Repairing soundness properties in data-aware processes

Paolo Felli, Marco Montali, Sarah Winkler

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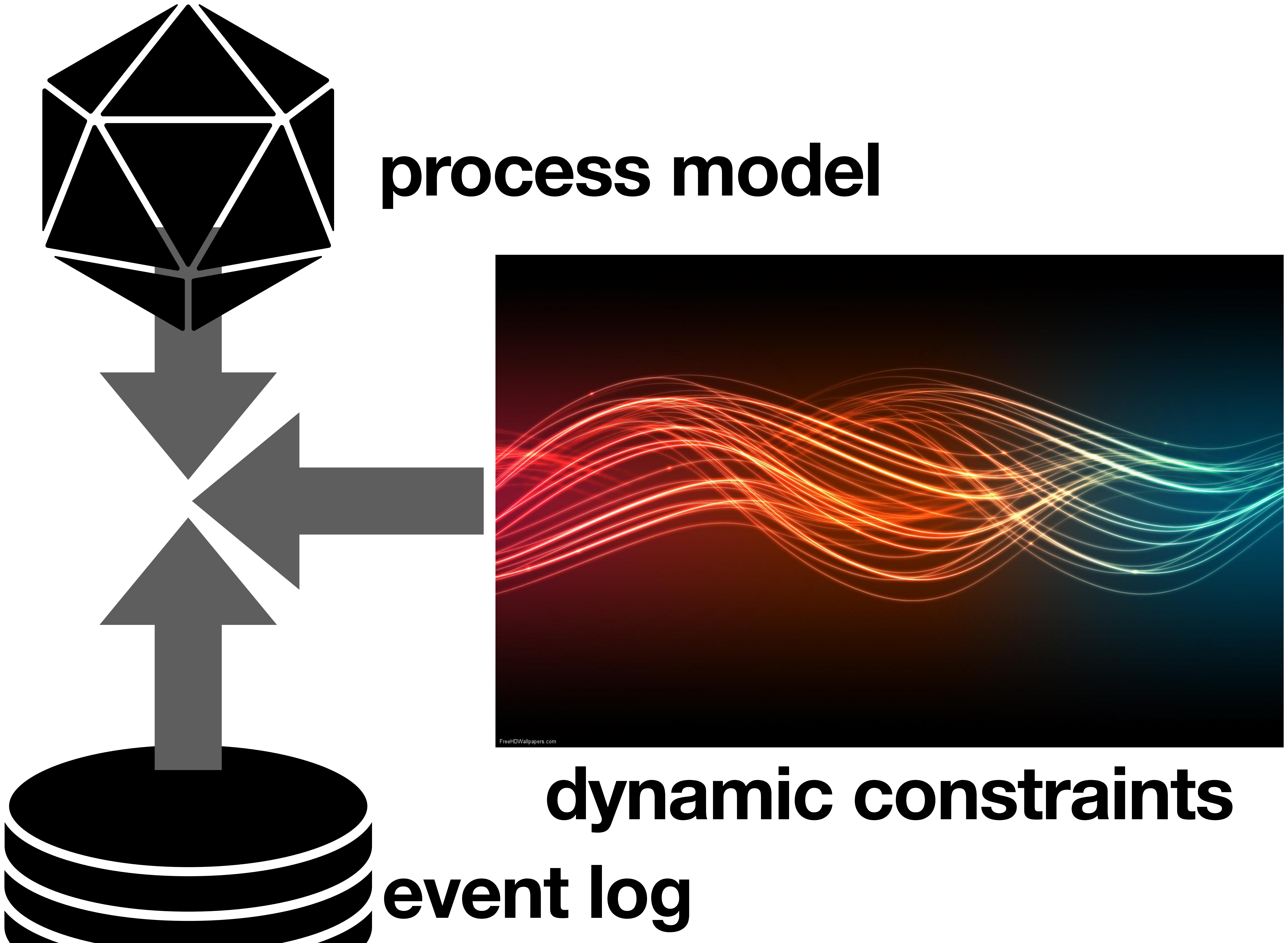
Rome, Italy

Starting point

A holistic view of information systems



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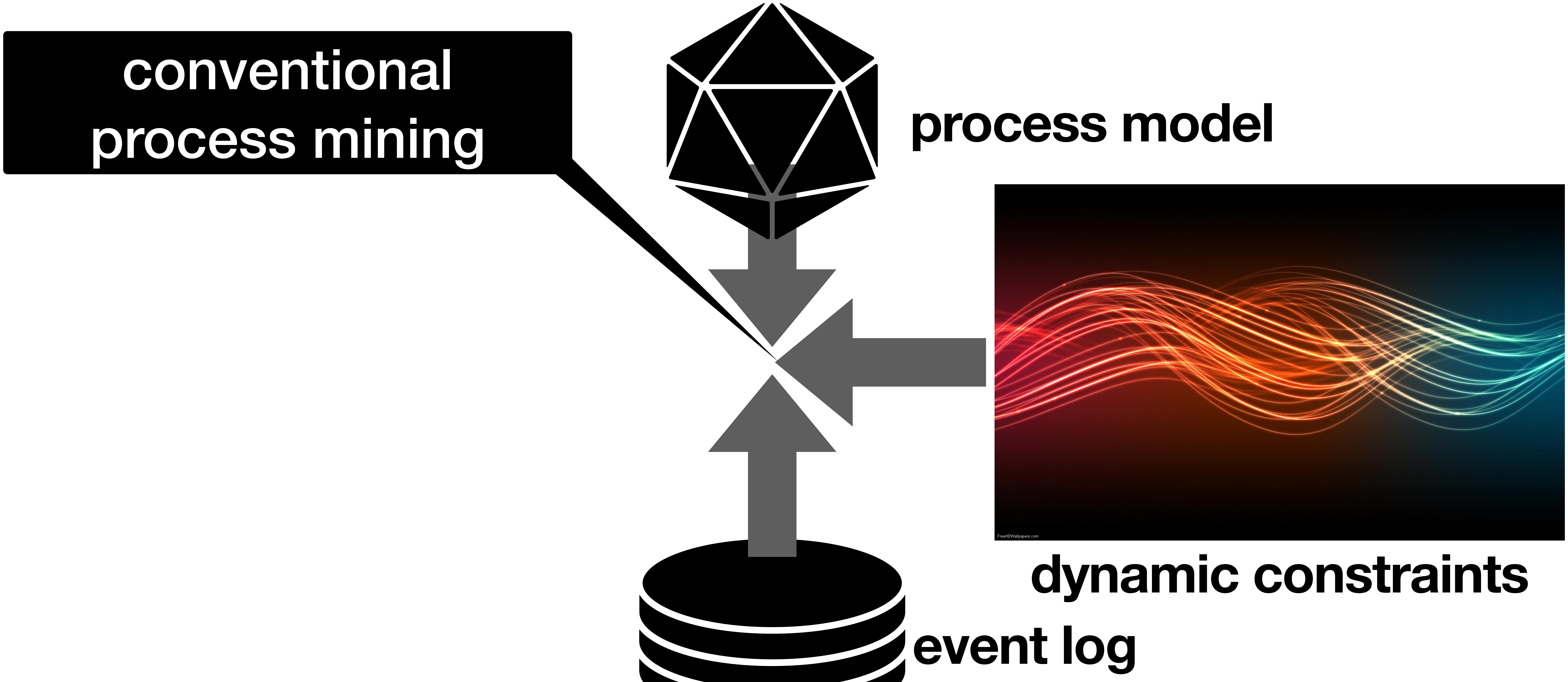

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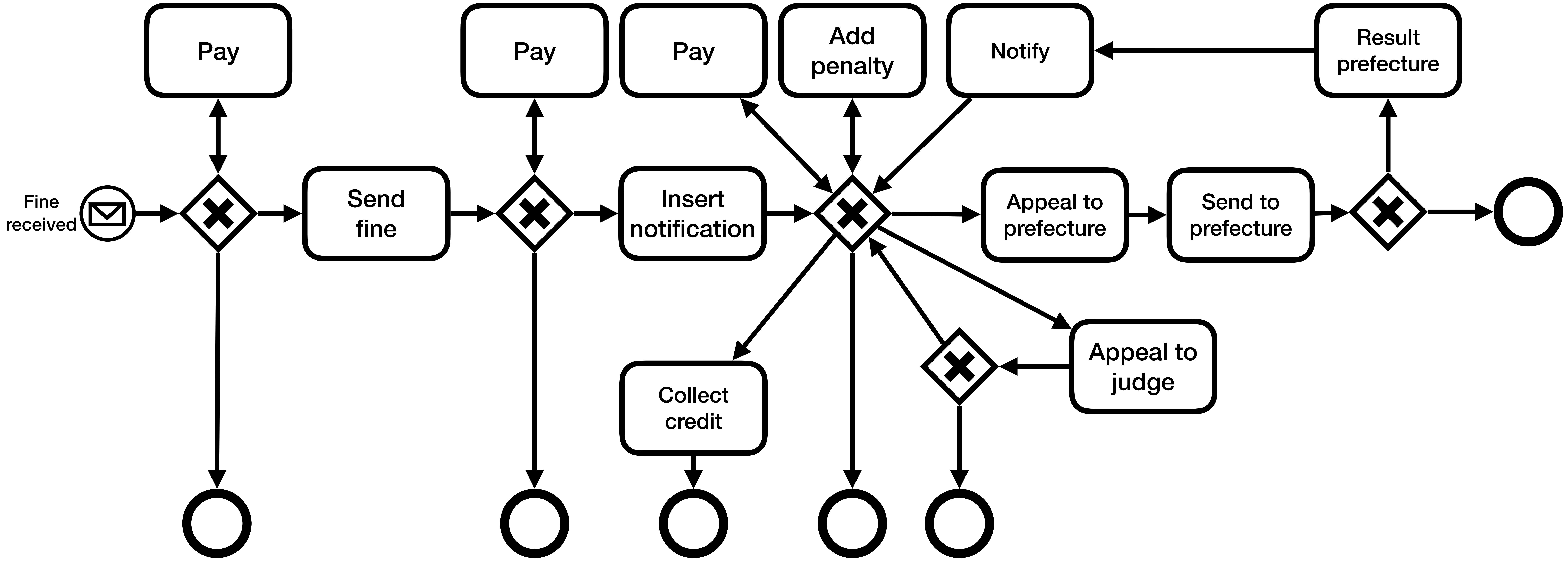
Why reasoning?

Adapted from [Mannhardt et al., Comput. 2016], studied in [____,CAiSE2022]



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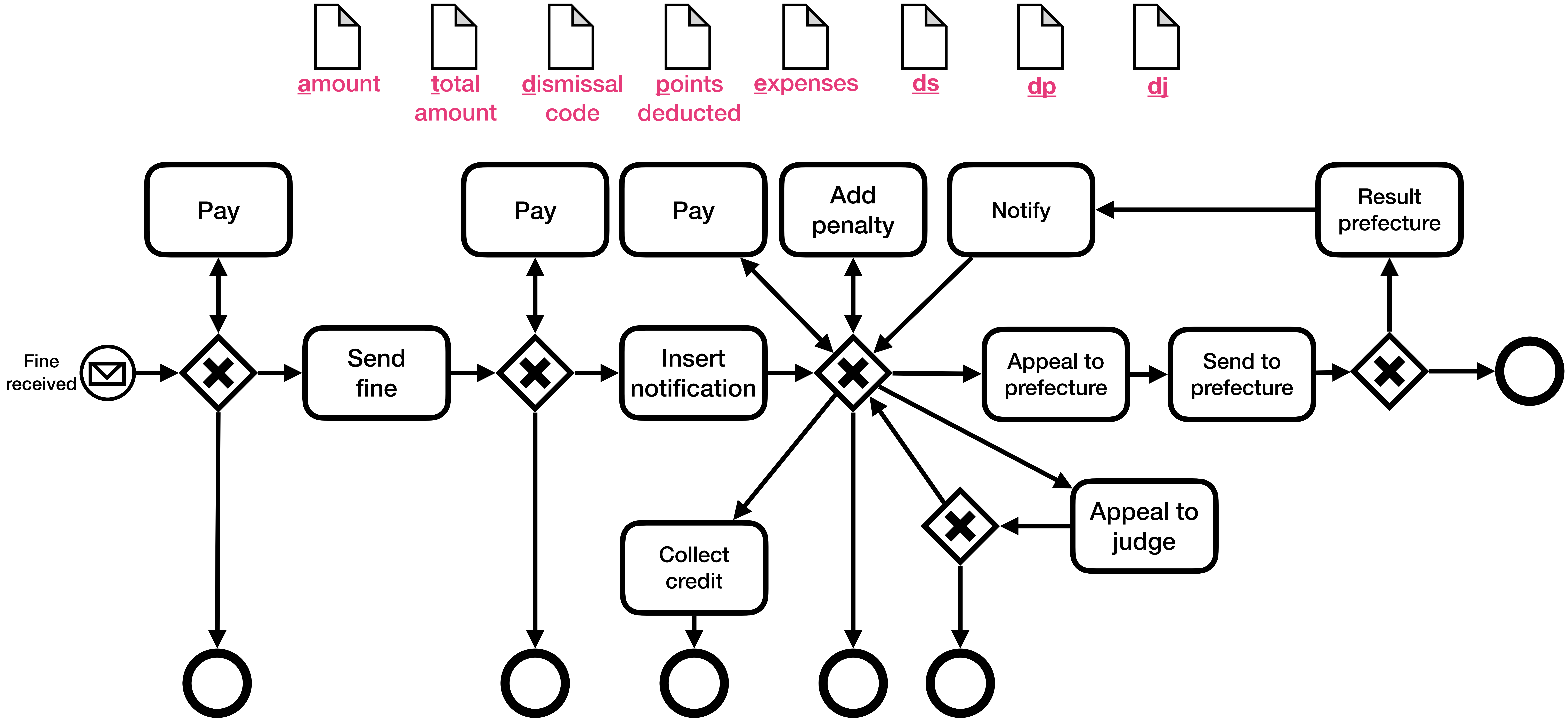

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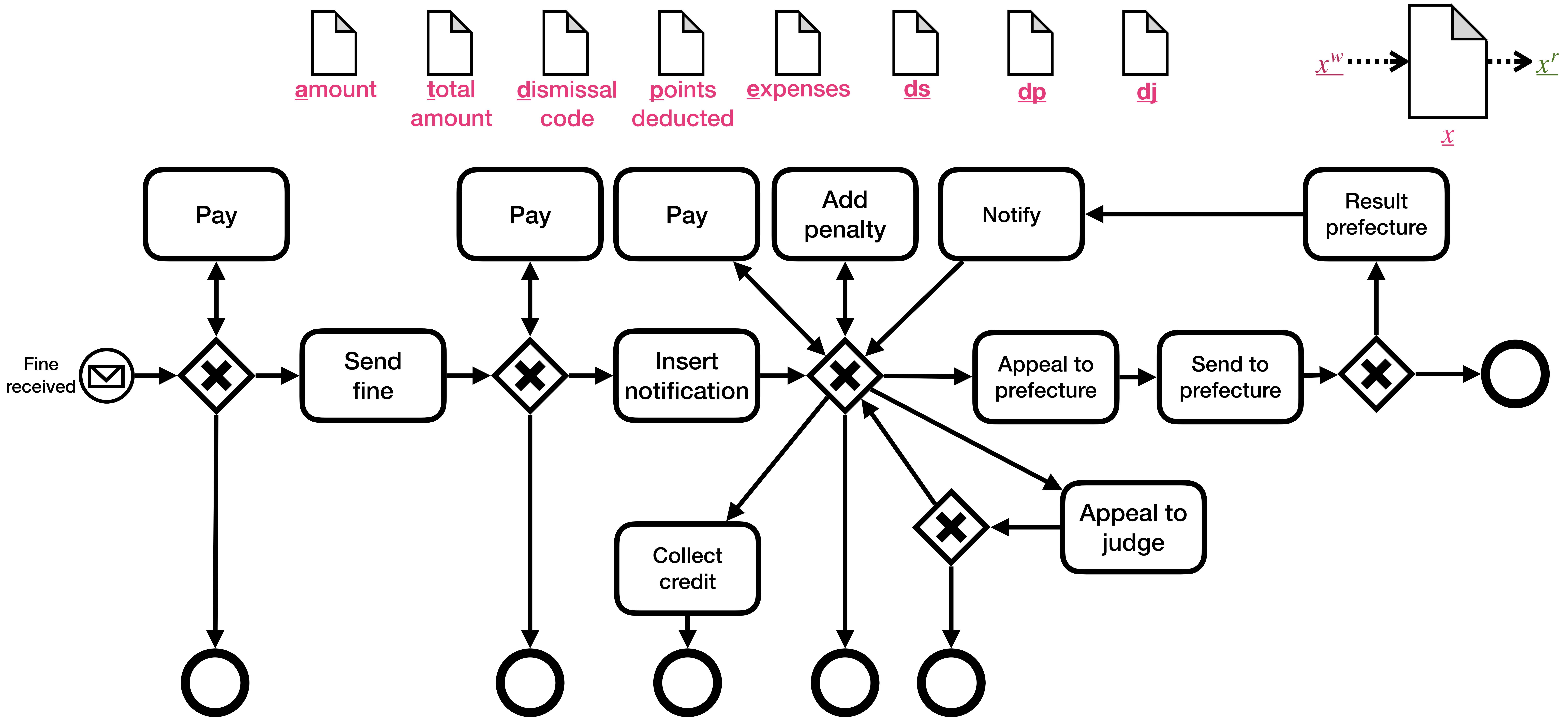

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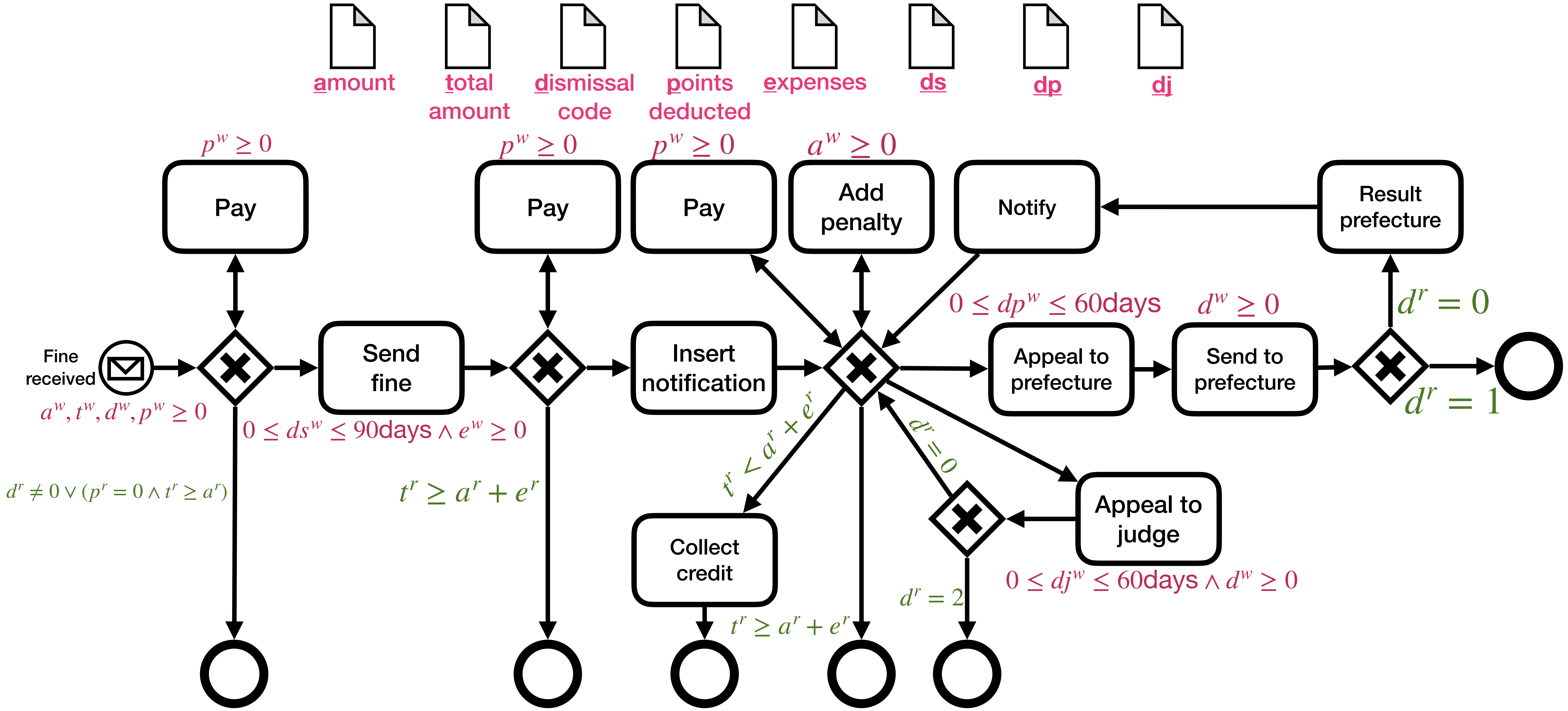
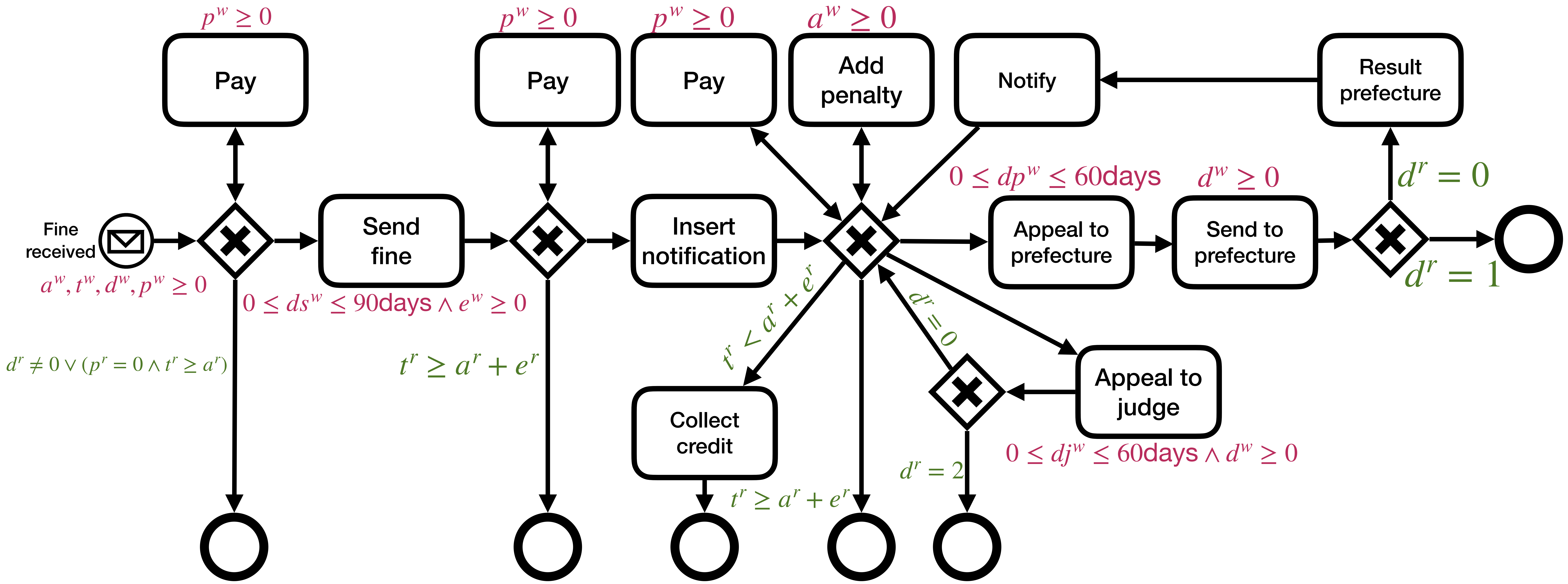


