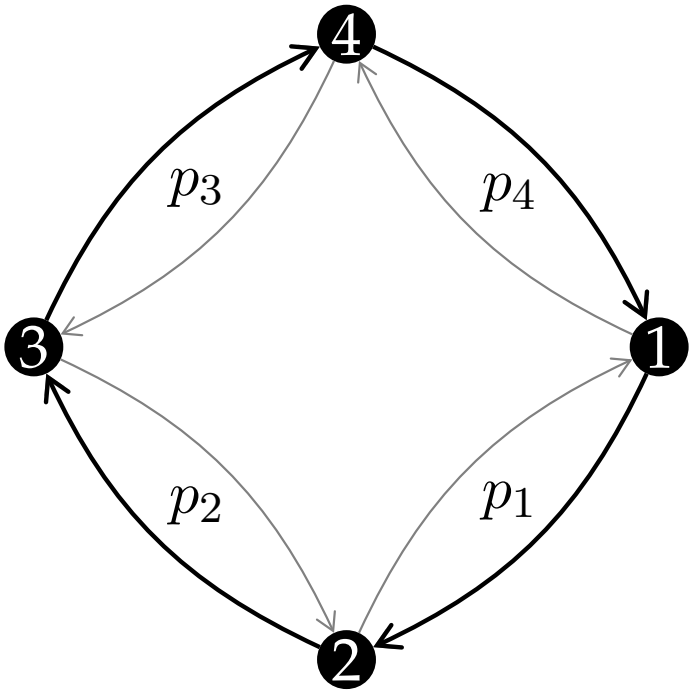
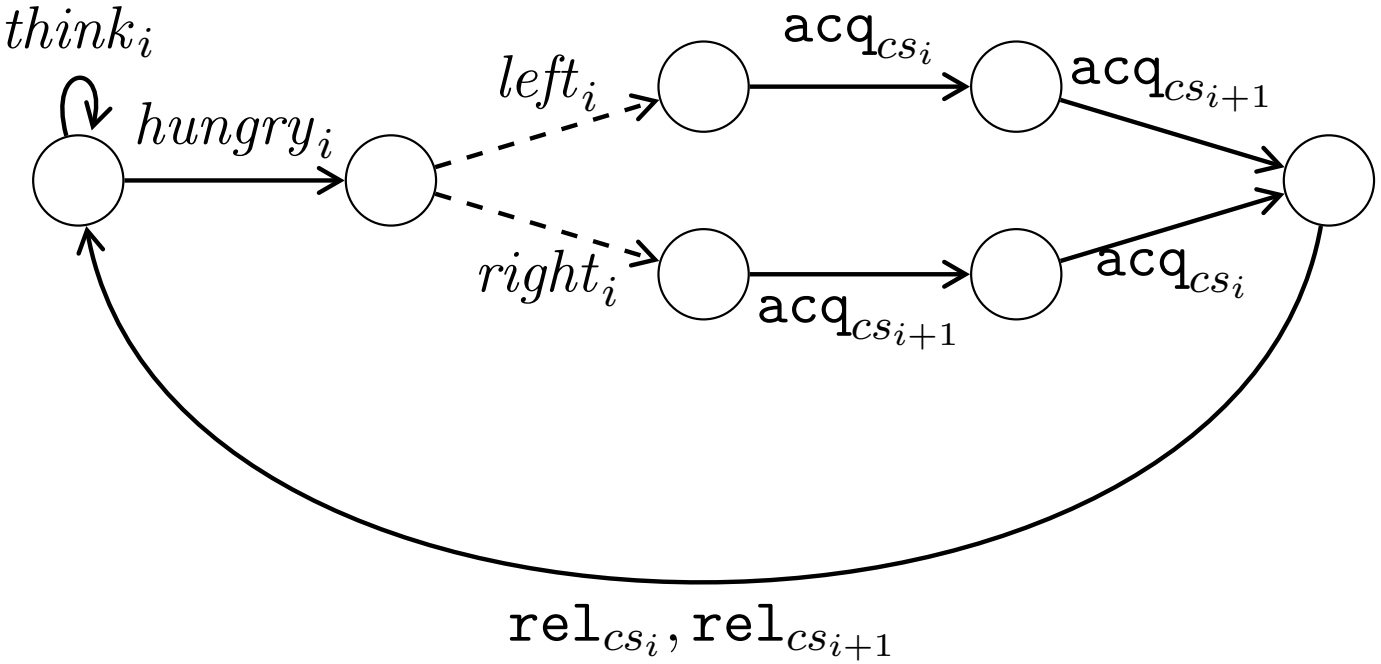