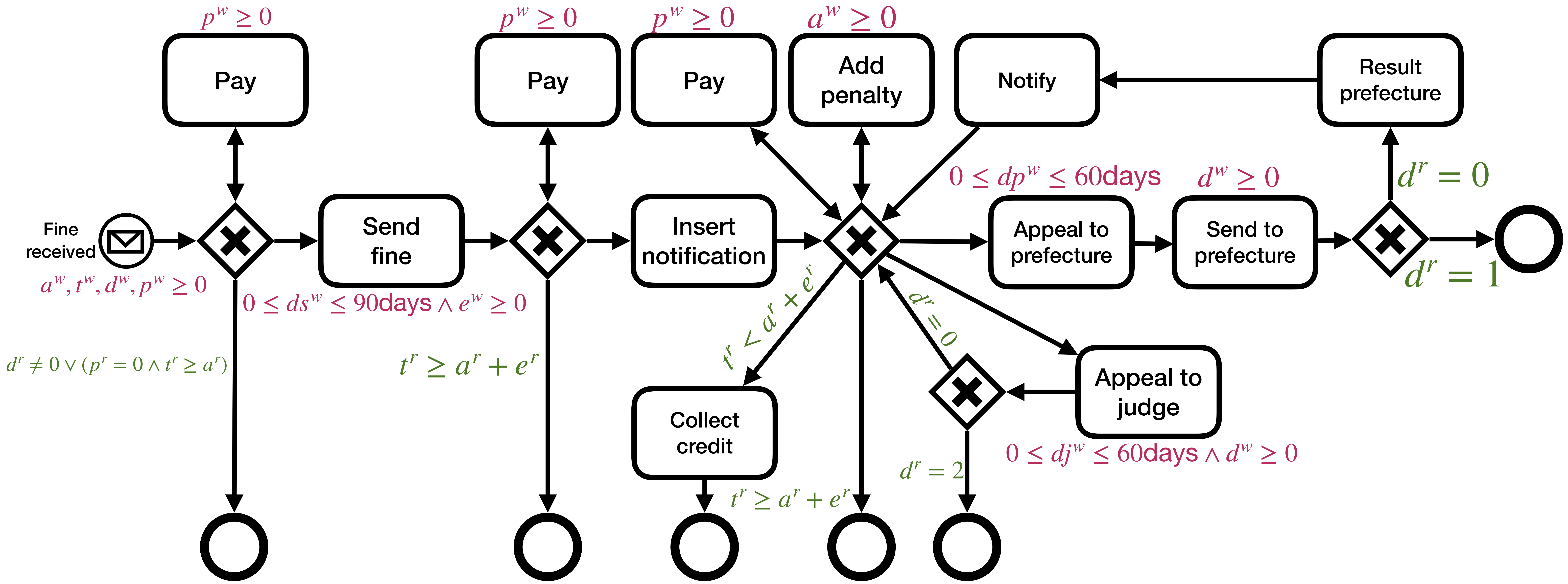
(multi-perspective) **mining** **modelling**

Is the model "correct"?



Is the model “correct”?

The control-flow way



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The control-flow way

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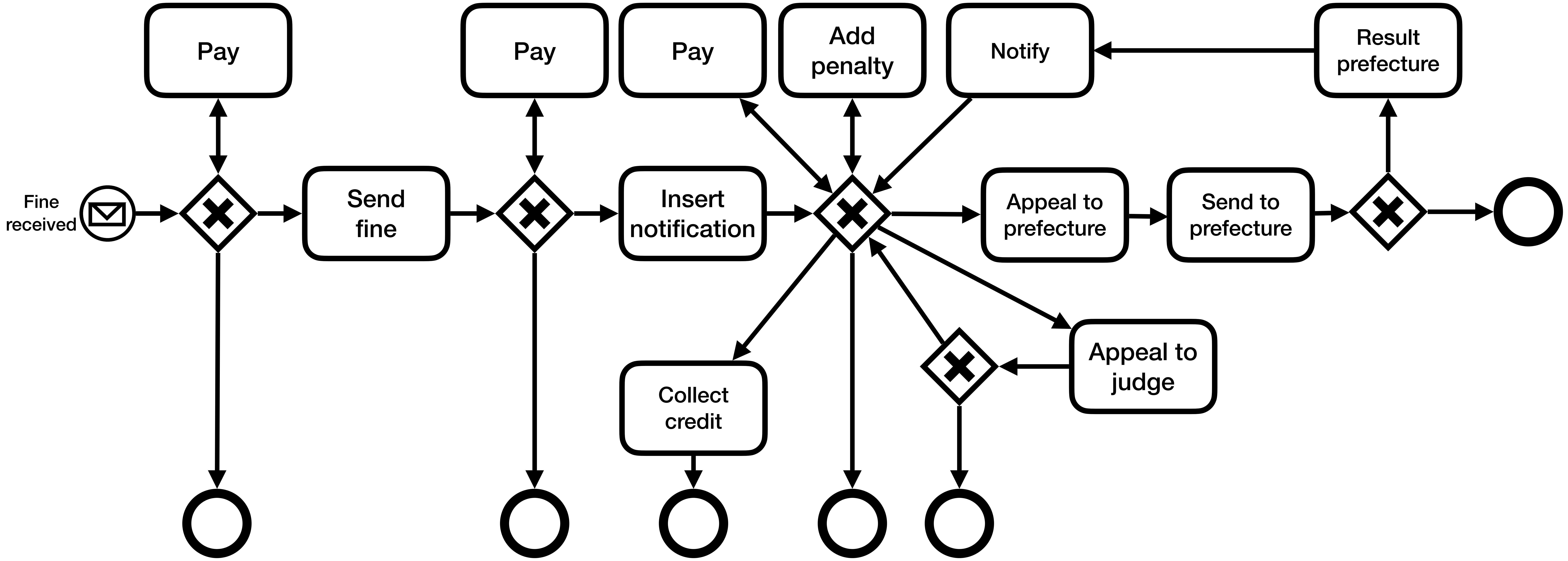

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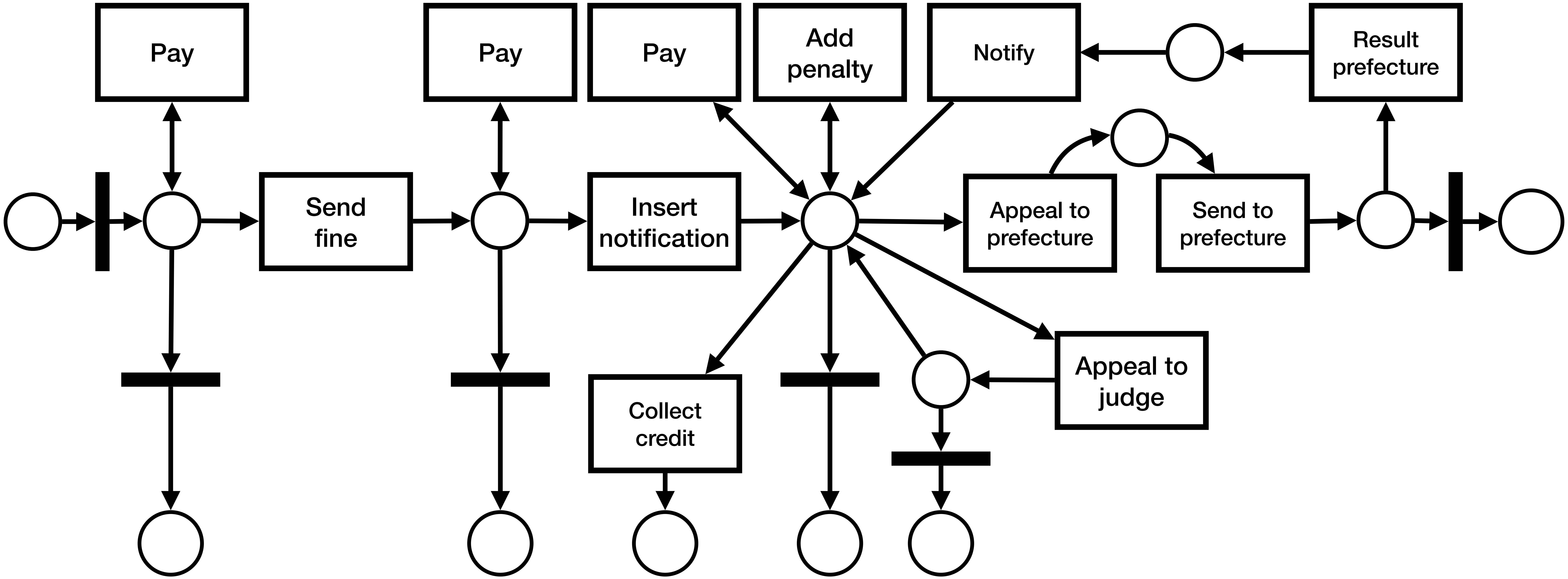
The control-flow way

1. Strip-off the data
2. Encode control-flow into bounded Petri net (finite state-space)

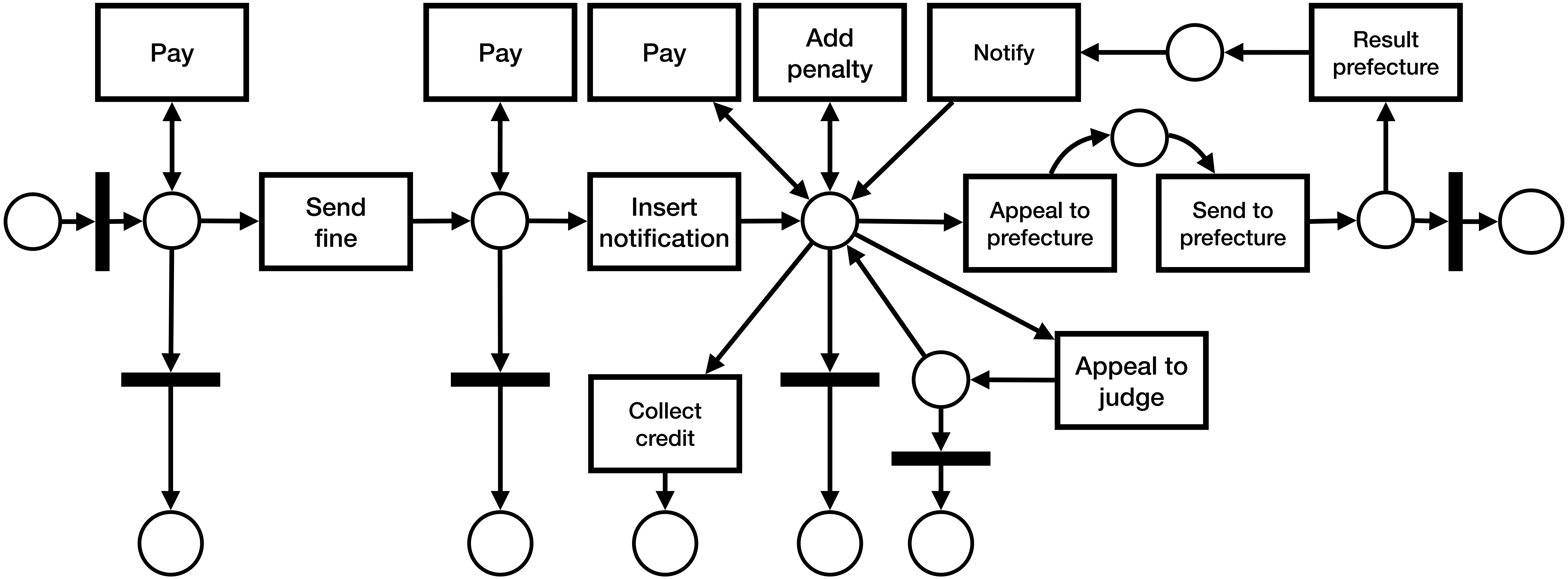


Is the model “correct”?

The control-flow way

1. Strip-off the data
2. Encode control-flow into bounded Petri net (finite state-space)
3. Explore the state space

Verdict: all good!



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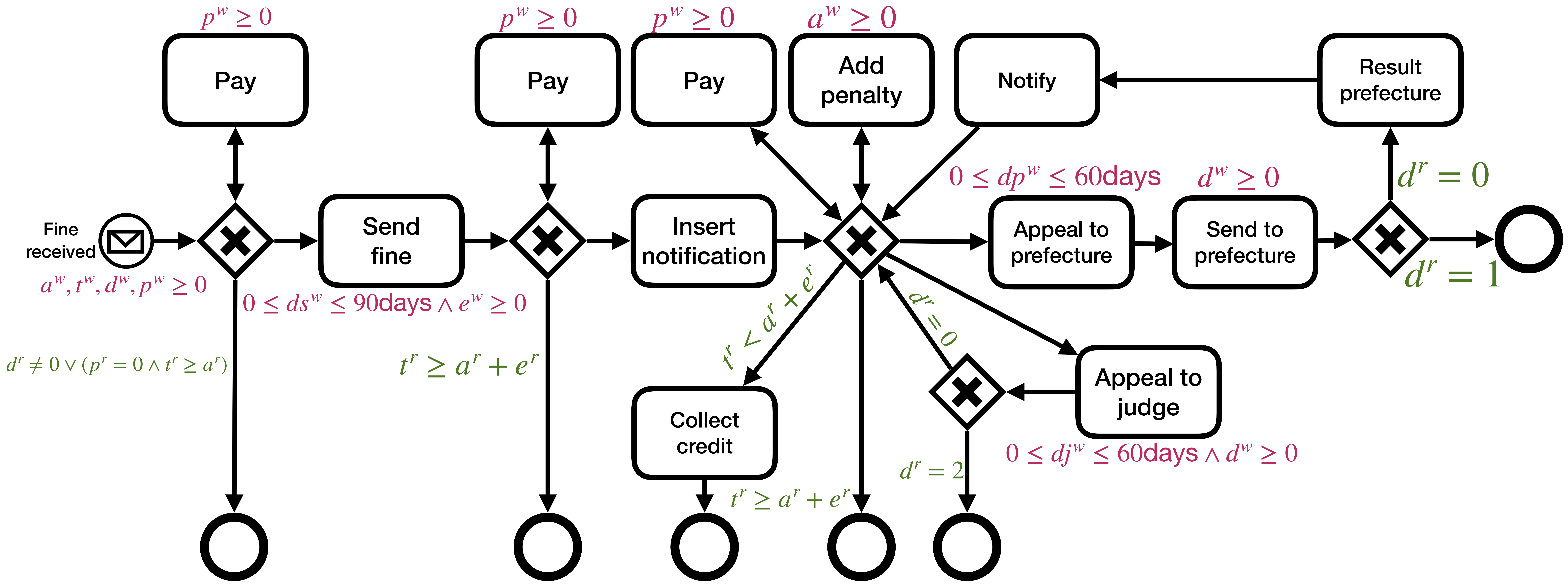
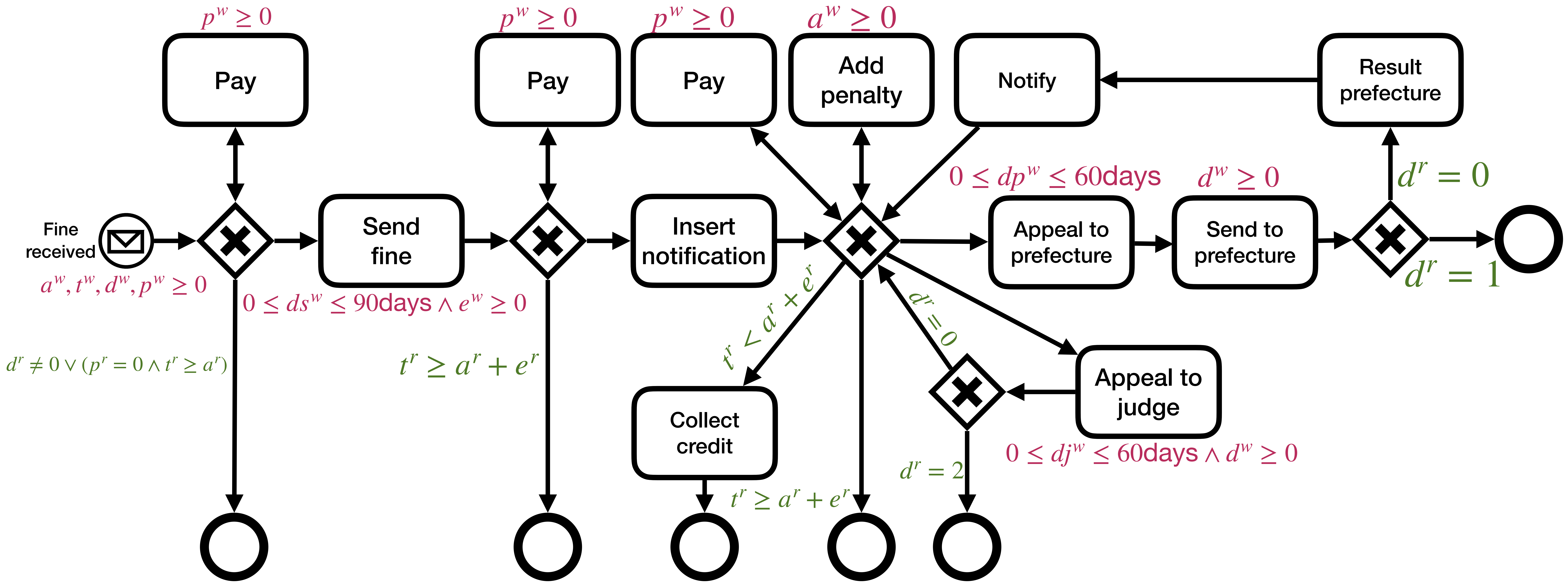
The integrated way



Is the model “correct”?

The integrated way

infinitely many runs with infinitely many distinct variable assignments



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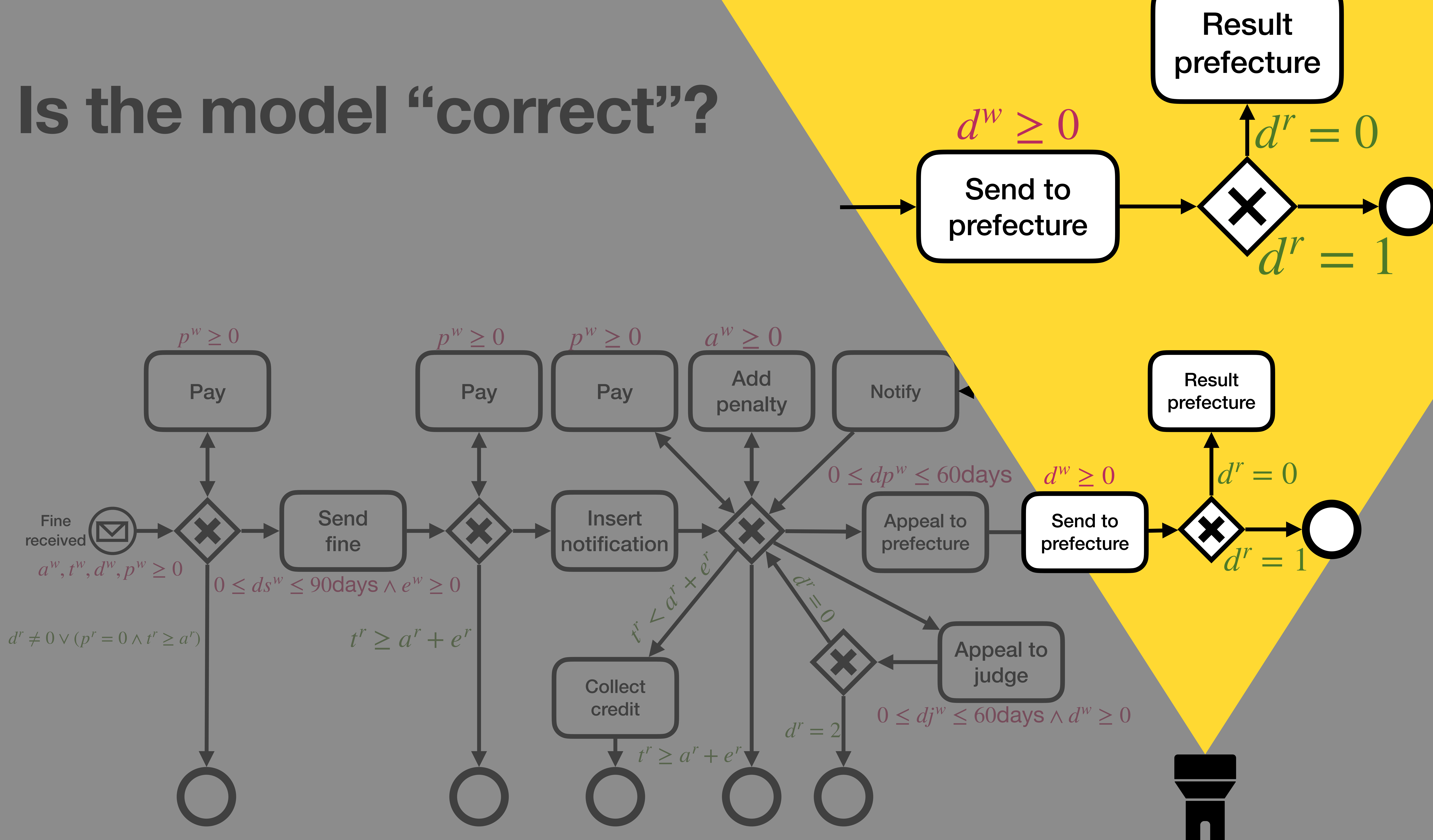
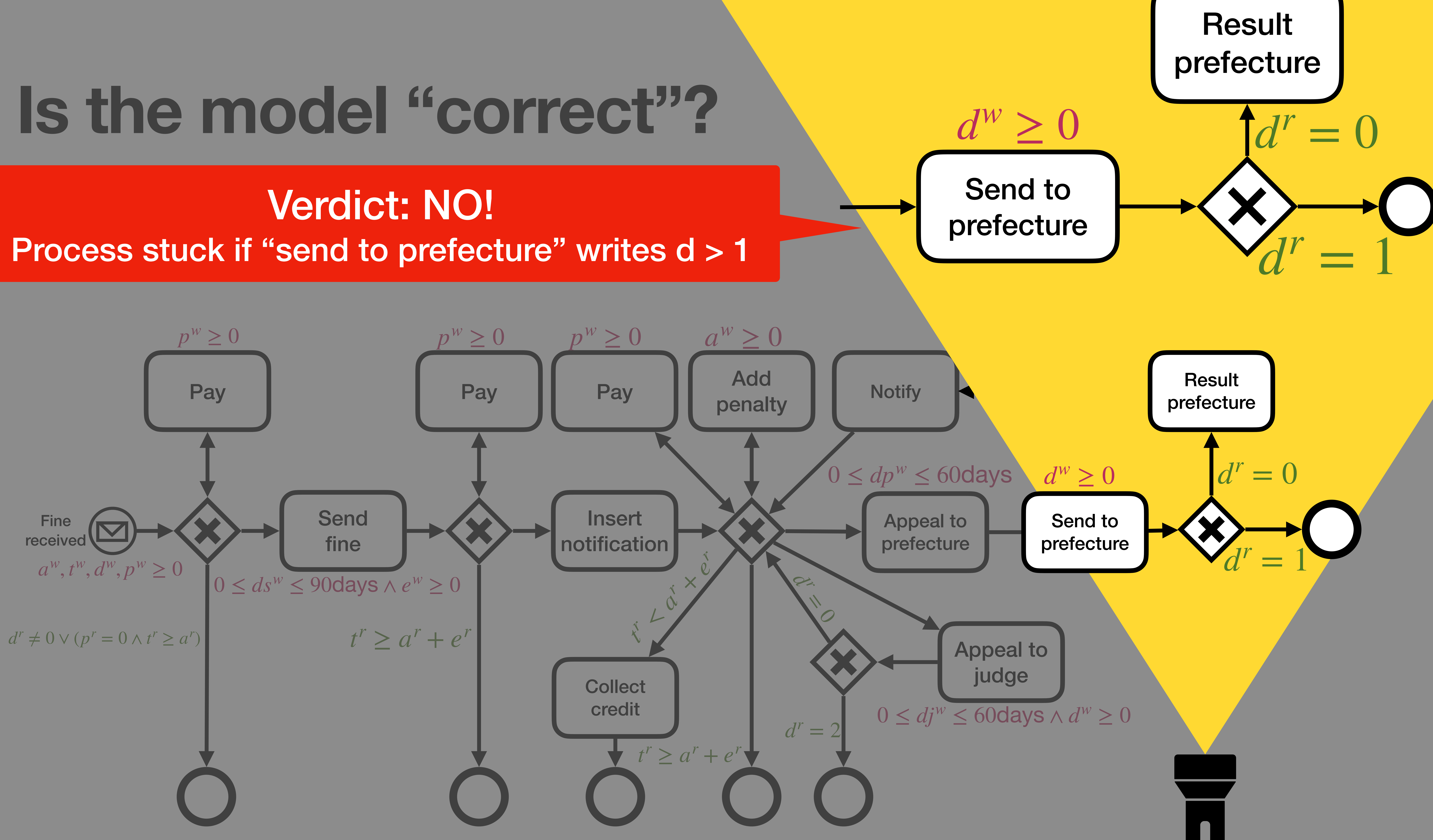


Is the model "correct"?

Verdict: NO!

Process stuck if "send to prefecture" writes d > 1



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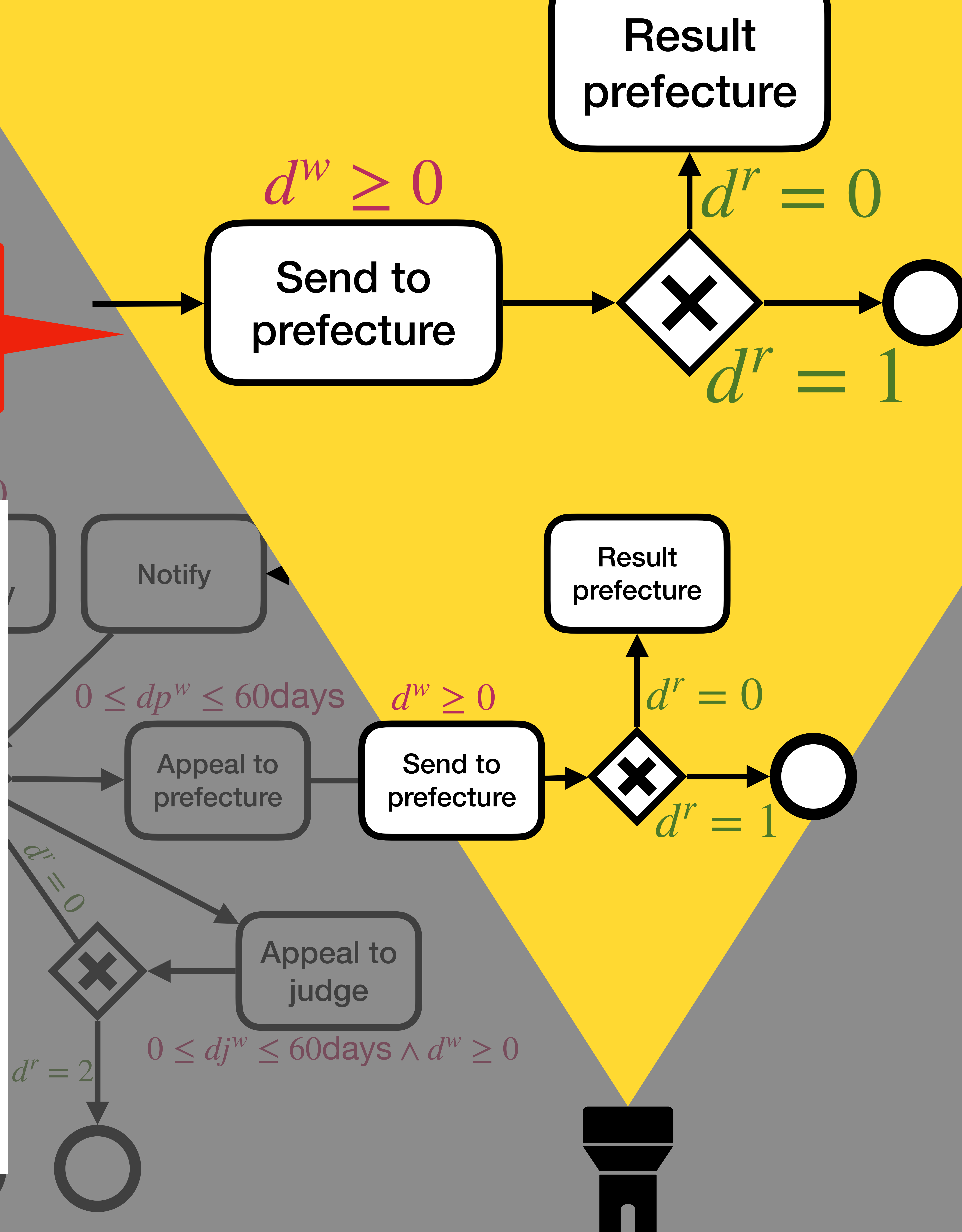
Issue: **blocked state**



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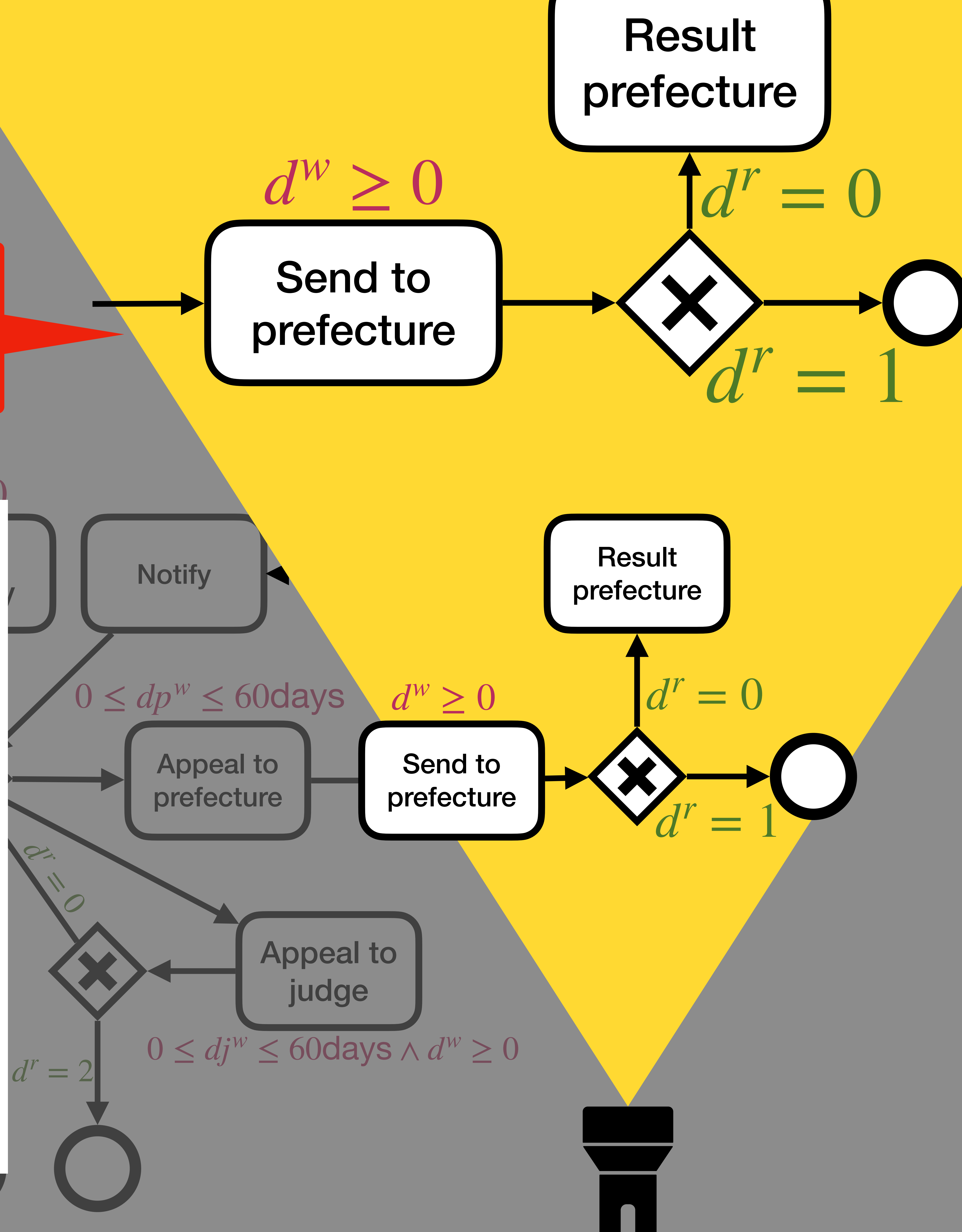

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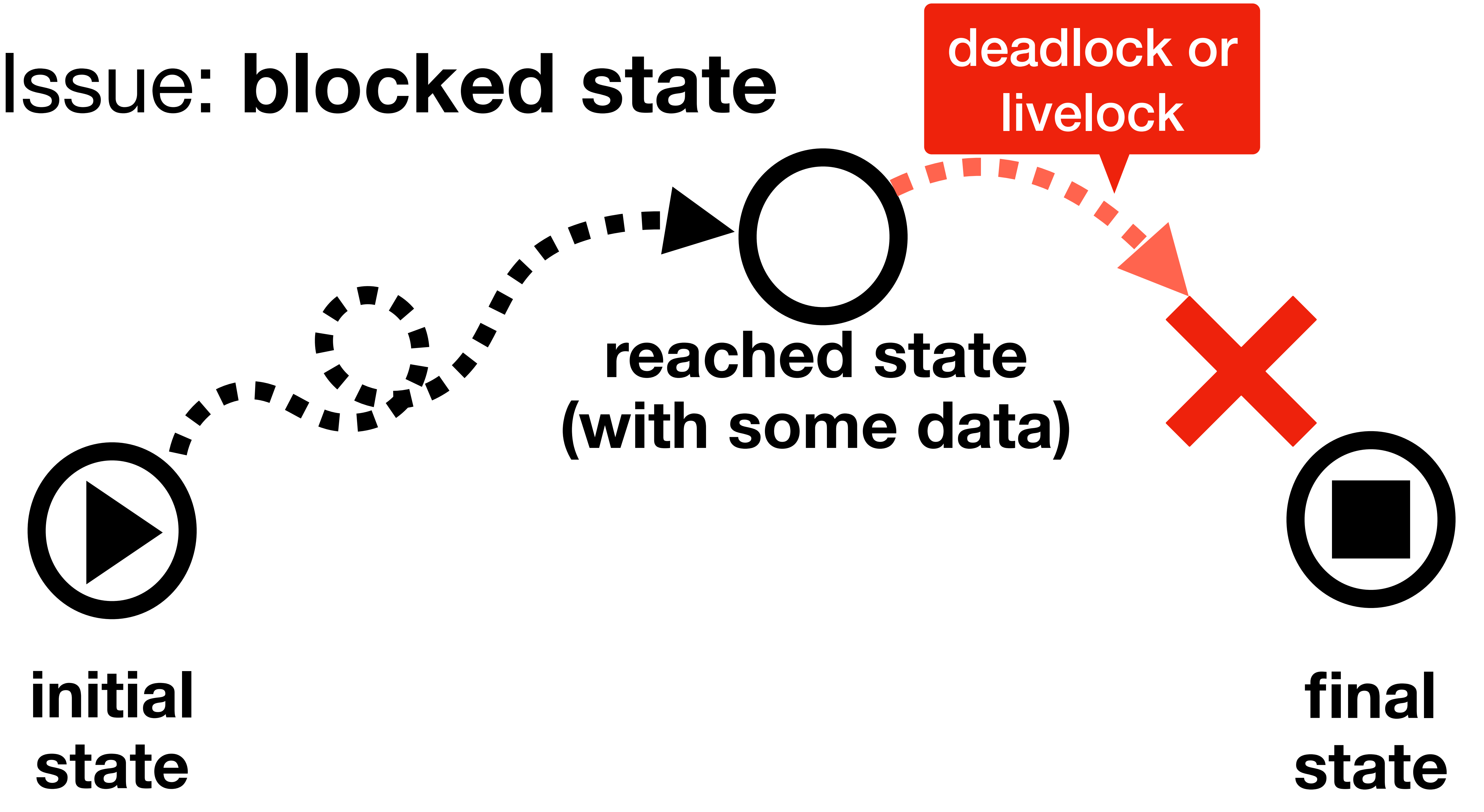

Process mining is an iterative process

Process mining is an iterative process

mining

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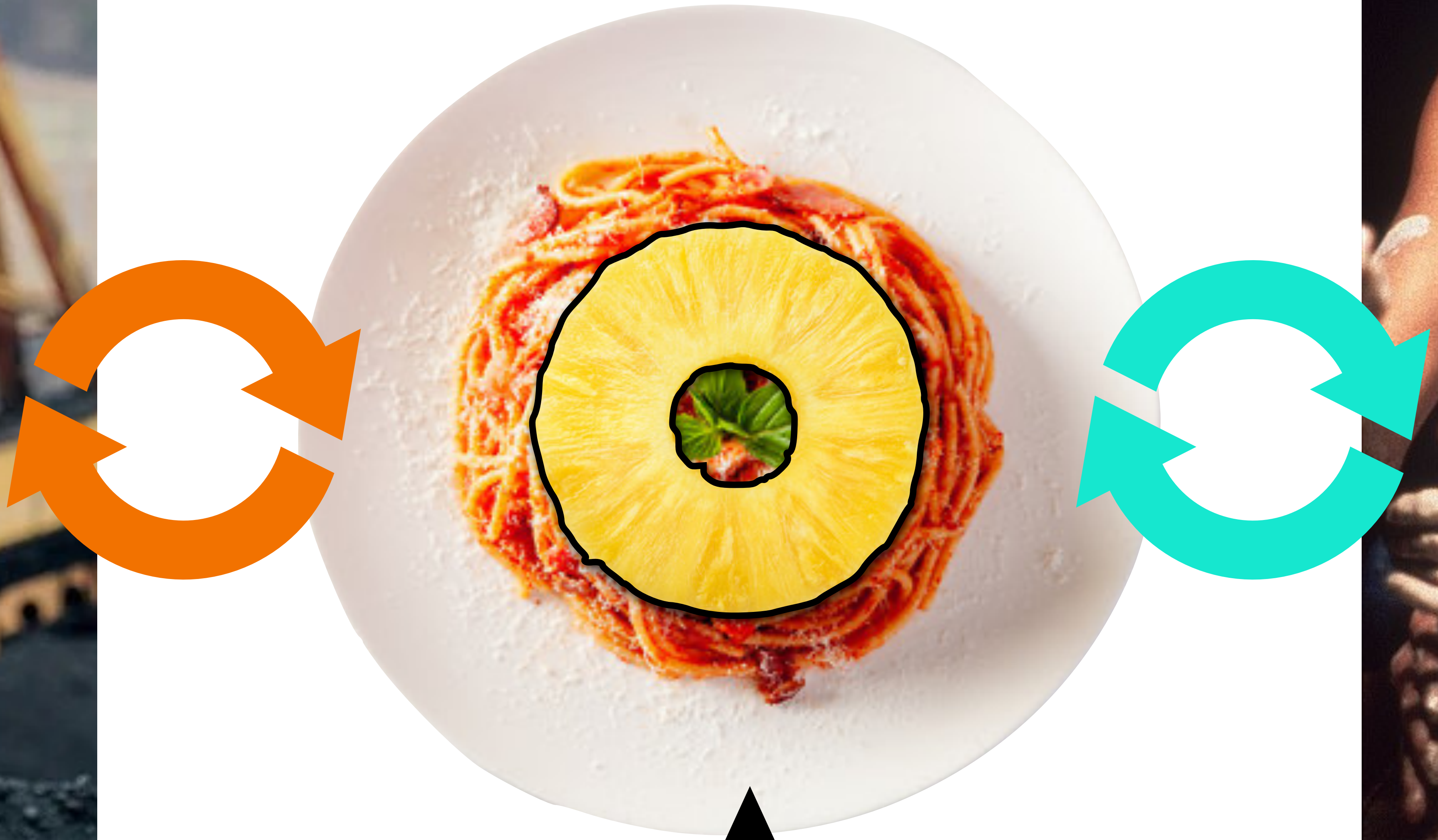
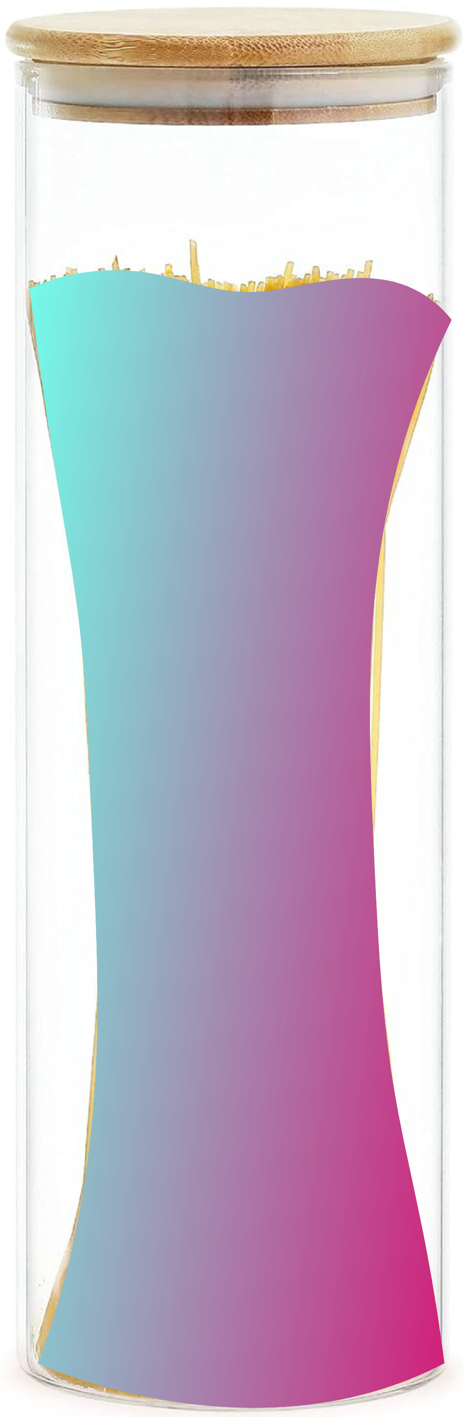
mining



unsound!