Synthesis

Processes can forbid some transitions



If σ_{p_i} always selects $left_i$ and σ_{p_j} $right_j$ for some processes $i \neq j$ then it avoids deadlocks.

Strategies

System and Environment actions $\Sigma_p = \Sigma_p^s \sqcup \Sigma_p^e$.

Strategy

$(\sigma_p)_{p \in Proc}$ with $\sigma_p : \Sigma_p^* \to 2^{\Sigma_p}$ such that $\Sigma_p^e \subseteq \sigma_p(u)$ for all u.

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Locally live strategy

σ is *locally live* if all processes always have an available local action.

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Locally live strategy

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Global deadlock

A σ-run u reaches a *global deadlock* if all processes are blocked at the end.

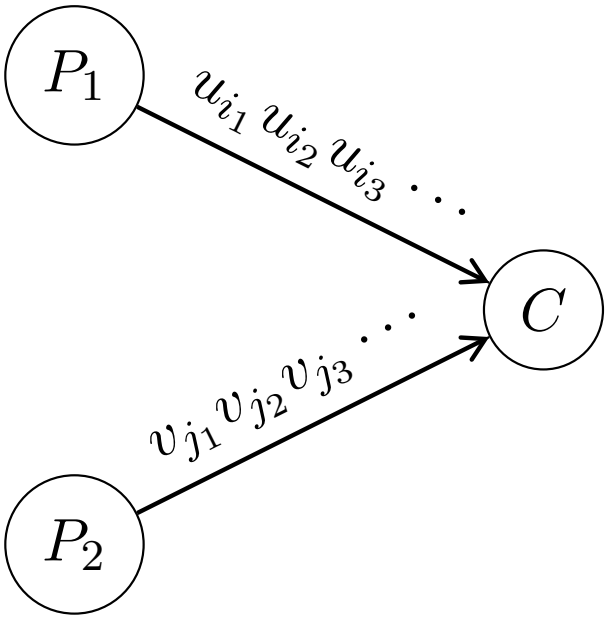
Undecidability

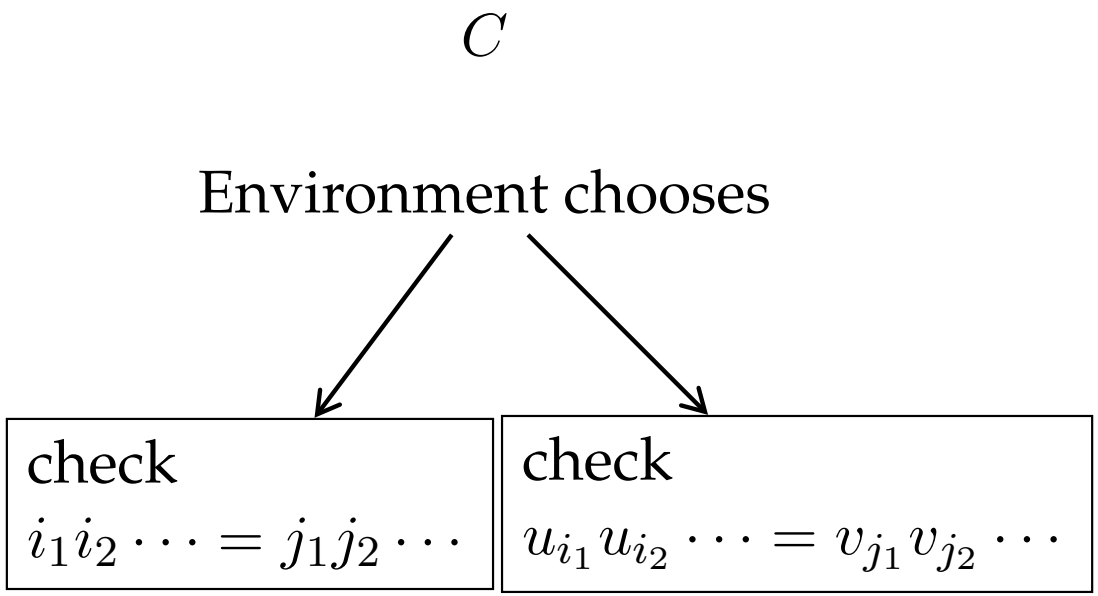
Theorem

The existence of a strategy avoiding global deadlocks is undecidable, even with 3 processes and 4 locks in total.

Proof scheme: PCP encoding

Let $(u_1, v_1), \ldots, (u_n, v_n)$ be a PCP instance.



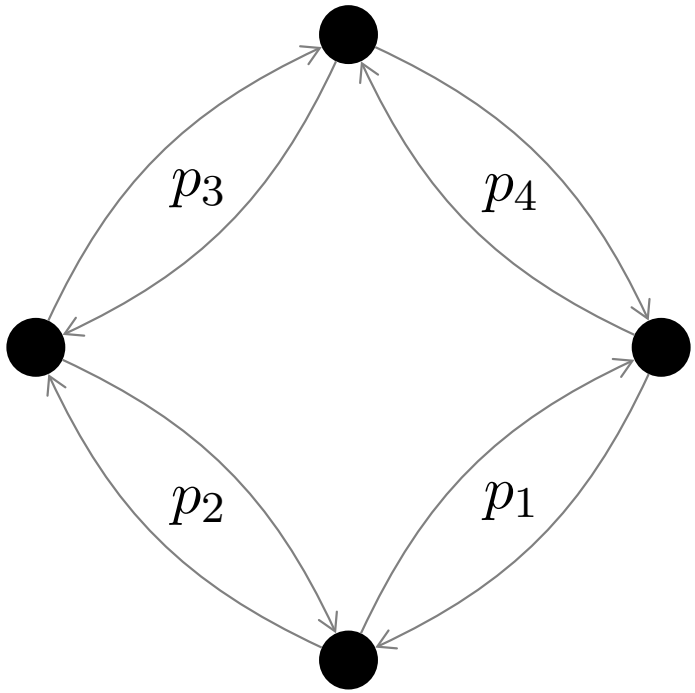


Decidability

Theorem

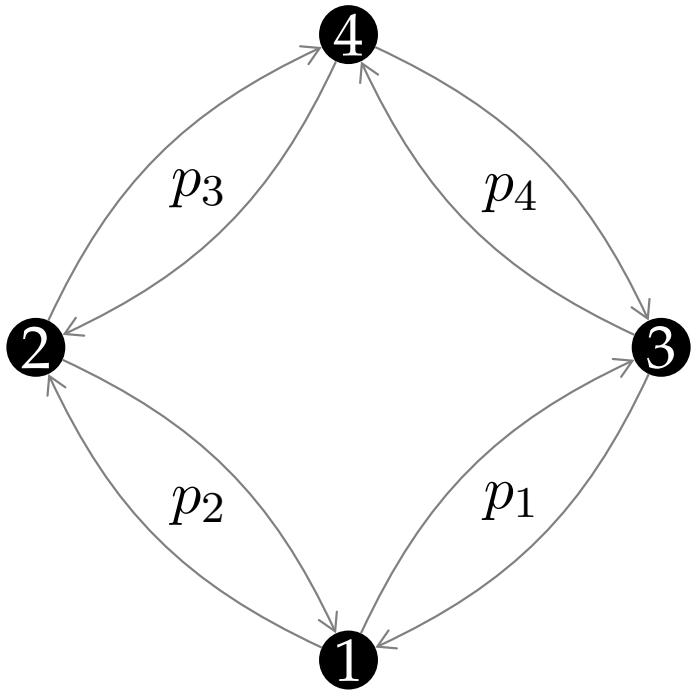
The existence of a strategy avoiding global deadlocks is Σ_2^P-complete for 2LSS
and NExpTime-complete for LSS respecting the nested lock condition.