modelling

Data-aware process mining with separate techniques



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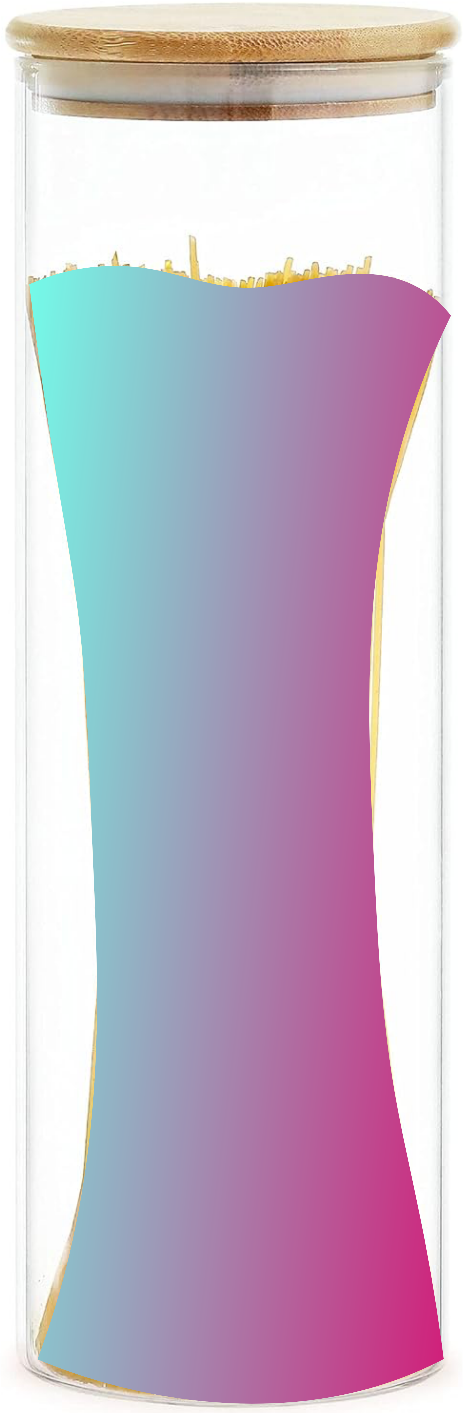
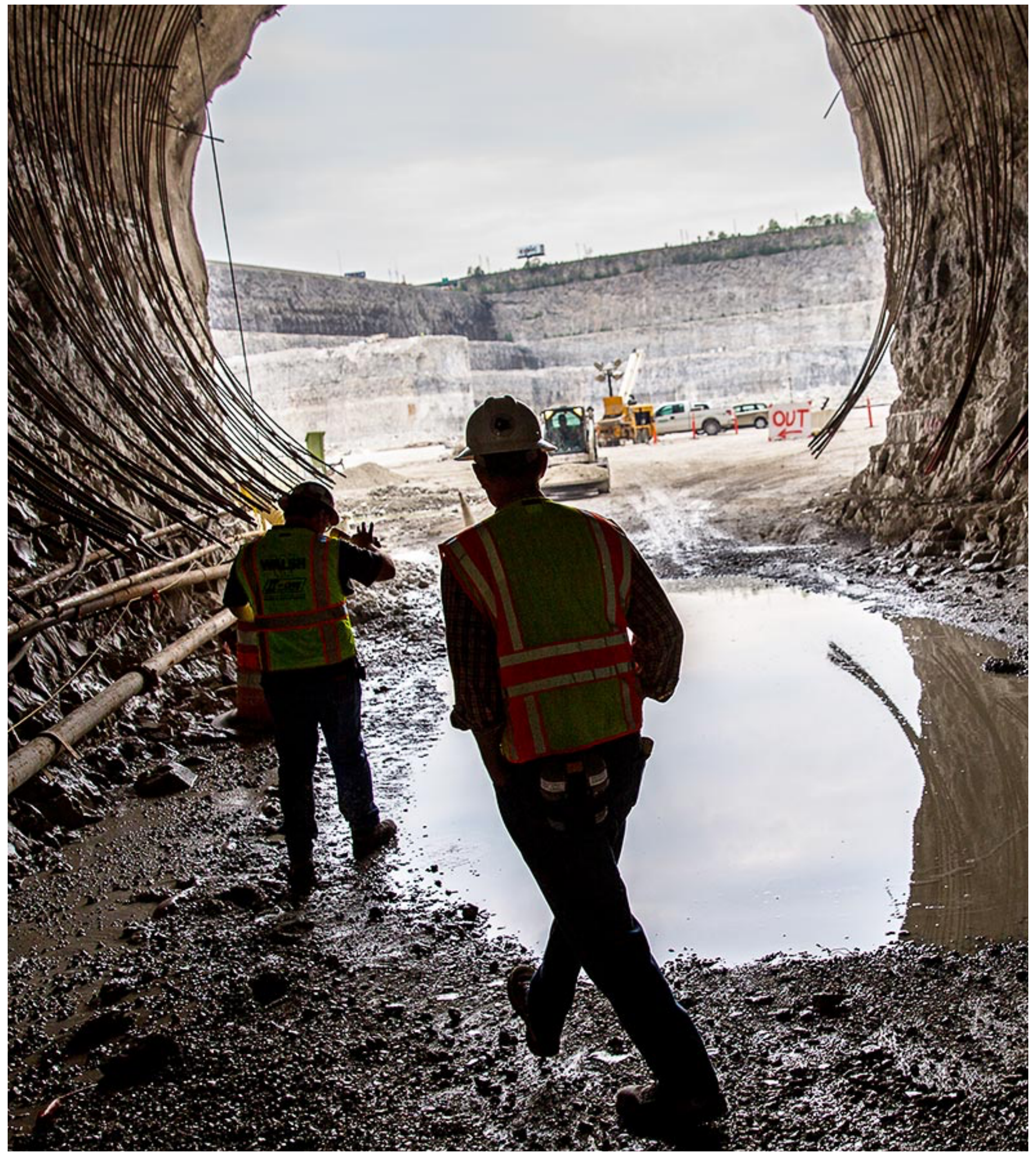
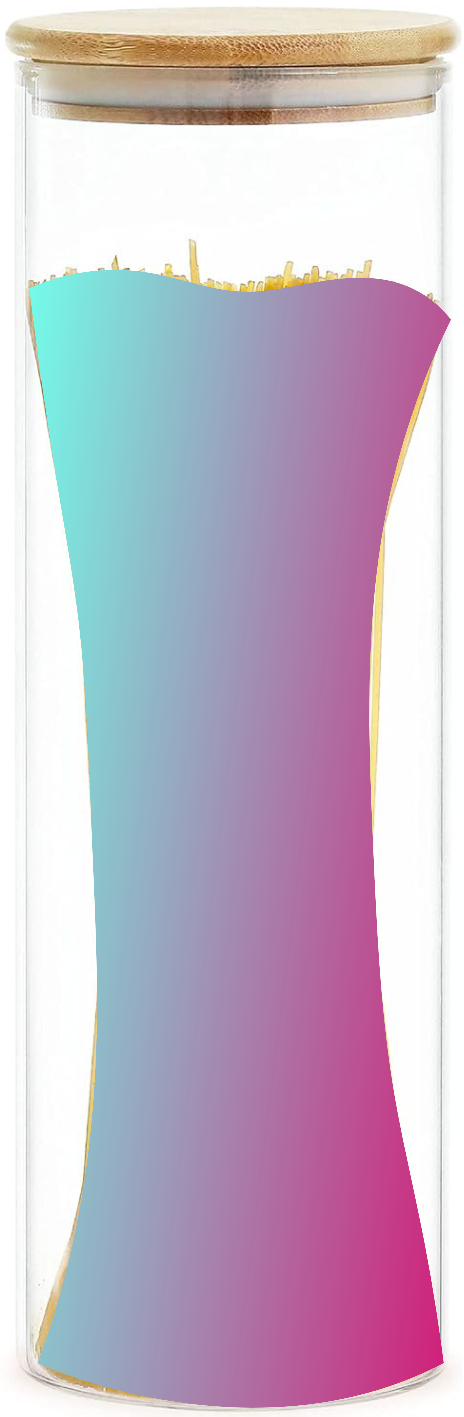
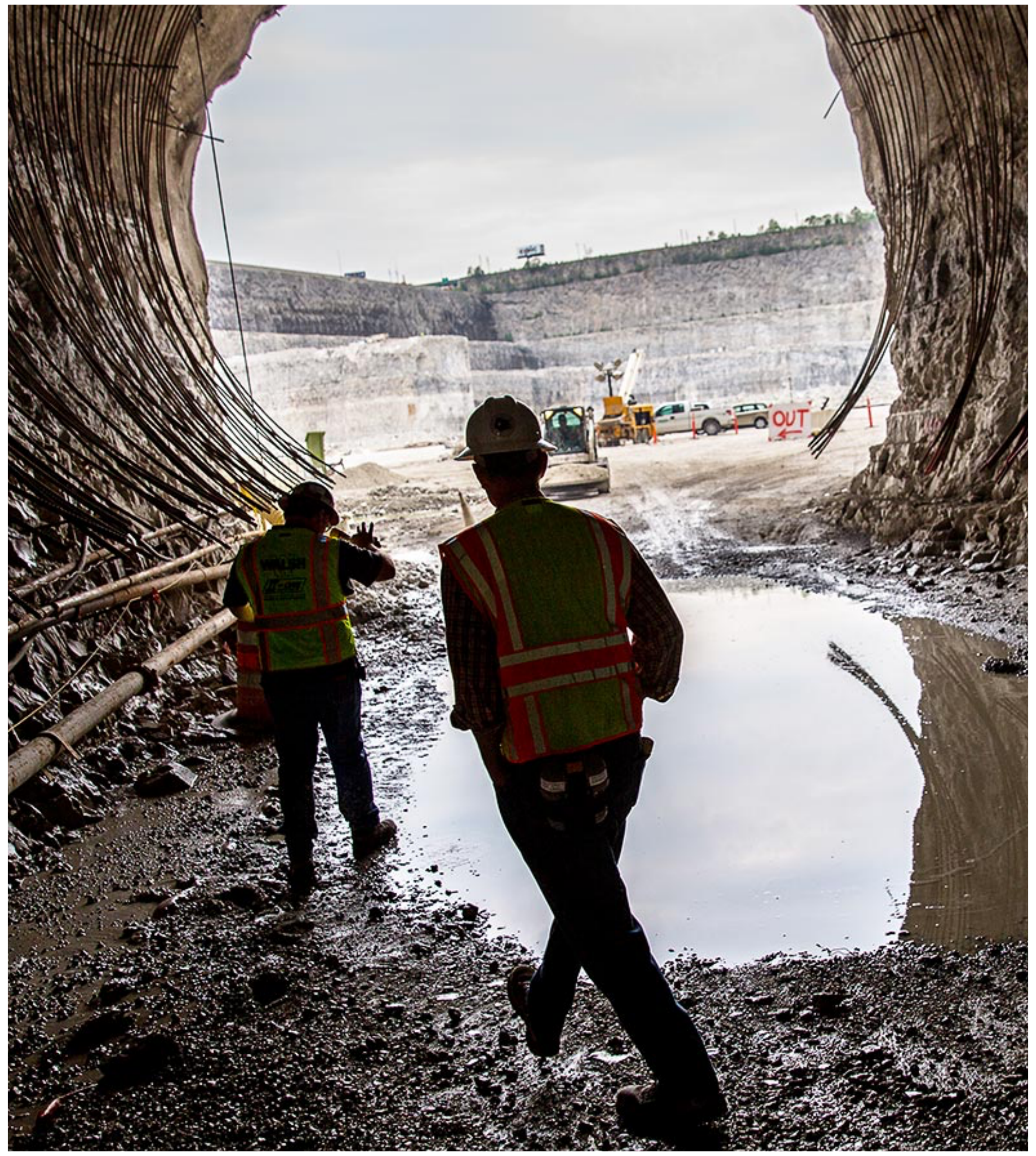




control-flow
mining

Data-aware process mining with separate techniques





control-flow
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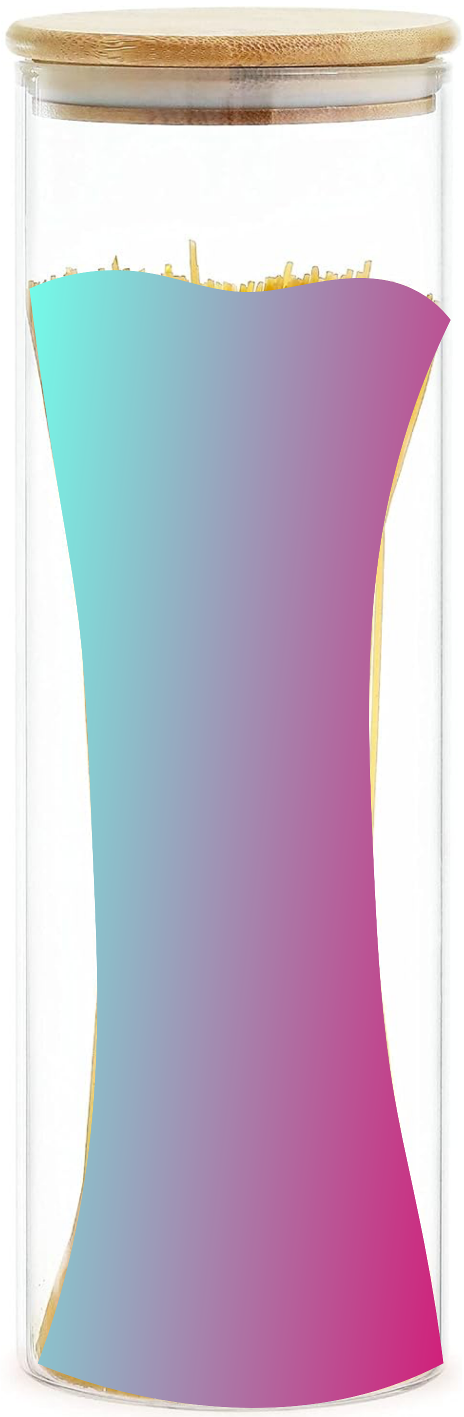
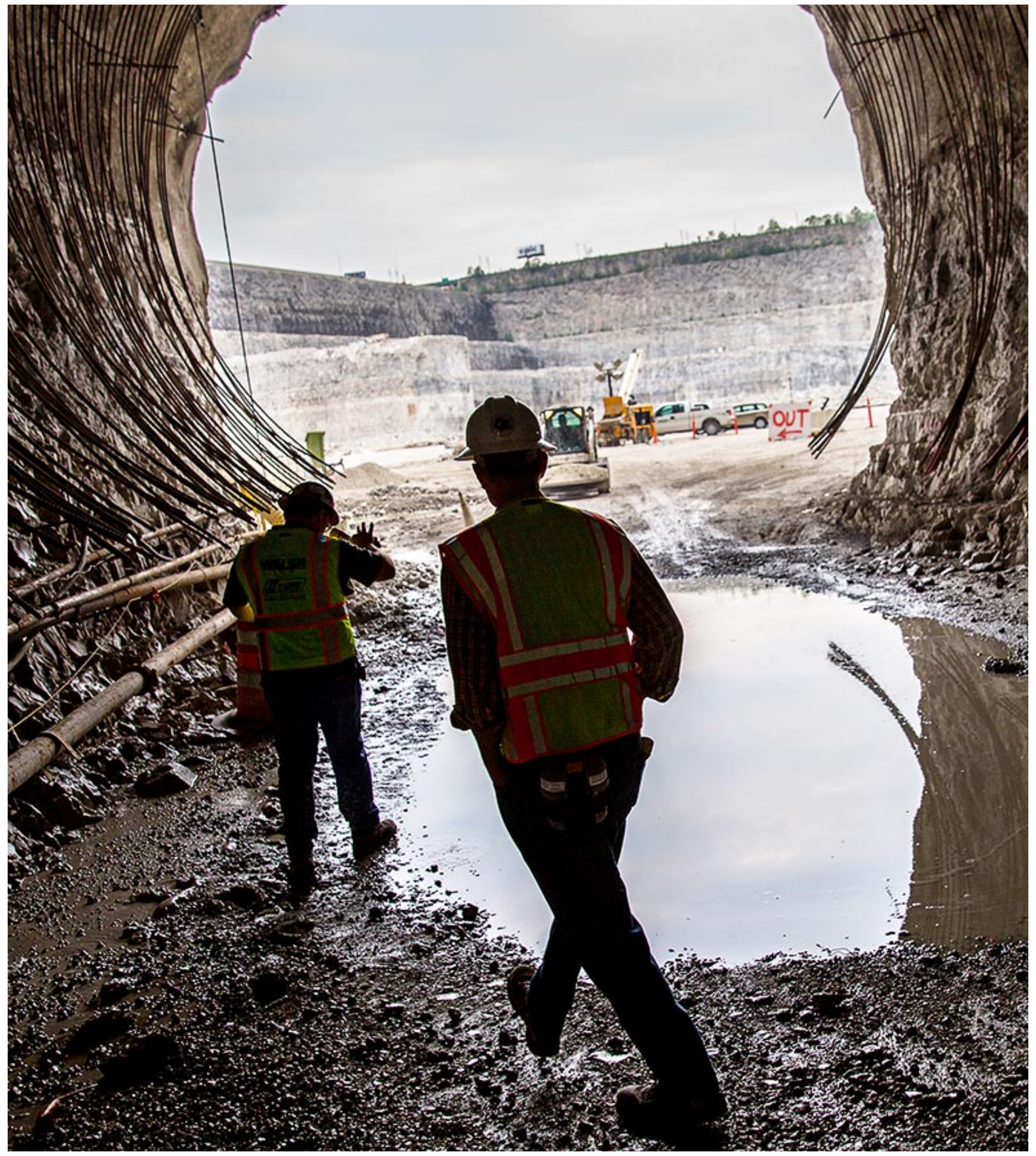
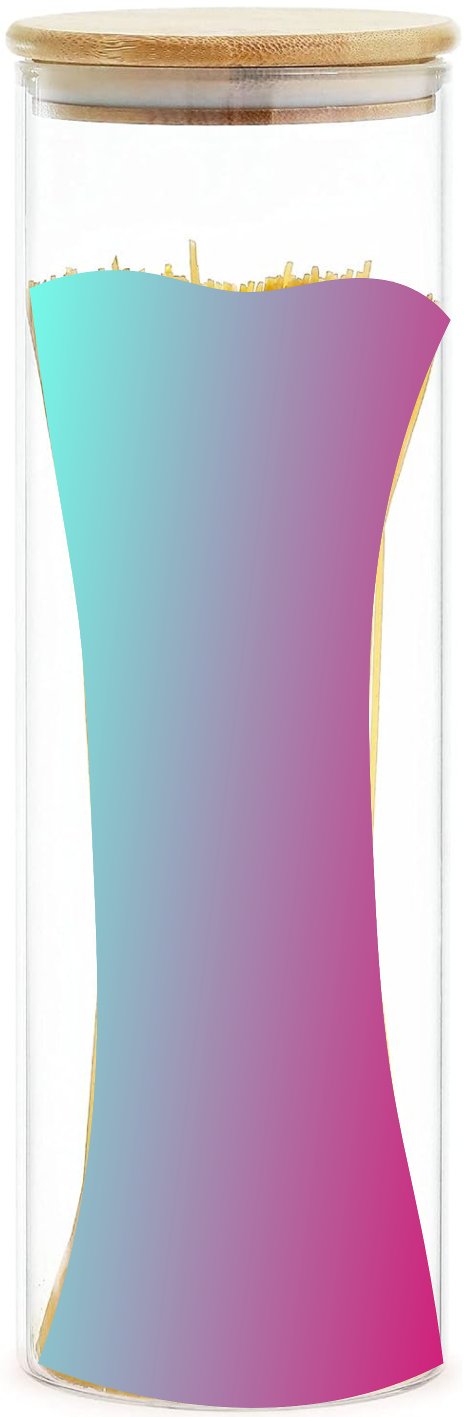


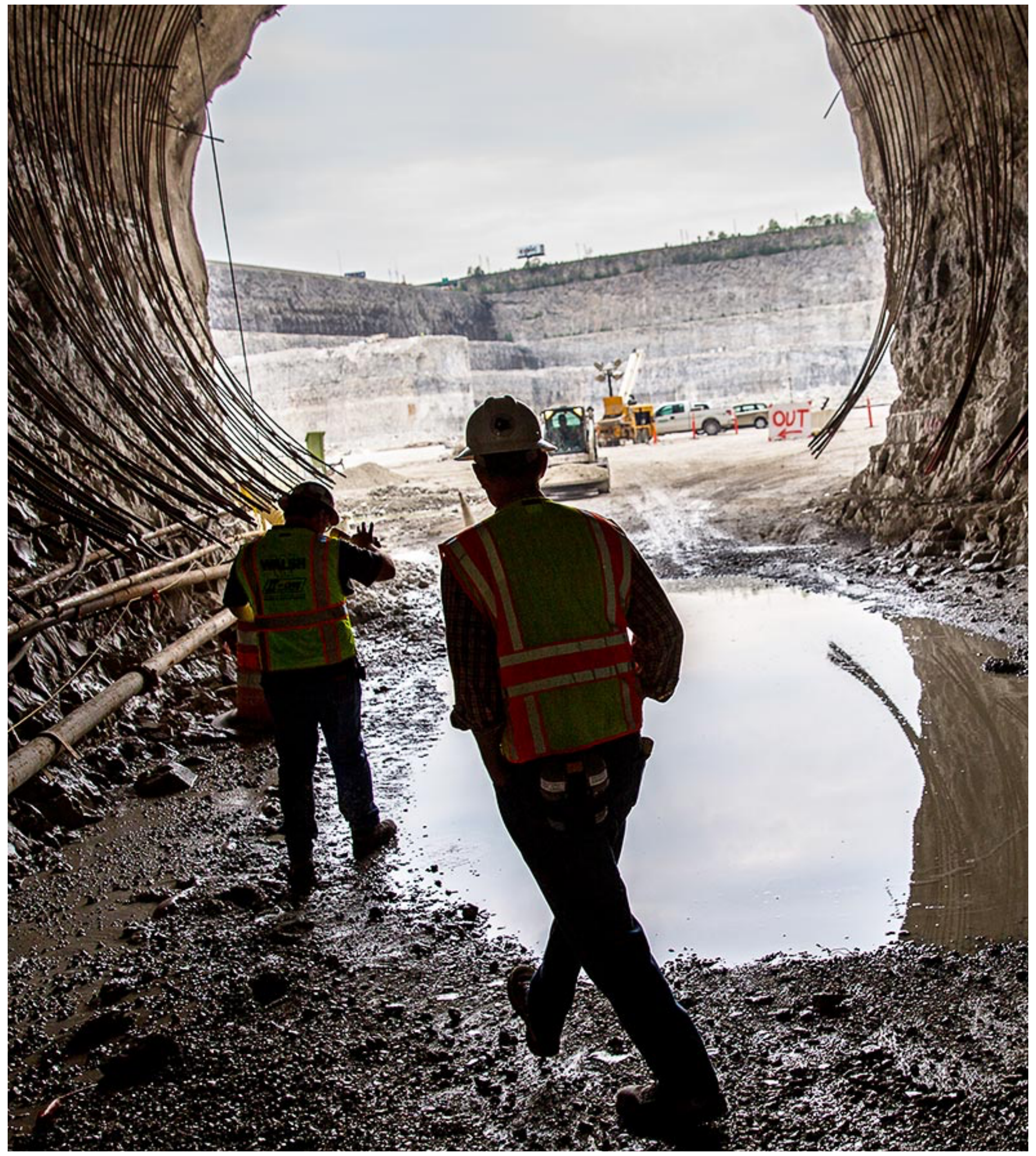


control-flow mining

guards/decision mining

Data-aware process mining with separate techniques





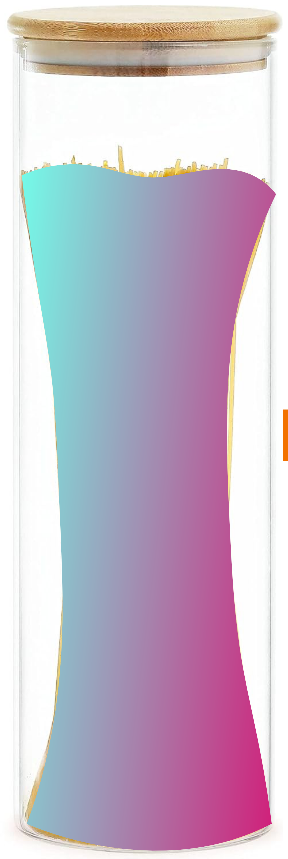
control-flow
mining

unsound!

guards/decision
mining

Data-aware process mining

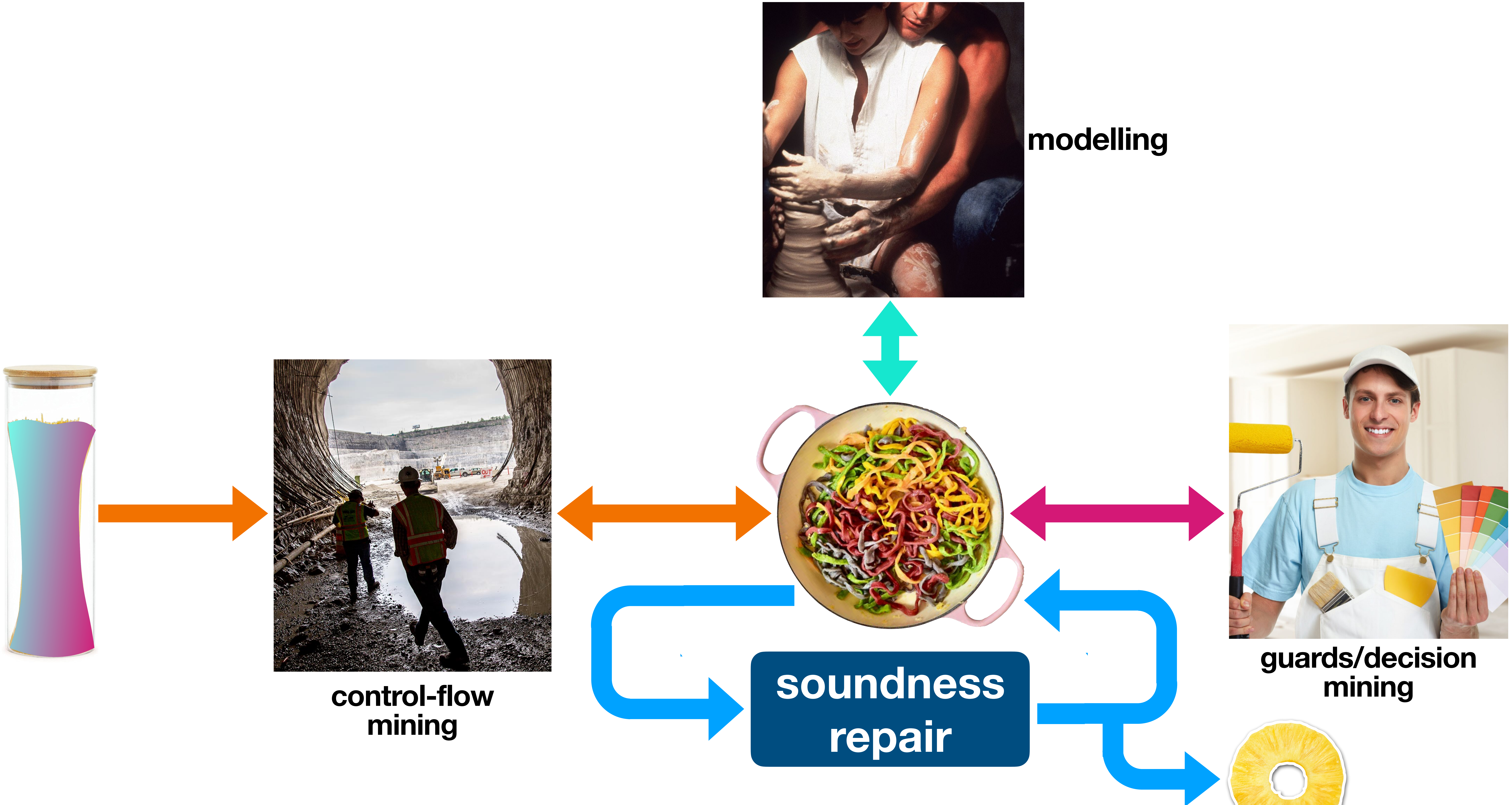
modelling



control-flow
mining

guards/decision
mining

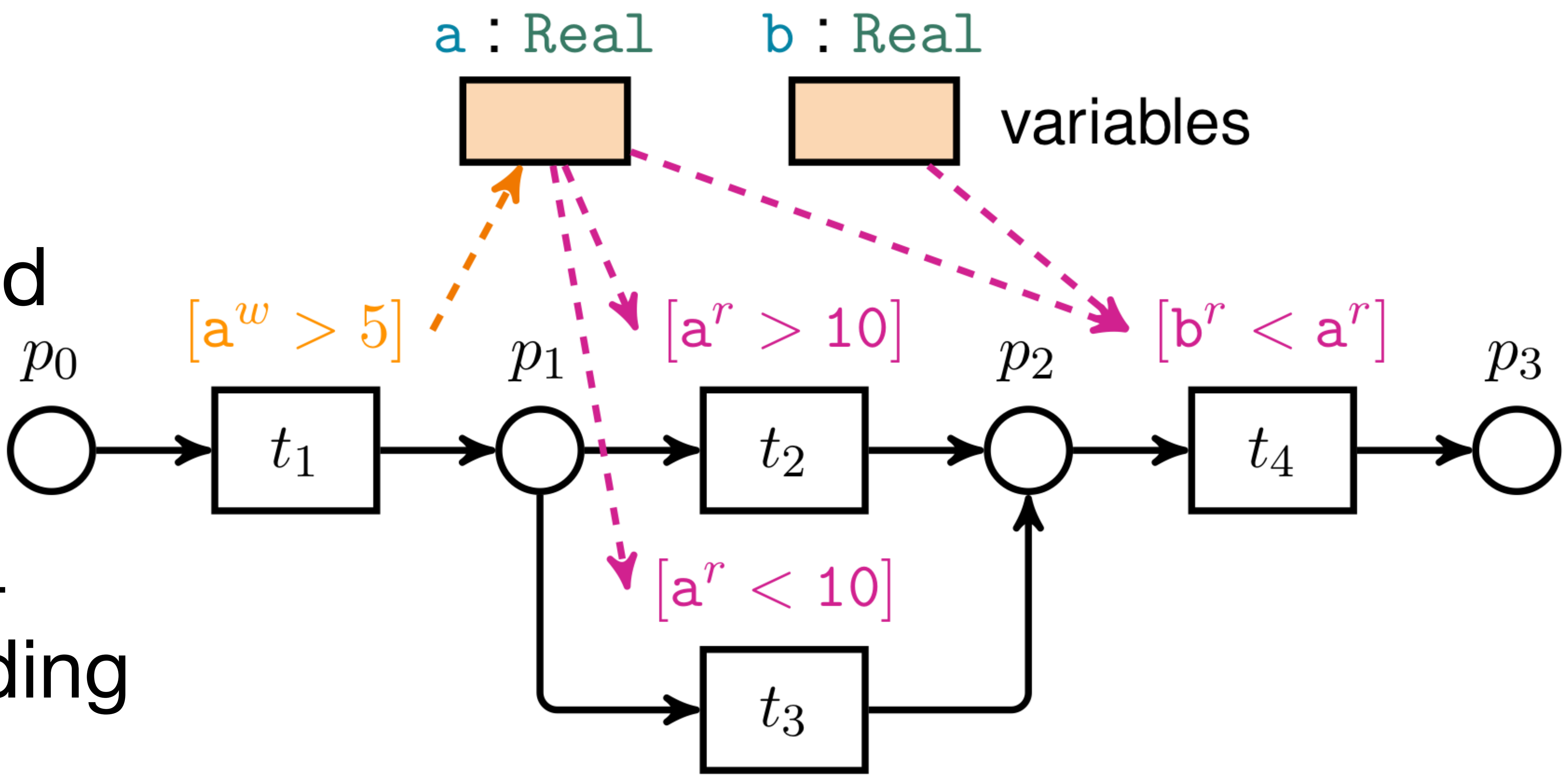
Data-aware process mining with reasoning



Data Petri Nets

[Mannhardt,PhD2018; _____,ER2018; _____,ACSD2019]

- Petri nets enriched with typed variables (ranging over infinite domains)
- Transitions access variables via **read** and **write guards**
- State: **marking + variable assignment**
- Transition firing: usual firing semantics + variable assignment update given a binding for the written variables



Infinite reachability graph even when the net is bounded

Possibility of reasoning depends on the guard language

Fragile setting: undecidability around the corner!

Goal

data-aware unsound DPN
N

has blocked states

Data-aware soundness checks: using [____,CAiSE 2022]

soundness repair

data-aware sound DPN
“minimally adapted”
from N

Assumptions

data-aware unsound DPN
N

has blocked states

soundness repair

data-aware sound DPN
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Assumptions

1.Underlying Petri net
(without data) is sound

data-aware unsound
DPN
N

has blocked
states

soundness
repair

data-aware sound DPN
“minimally adapted”
from N

Assumptions

1.Underlying Petri net (without data) is sound

data-aware unsound DPN
N

has blocked states

soundness repair

data-aware sound DPN "minimally adapted" from N

2.Guard language in a fragment where soundness can be checked [____,CAiSE 2022]
E.g.: variable-to-constant guards

Assumptions

1.Underlying Petri net (without data) is sound

3.Does not modify control structure, only guards

data-aware unsound DPN
N

has blocked states

soundness repair

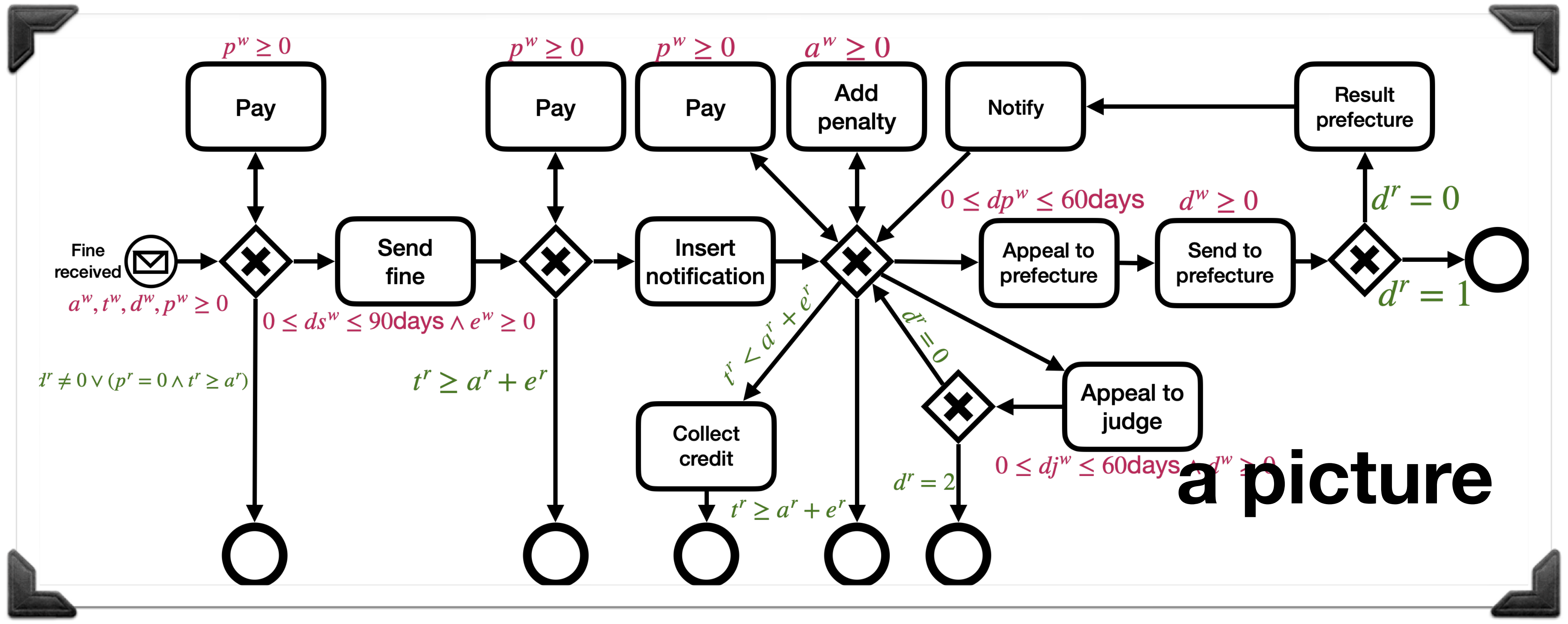
data-aware sound DPN
“minimally adapted” from N

2.Guard language in a fragment where soundness can be checked [____,CAiSE 2022]
E.g.: variable-to-constant guards

The two views of a process model…

… and what "minimality" means!

process representation



a picture

Minimal number of interventions on guards

[Zavatteri et al., FM-BPM 2023]

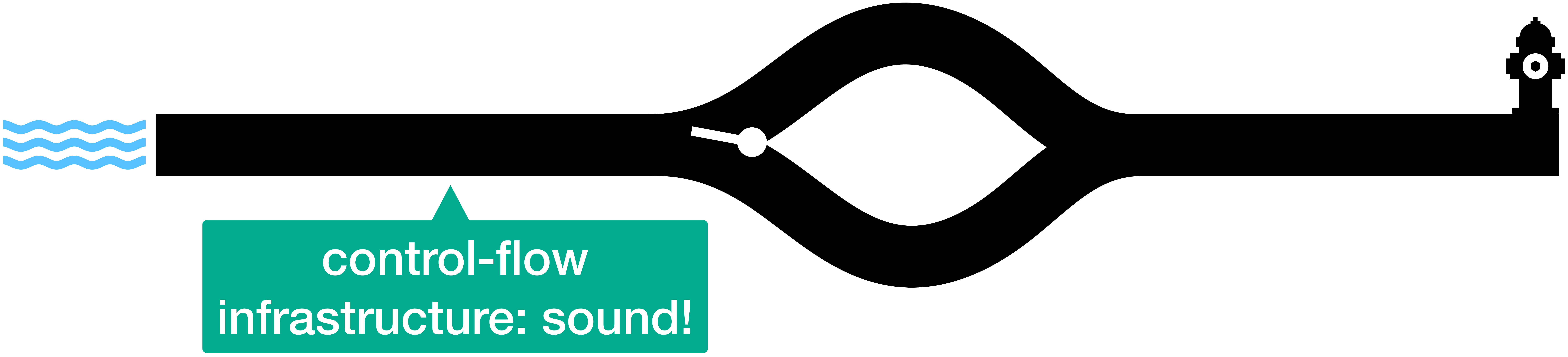
process model

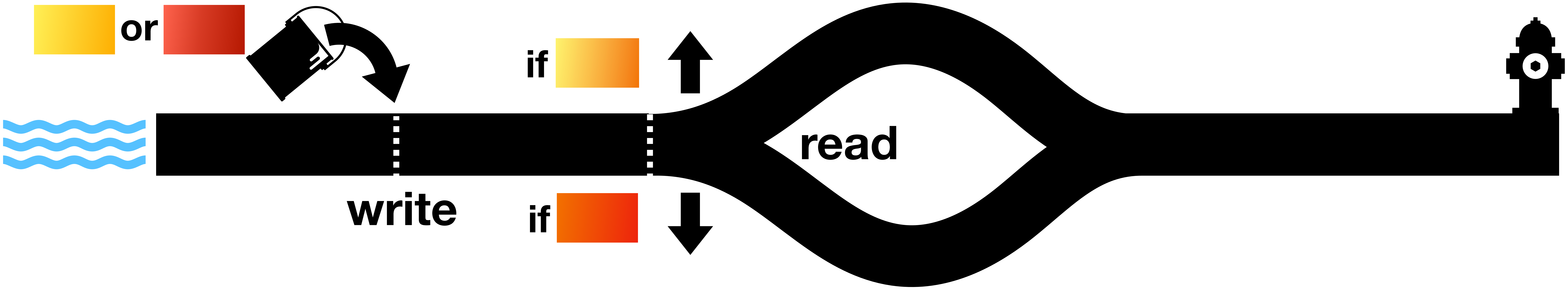
process behaviors

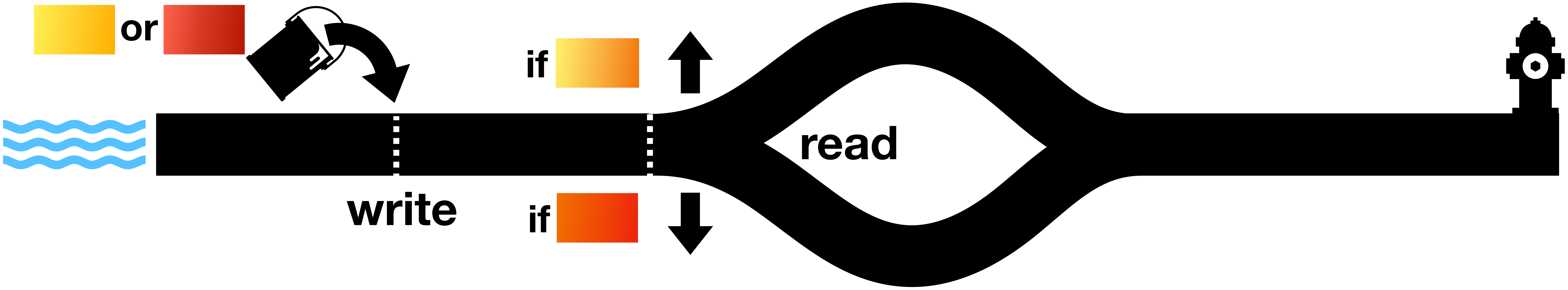
⋮ infinitely many traces

Our approach: minimal impact on behavior

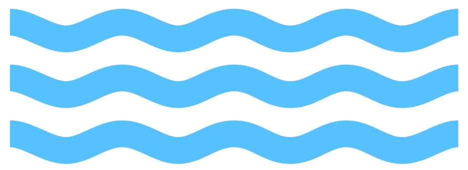
We only impact traces leading to a blocked state

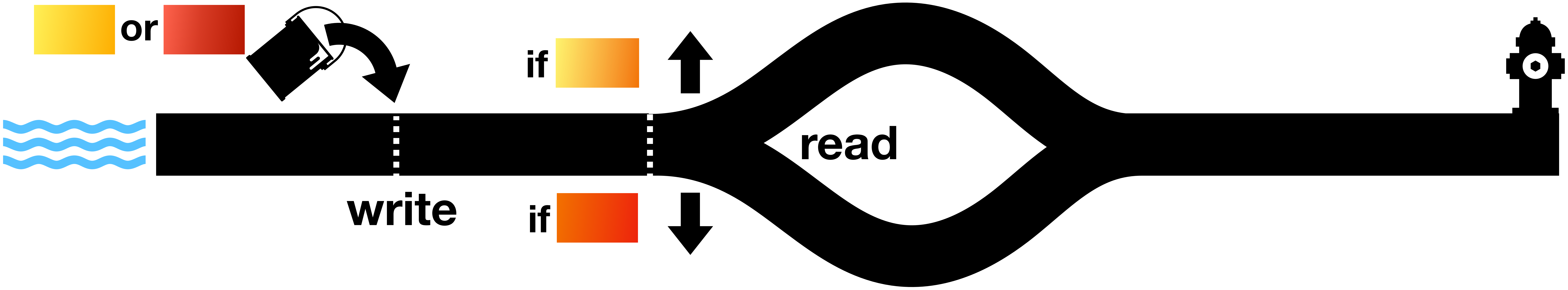

control-flow
infrastructure: sound!