Solving the dining philosophers



$\rightarrow$ Just pick an order on chopsticks and have all philosophers take them accordingly!

Solving the dining philosophers



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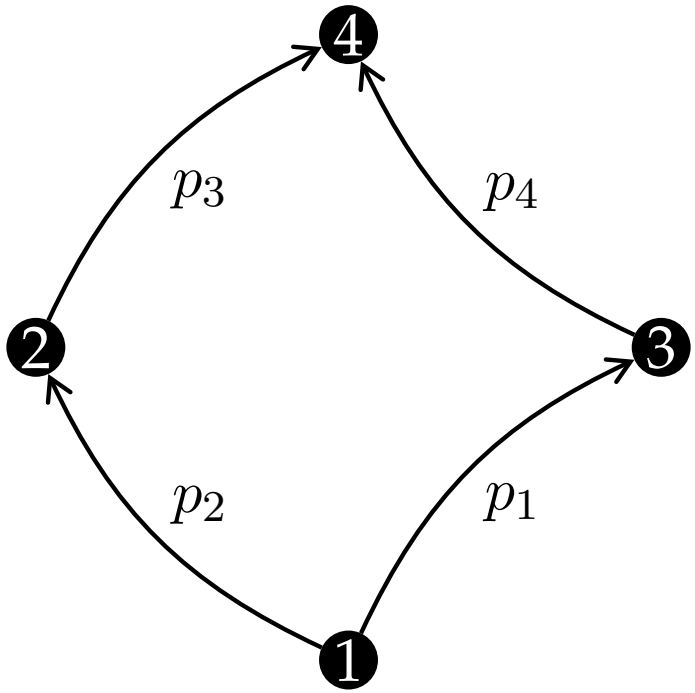

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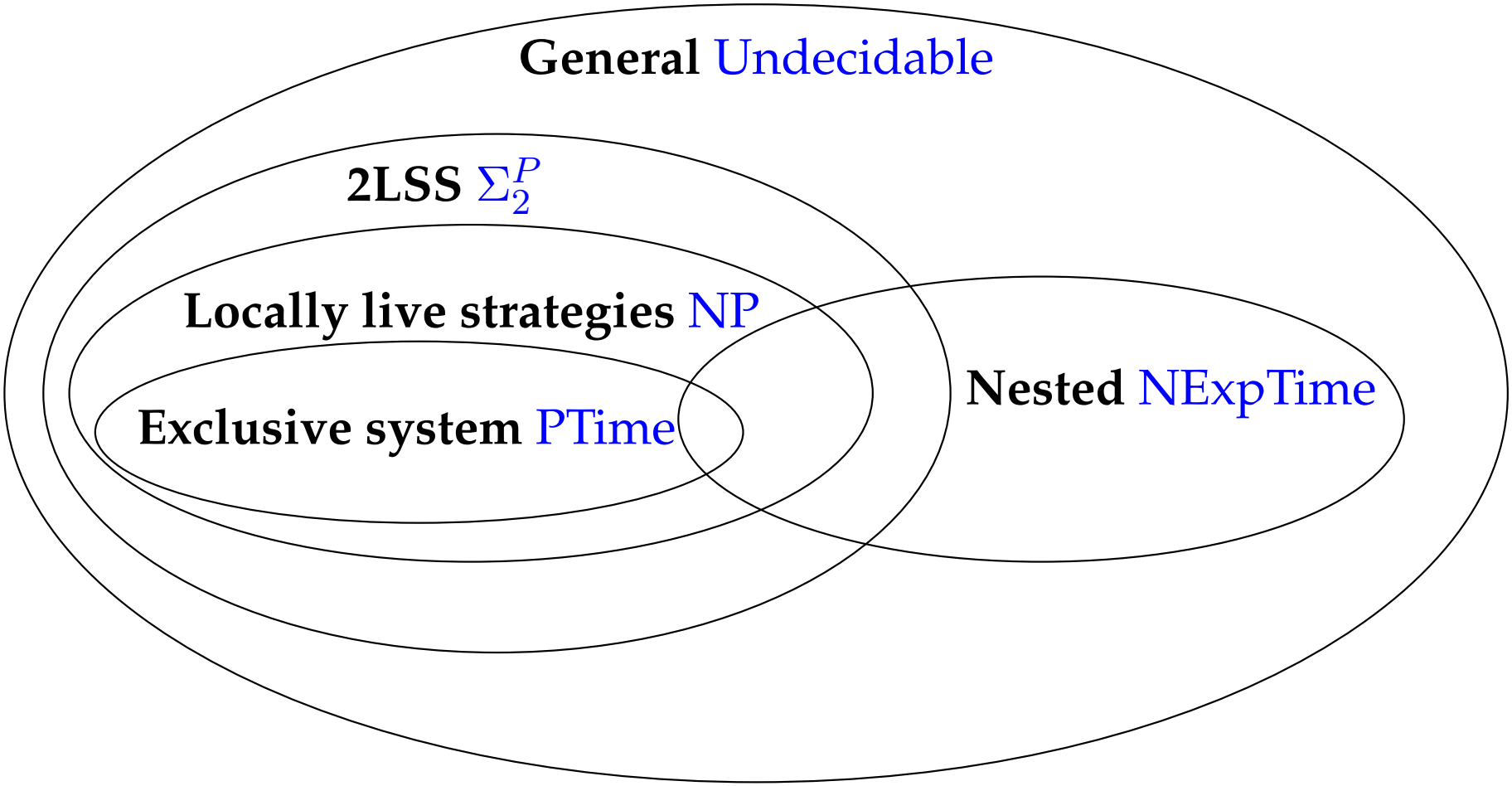
Results