or
if
write
read
if



execution





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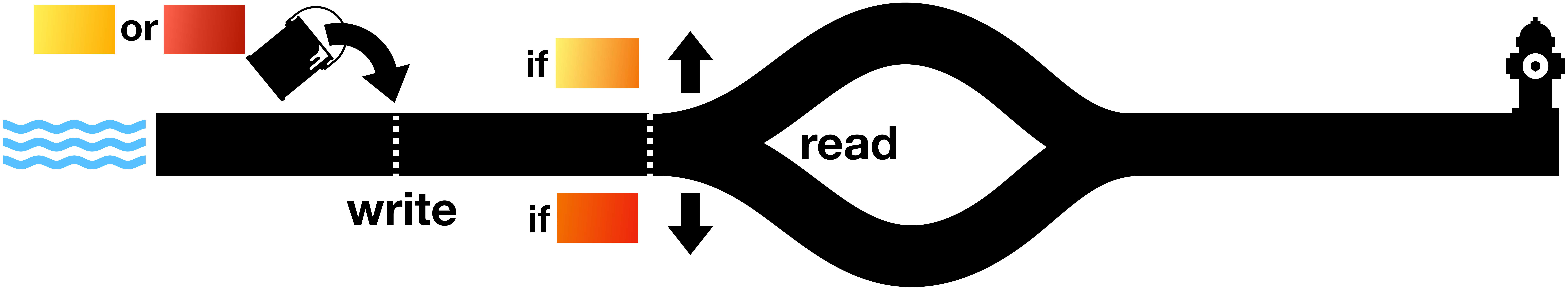
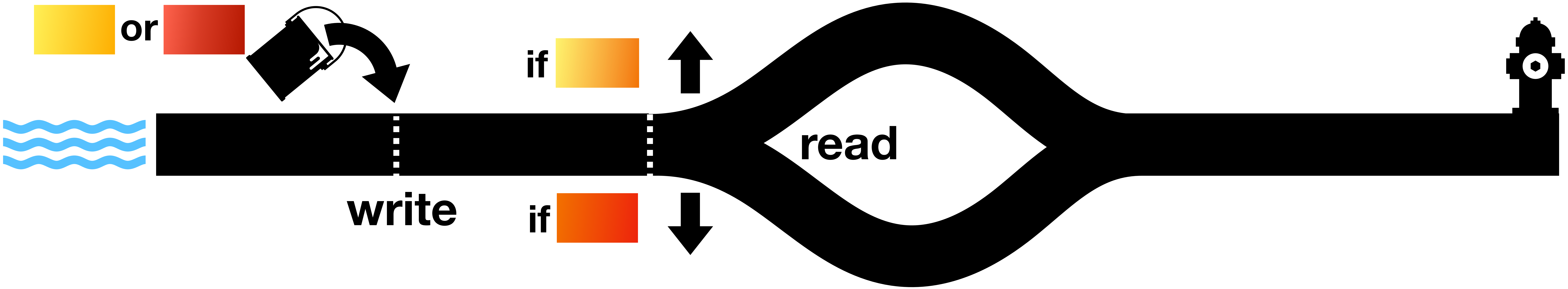
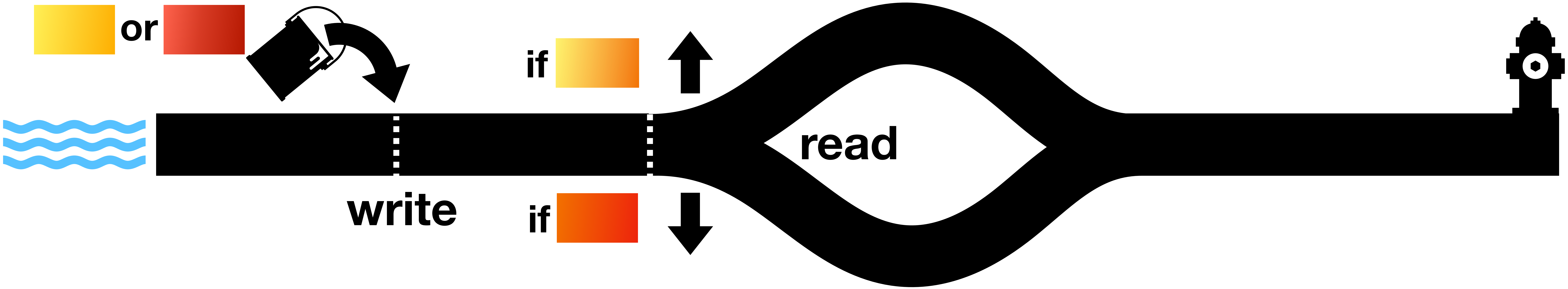

or
write
if
if
read

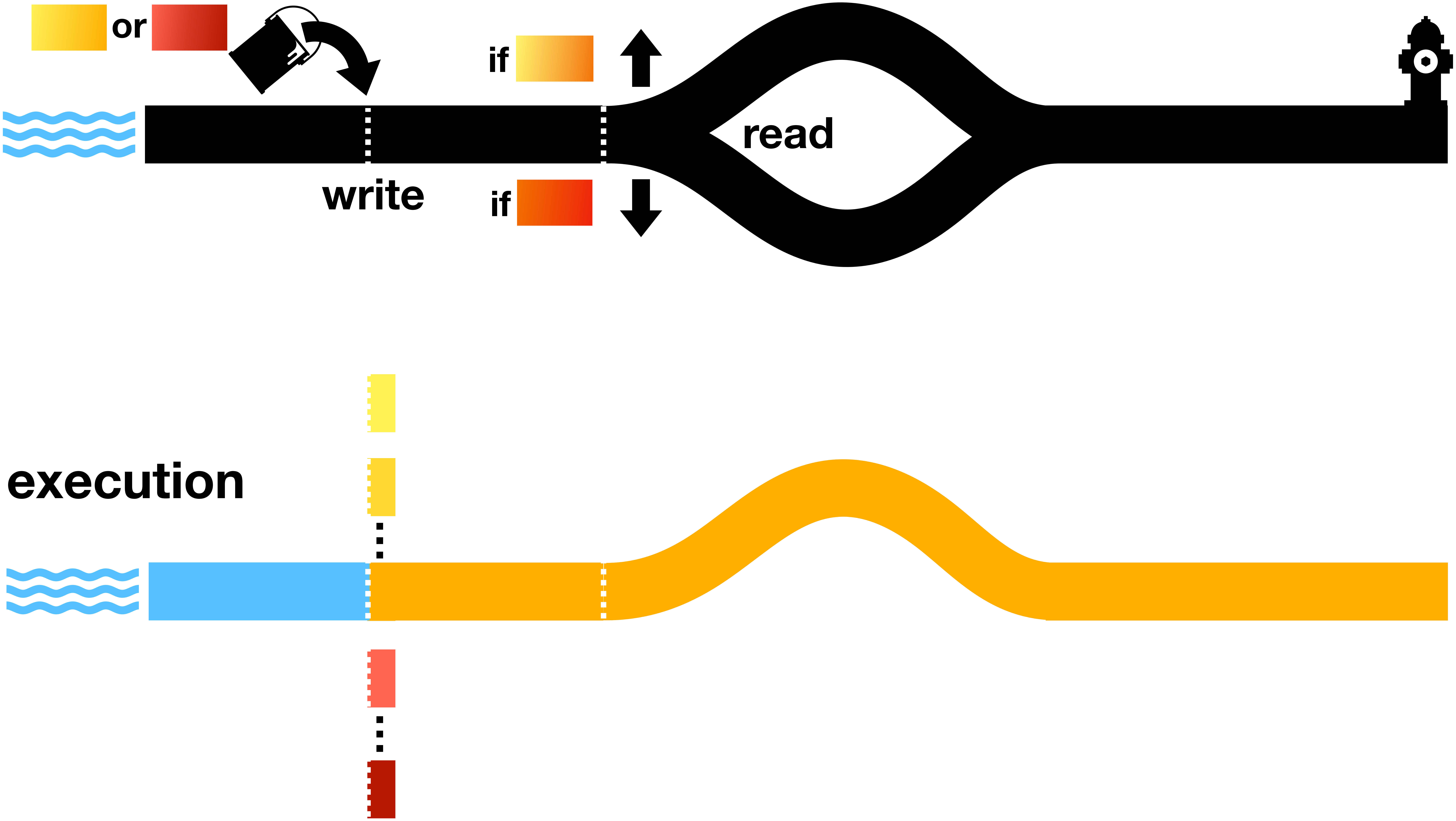

execution
pick



execution



execution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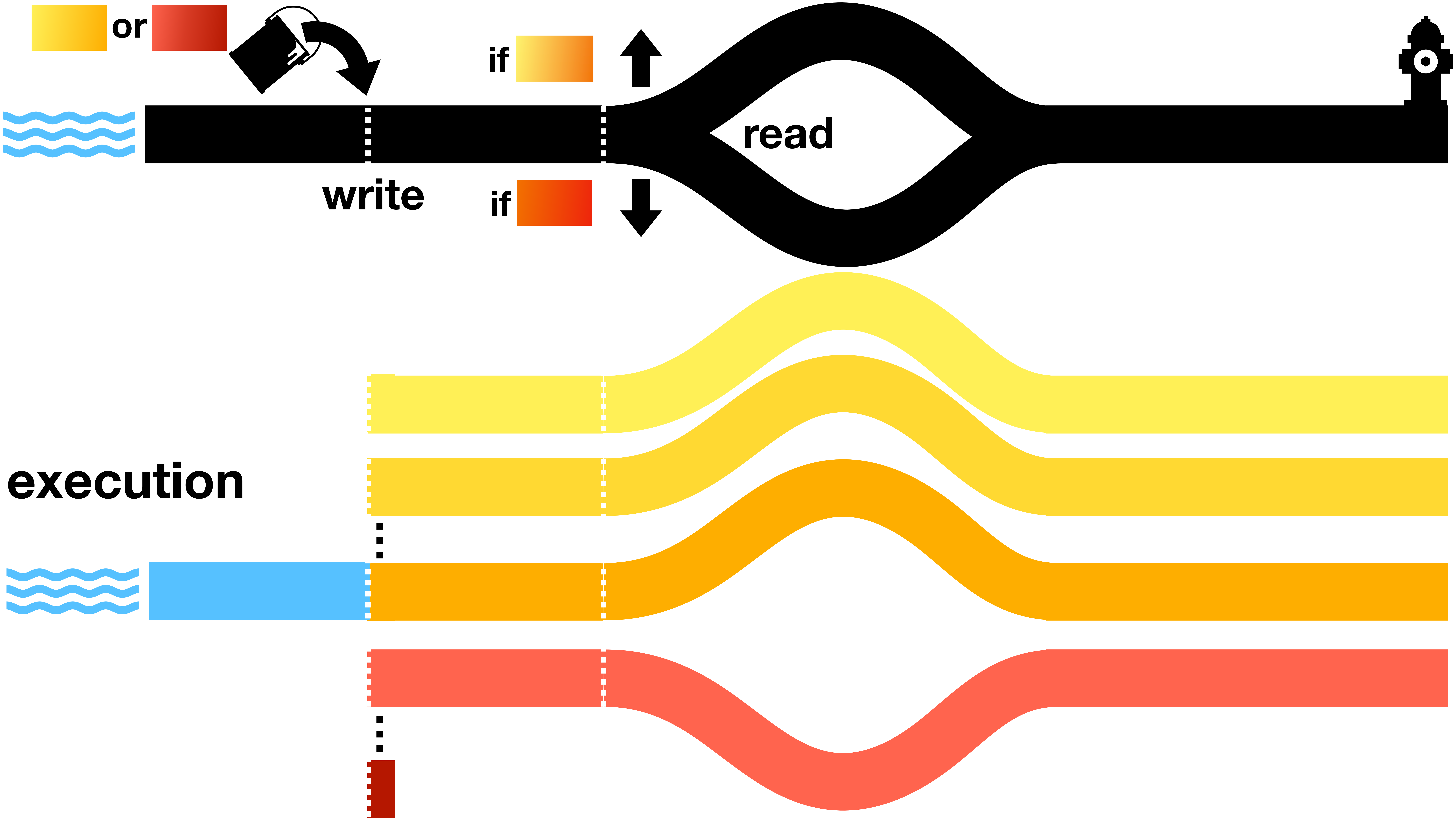
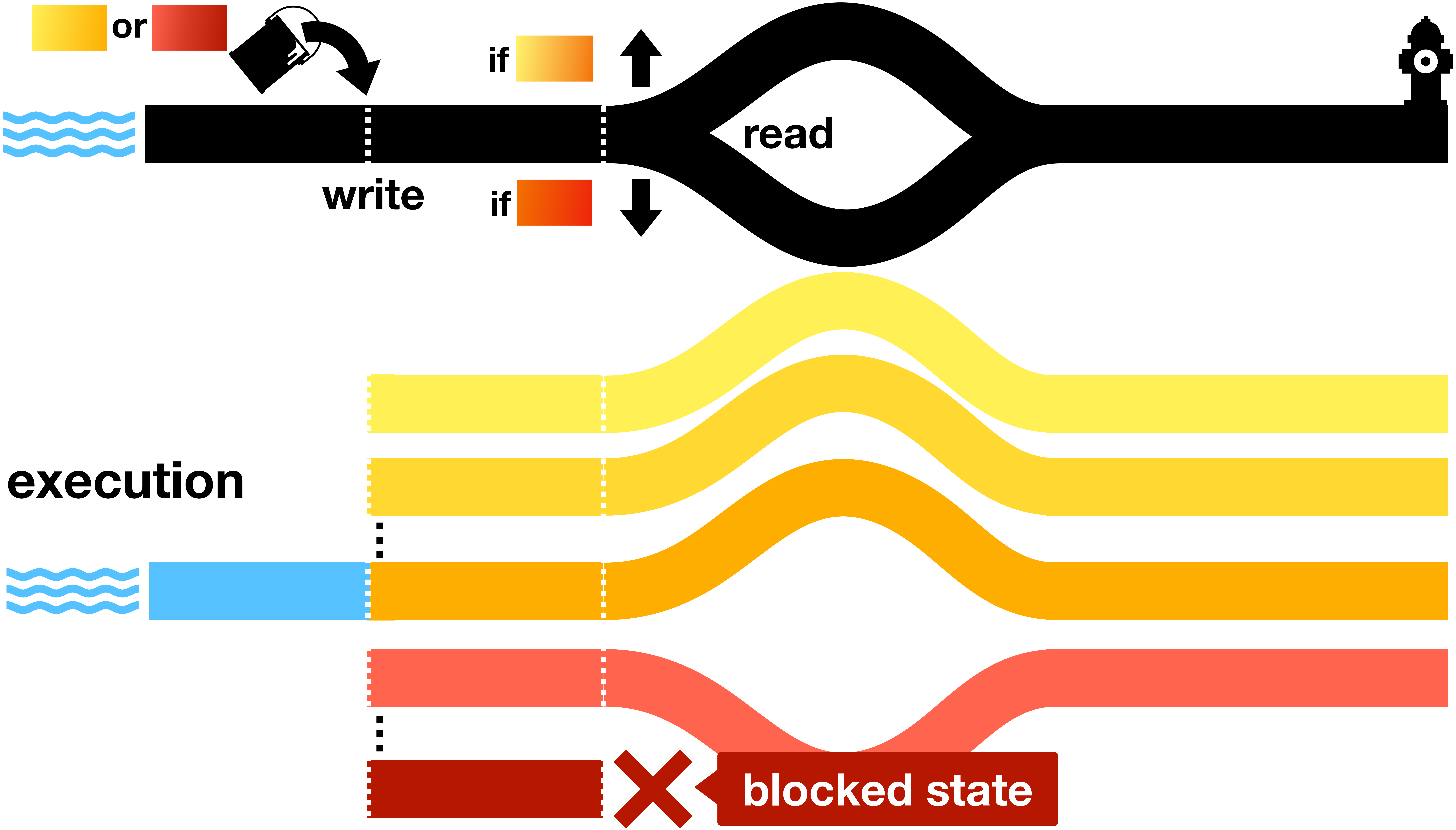
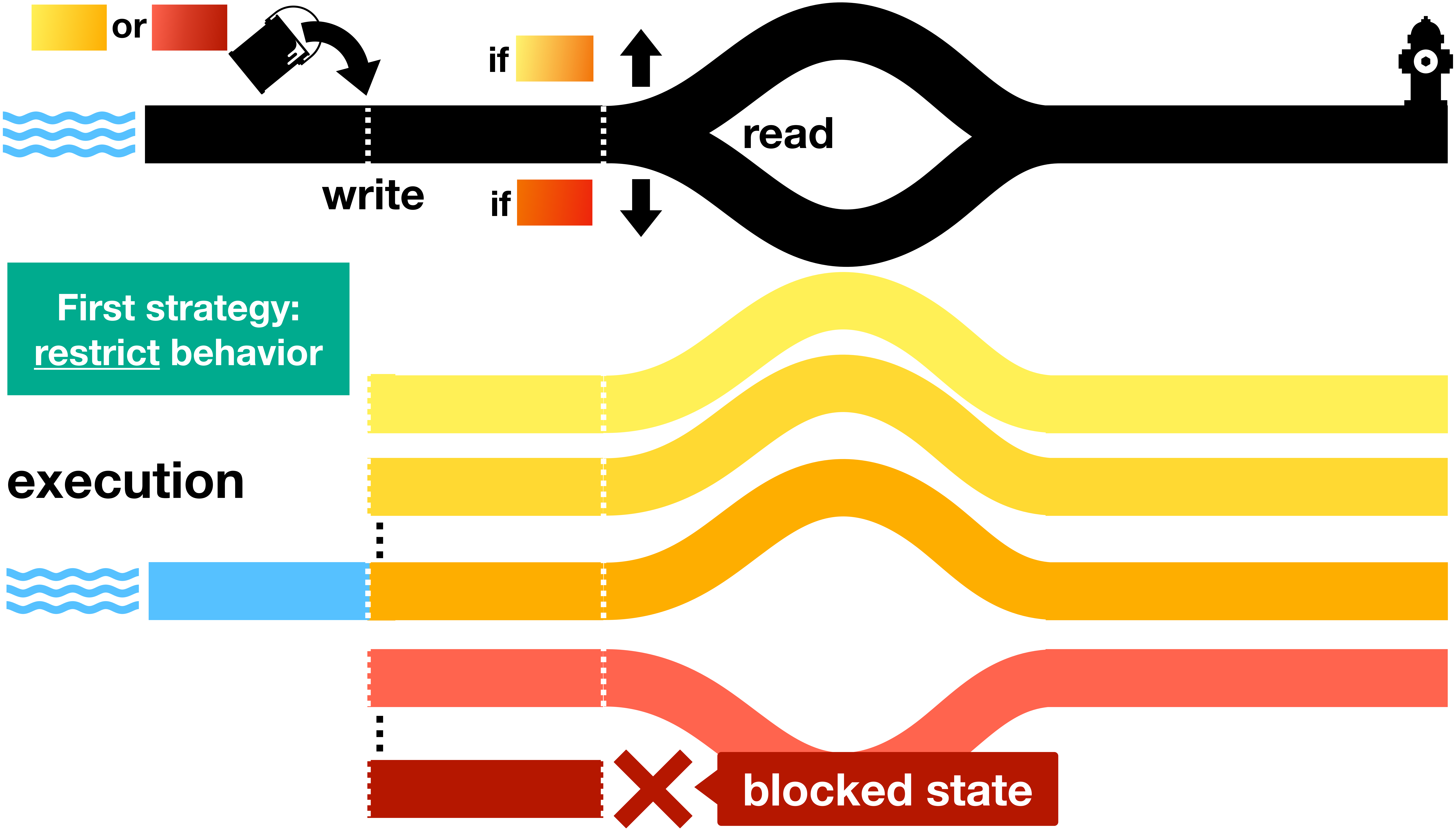
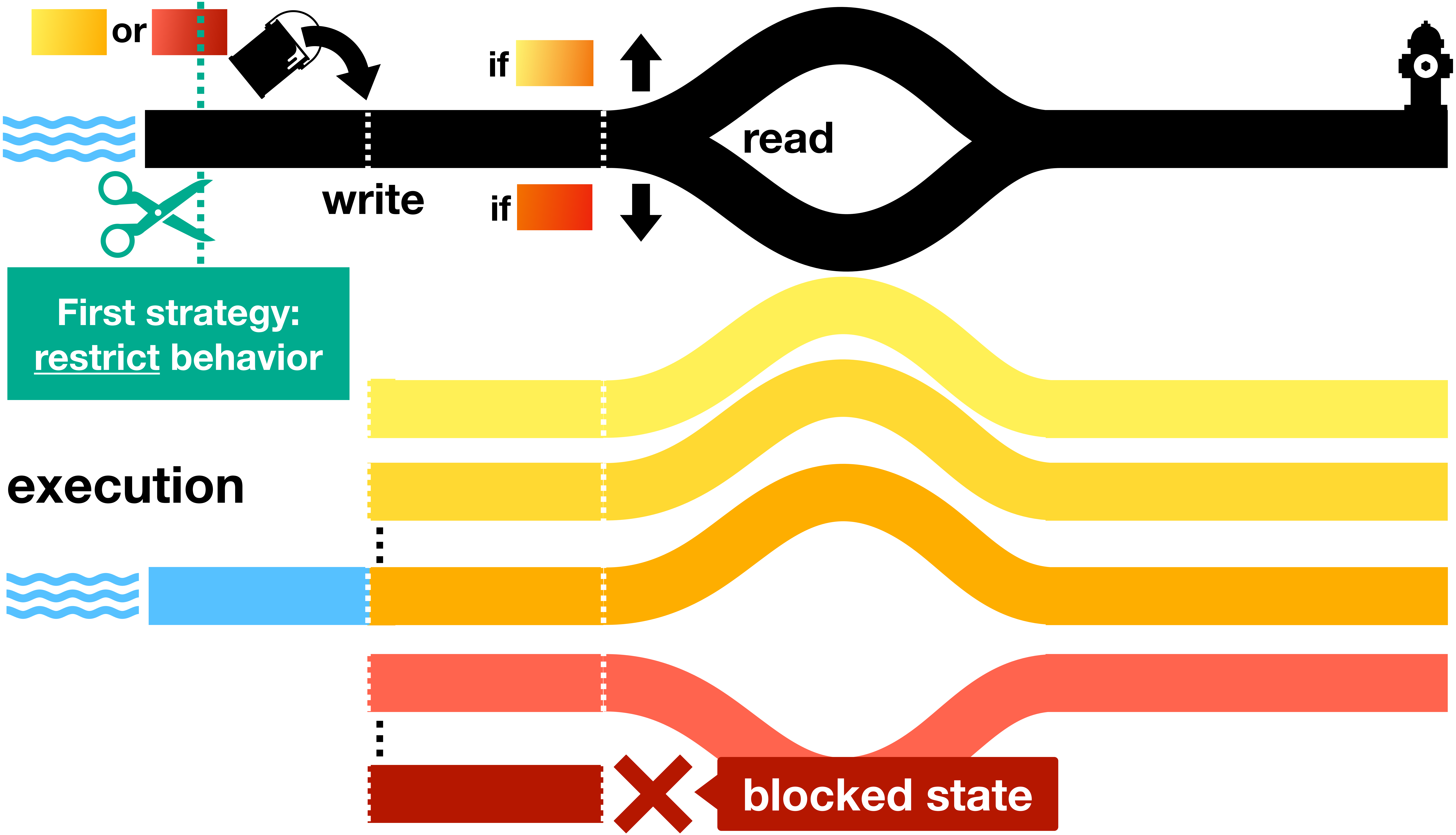


or
if
if
read
write
execution



or
if
write
if
read
execution
blocked state


or
if
if
write
read
First strategy:
restrict behavior
execution
blocked state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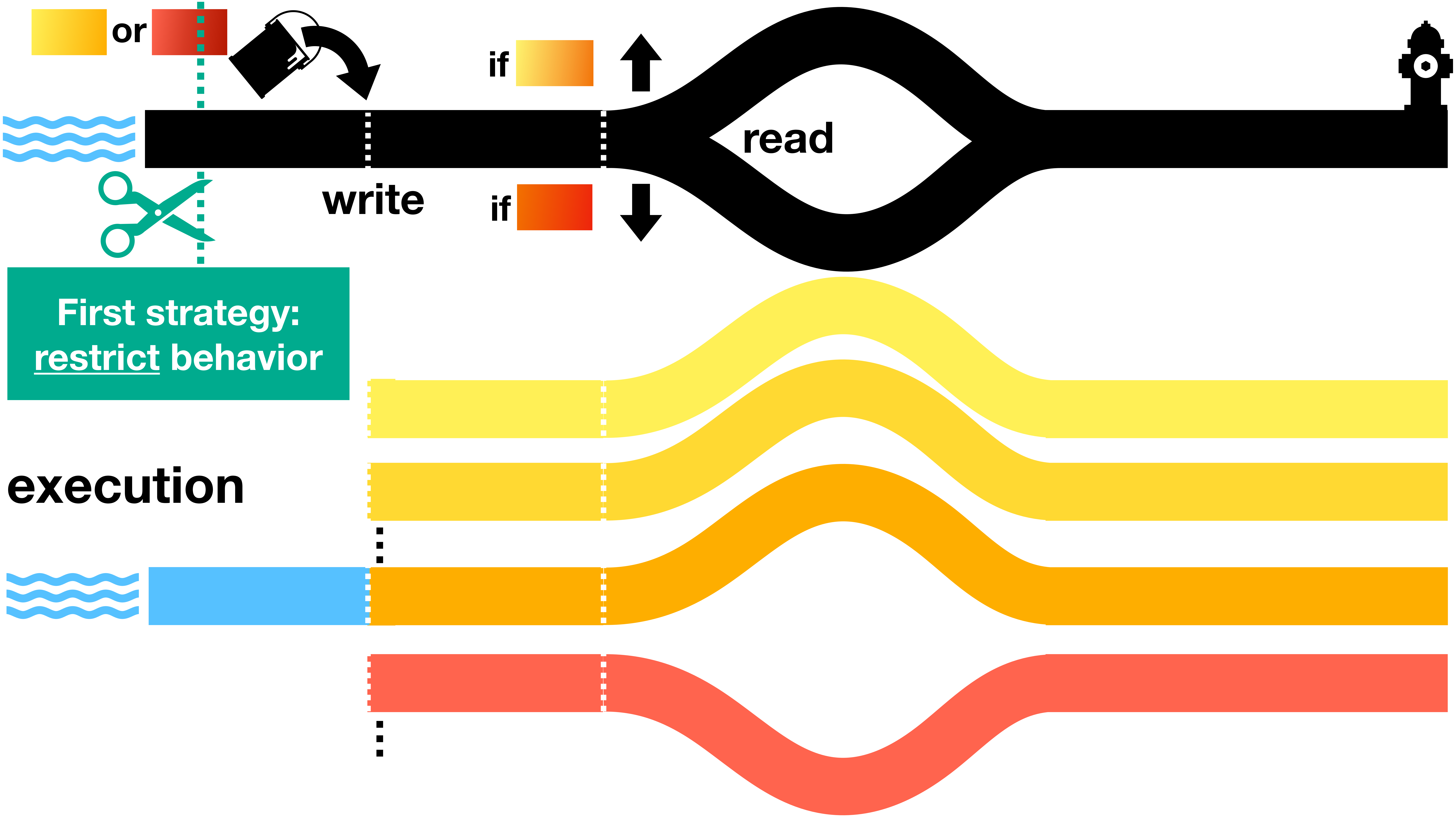
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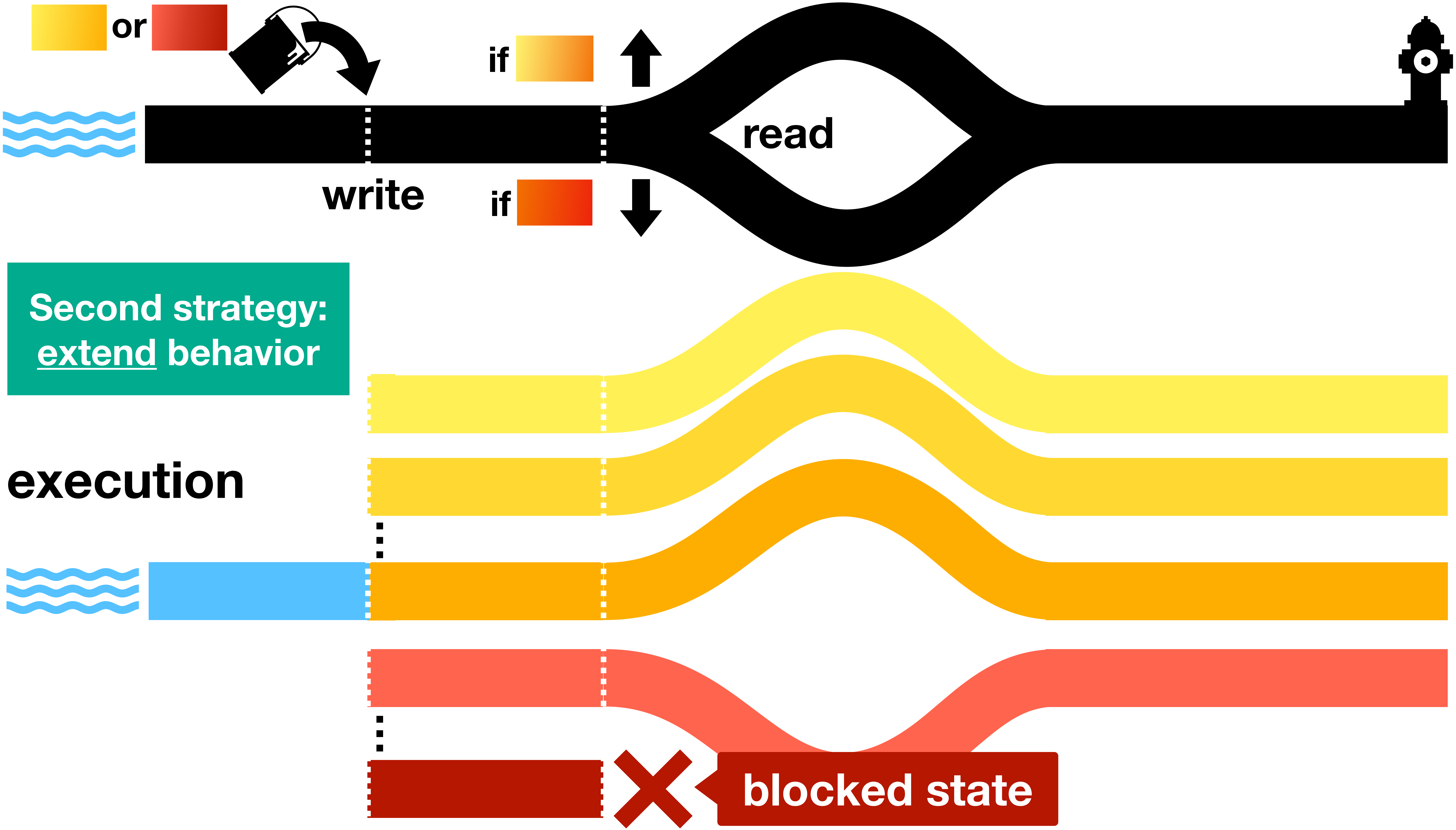
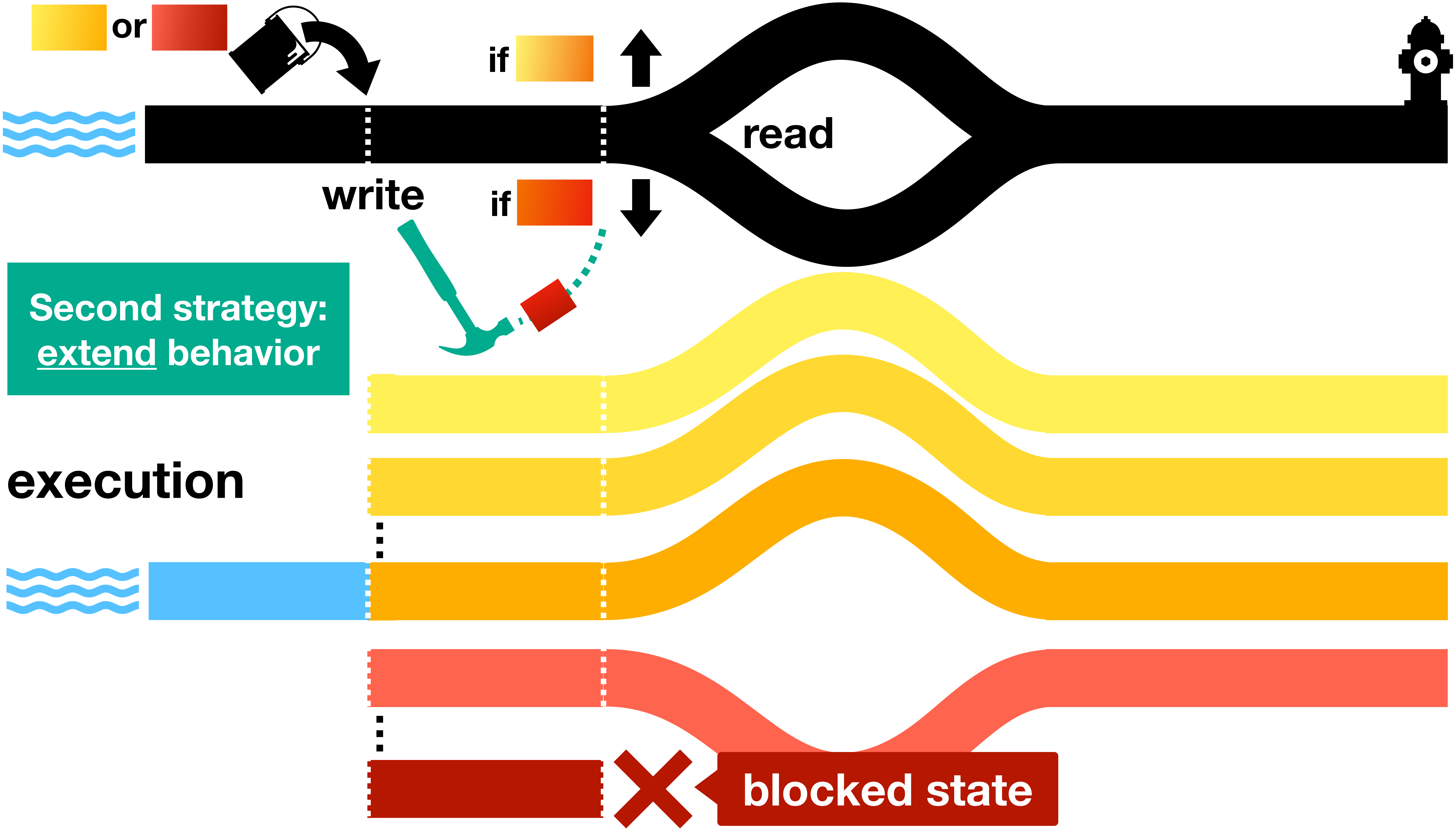

or
write
if
if
read
Second strategy:
extend behavior
execution
blocked state



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blocked state

or
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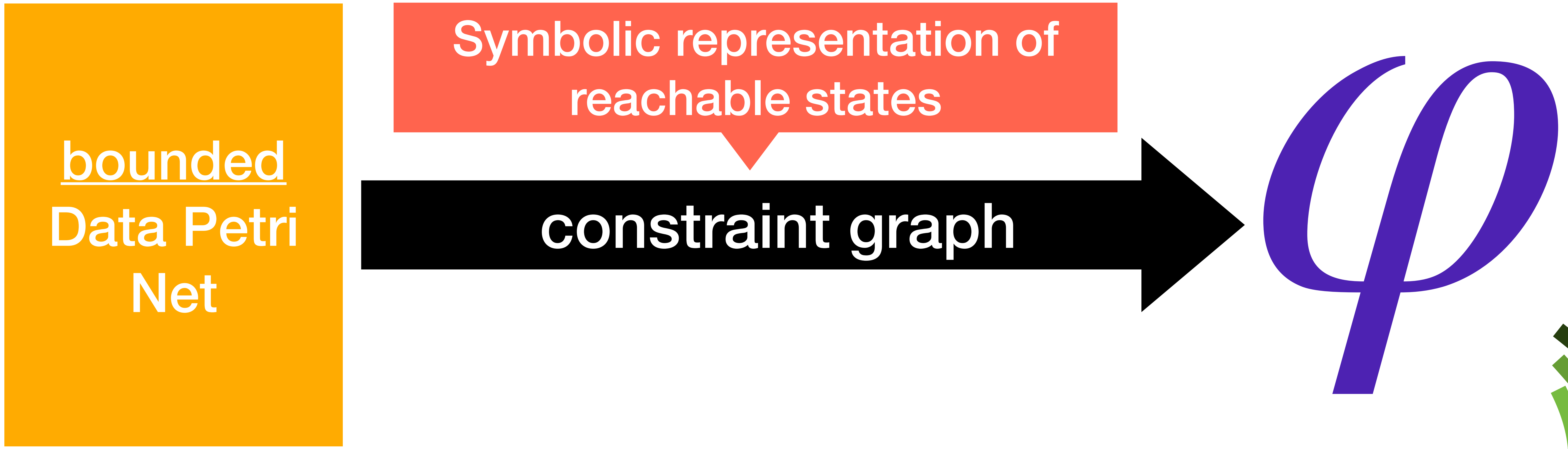
execution

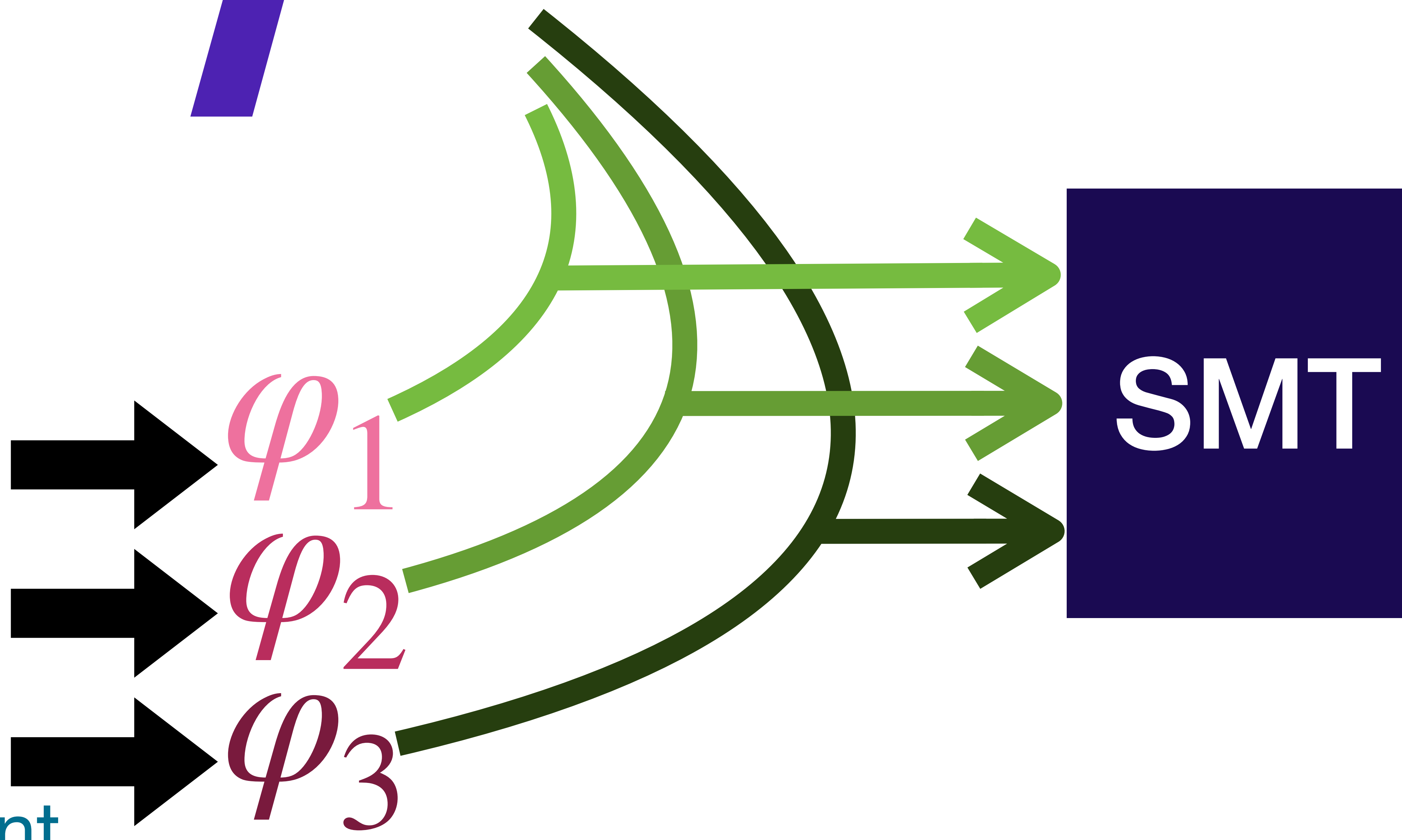
How to?

Step 1. Formula to characterise blocking runs



Data-aware soundness

- There are no dead tasks
- The final marking is only reached in a clean way for some variable assignment
- In every reachable marking, it must be possible to reach the final marking for some variable assignment



How to?

Step 1. Formula to characterise blocking runs

<u>bounded</u> Data Petri Net

Symbolic representation of reachable states

constraint graph

φ

Extract formula $\varphi_{blocked}$ capturing exactly those runs that get stuck

Data-aware soundness

- There are no dead tasks
- The final marking is only reached in a clean way for some variable assignment
- In every reachable marking, it must be possible to reach the final marking for some variable assignment

φ_1

φ_2

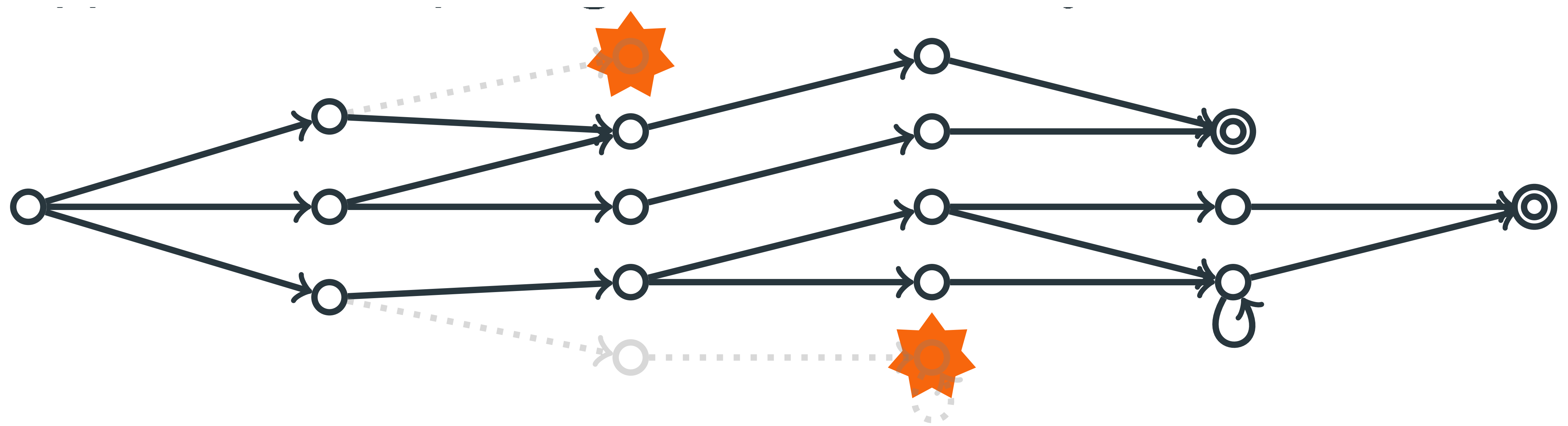
φ_3

SMT

How to?

Step 2. Carefully iterate over blocked states, using $\varphi_{blocked}$ to minimally avoid/unblock them

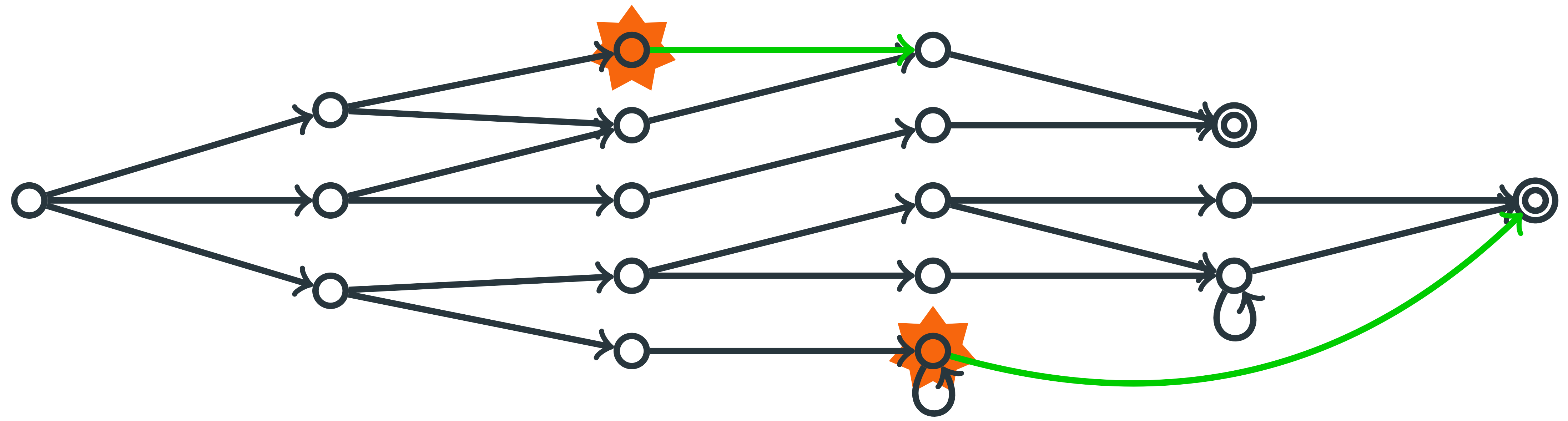
Restriction: avoid blocked states by tightening guards



How to modify guards?

- Retrieve formula $\varphi_{blocked}$
- Let *a* be a transition leading to that blocked state
- **Update** $guard(a) = guard(a) \wedge \neg\varphi_{blocked}$

Extension: let blocked states proceed by relaxing guards



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How to?