General Undecidable
2LSS Σ_2^P
Locally live strategies NP
Exclusive system PTime
Nested NExpTime

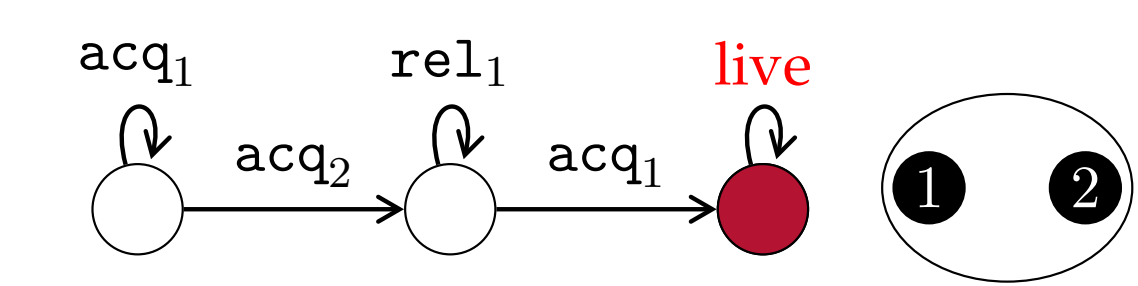
An open problem

Can the following problem be solved in PTIME ?

Mortality problem

Input: A 2LSS (each process uses at most 2 locks).
Output: Is there a run such that one of the processes cannot execute any action ever from some point on?

Example



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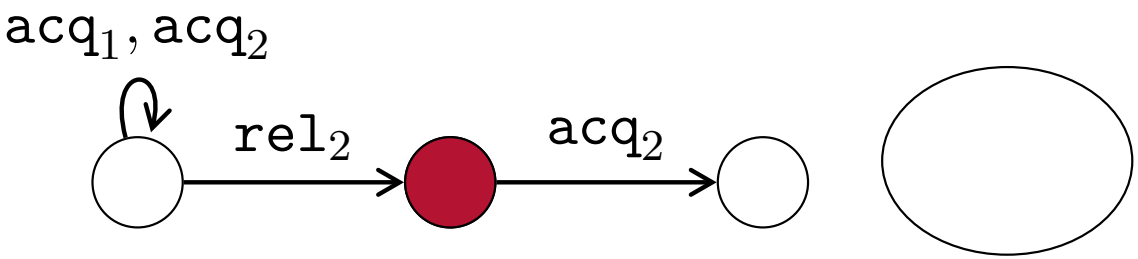

p_2

Thank you for your attention!