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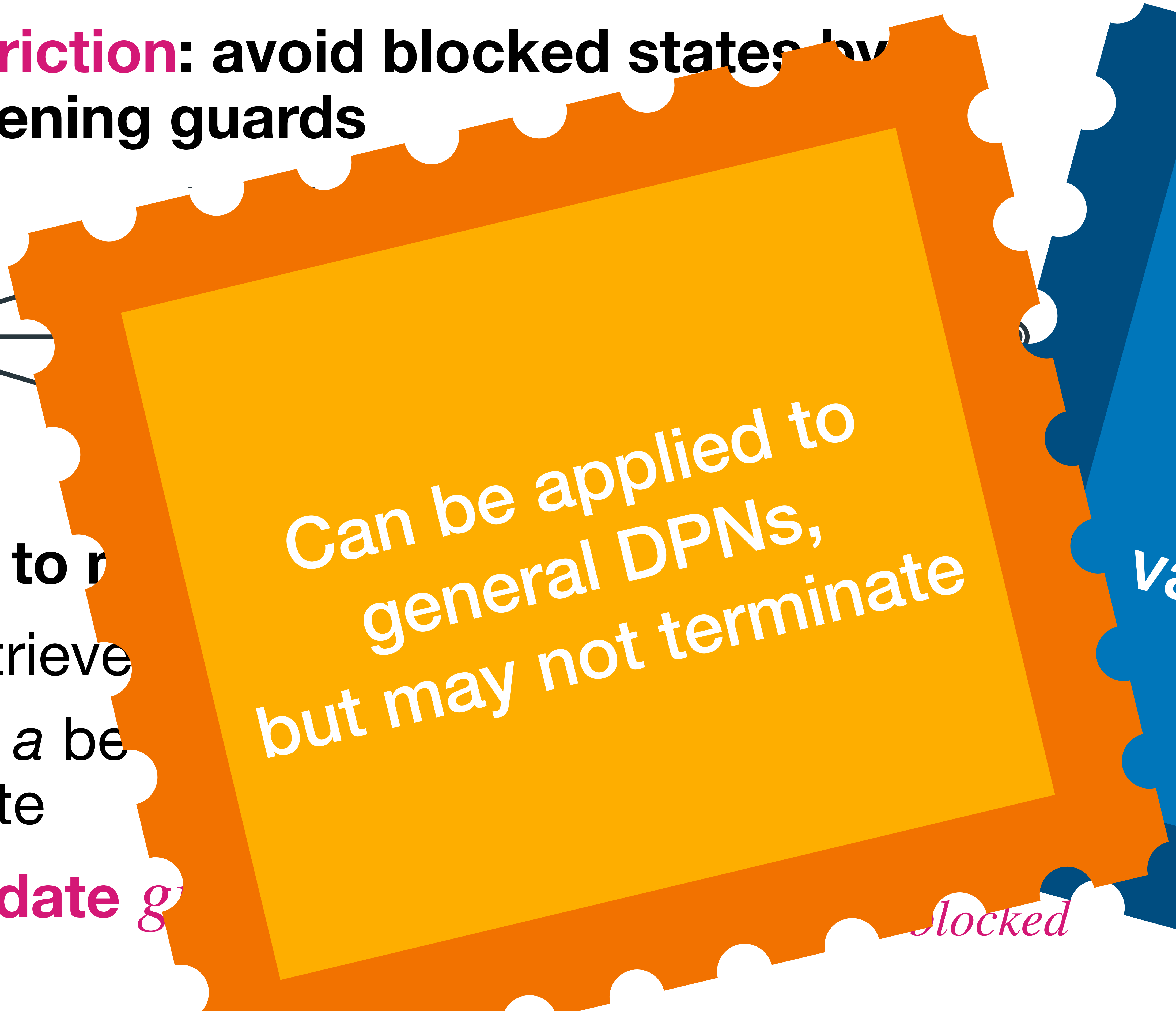
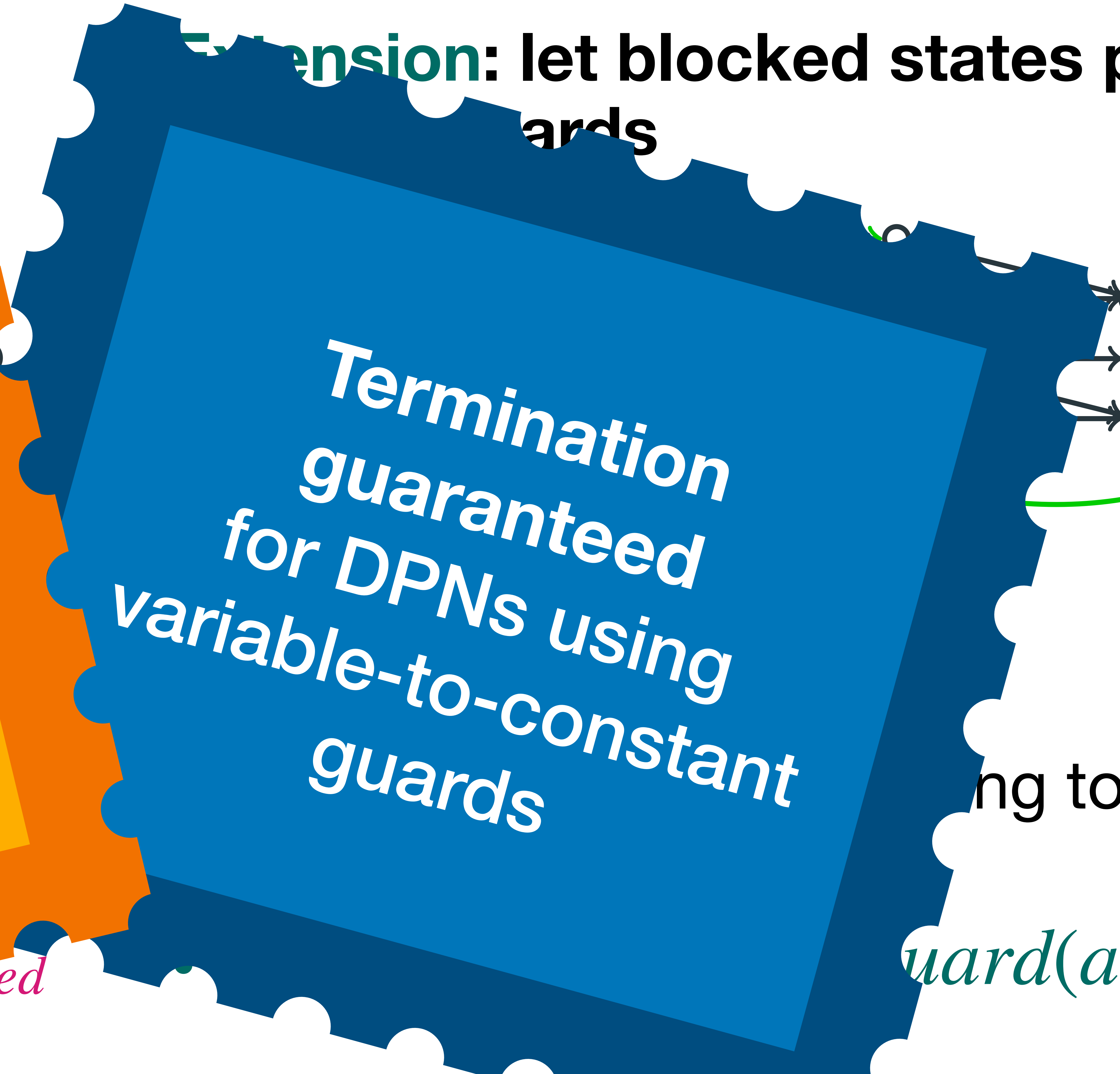
using $\varphi_{blocked}$ to minimally avoid/unblock them

Restriction: avoid blocked states by tightening guards

Extension: let blocked states proceed by ...ards

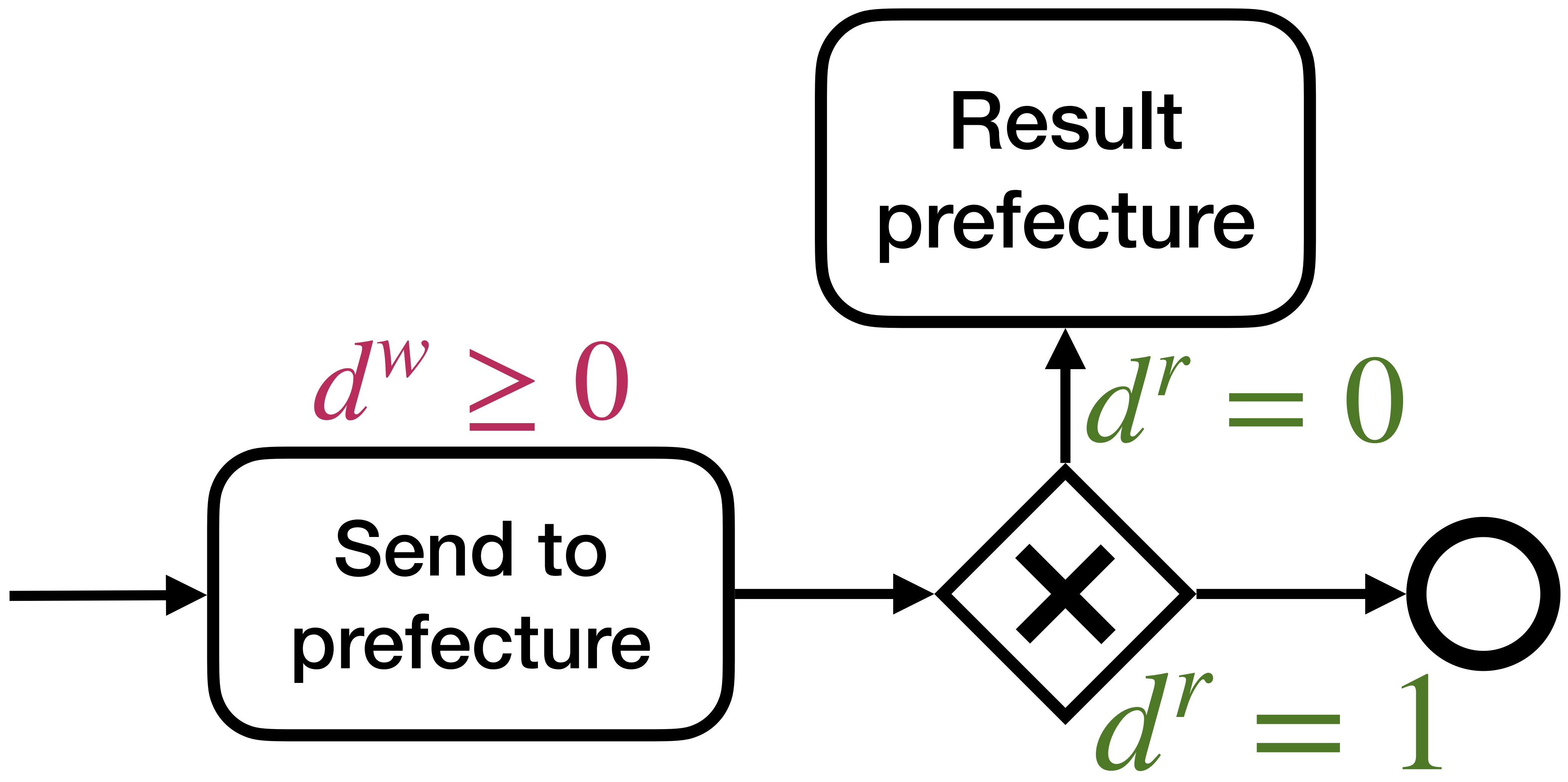




How to r

- Retrieve
- Let *a* be ... ng to that state
- **Update** g ... $\varphi_{blocked}$ ... $guard(a) \vee \varphi_{blocked}$

Back to the road fine example



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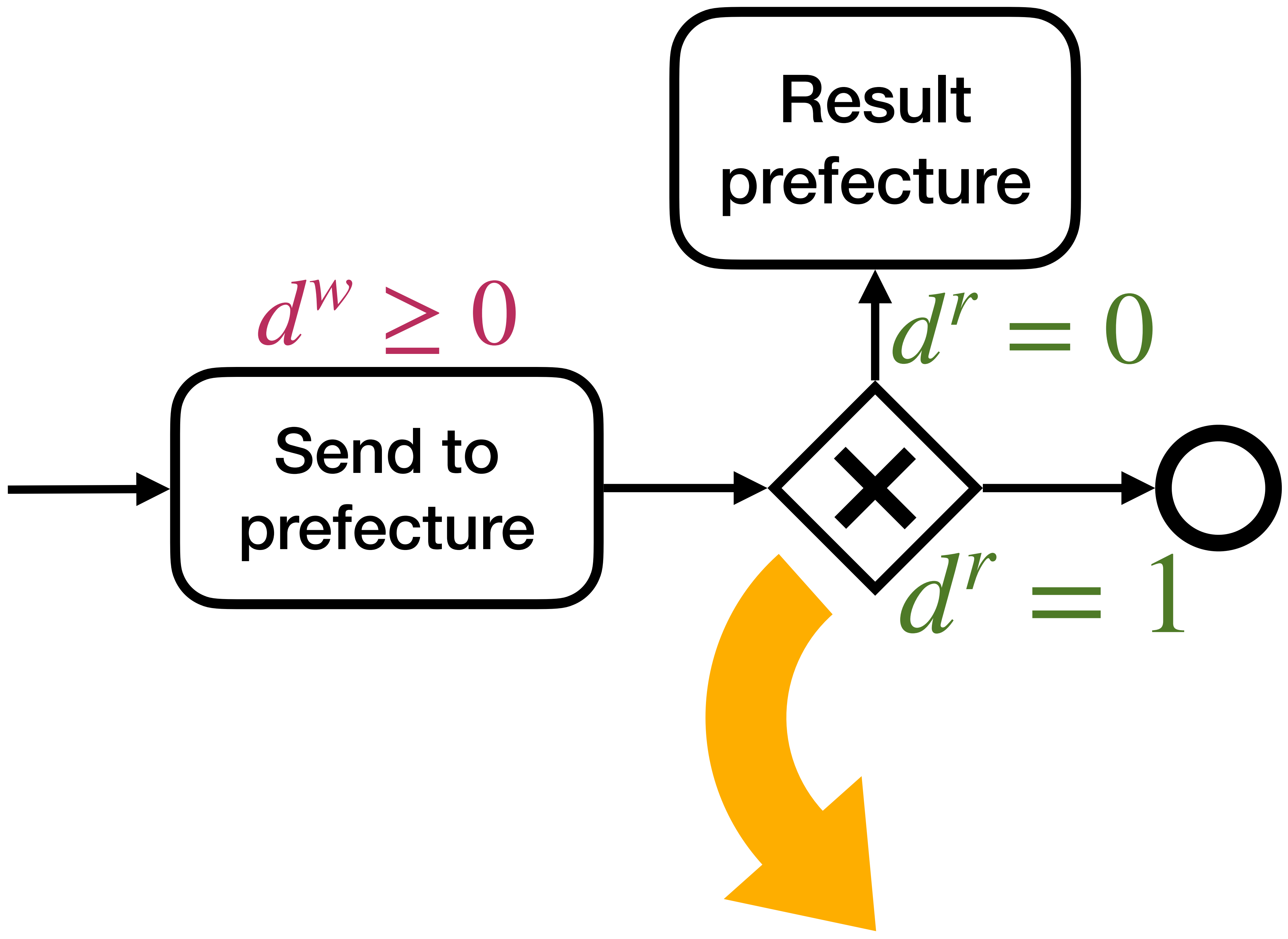
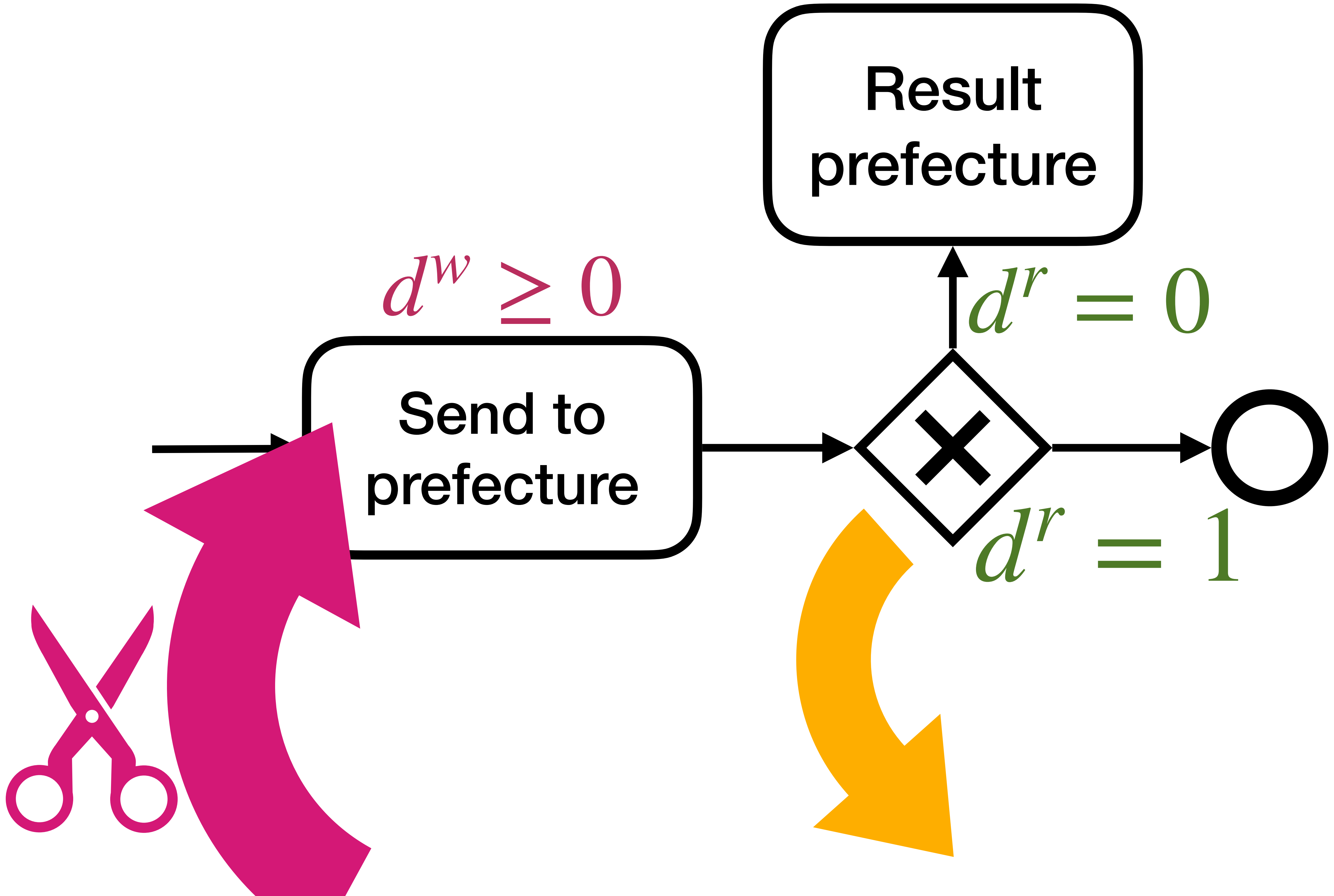


$$\varphi_{blocked} = d > 0 \land d \neq 0 \land d \neq 1$$

Back to the road fine example

Restriction: modify the write guard on "send to prefecture"



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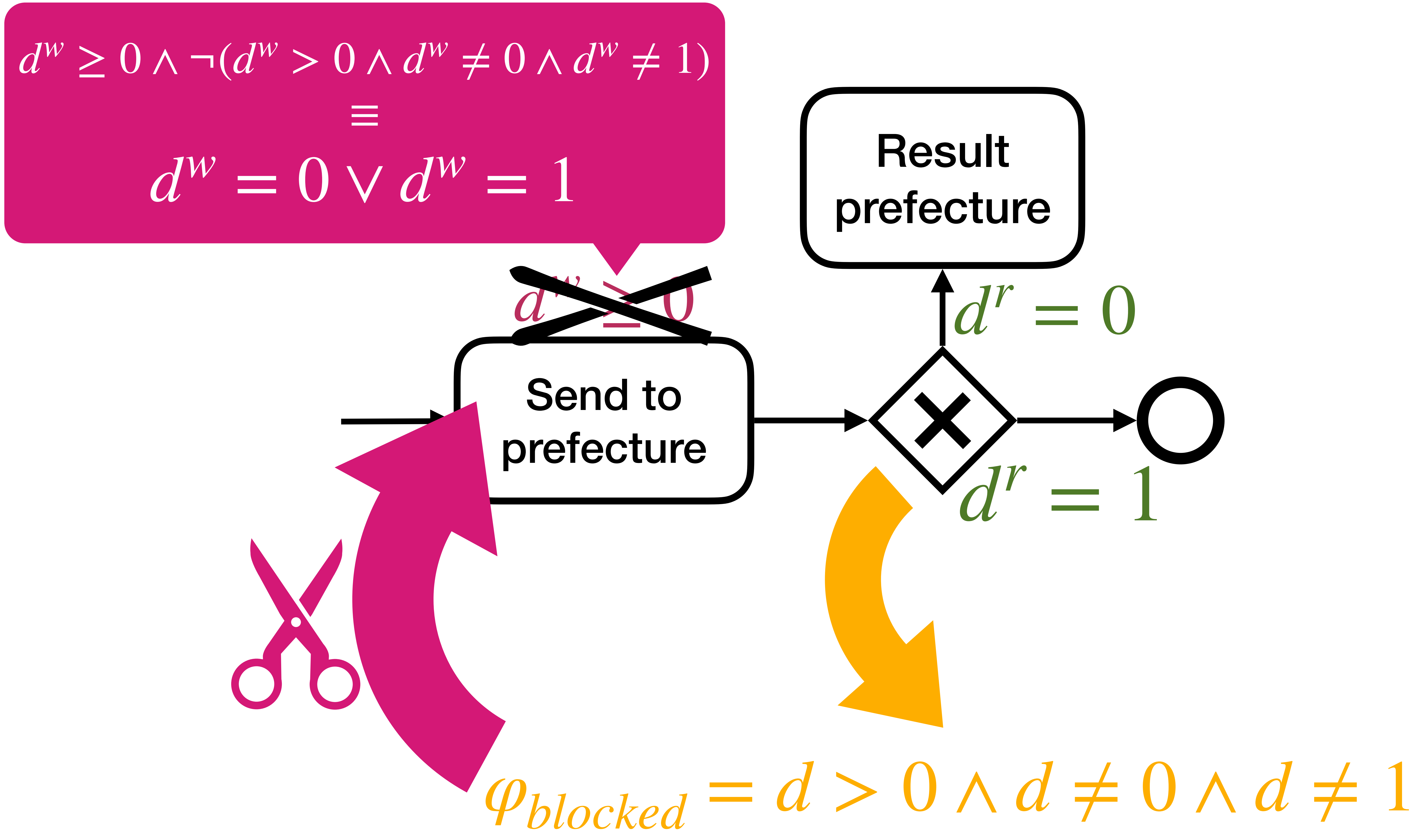
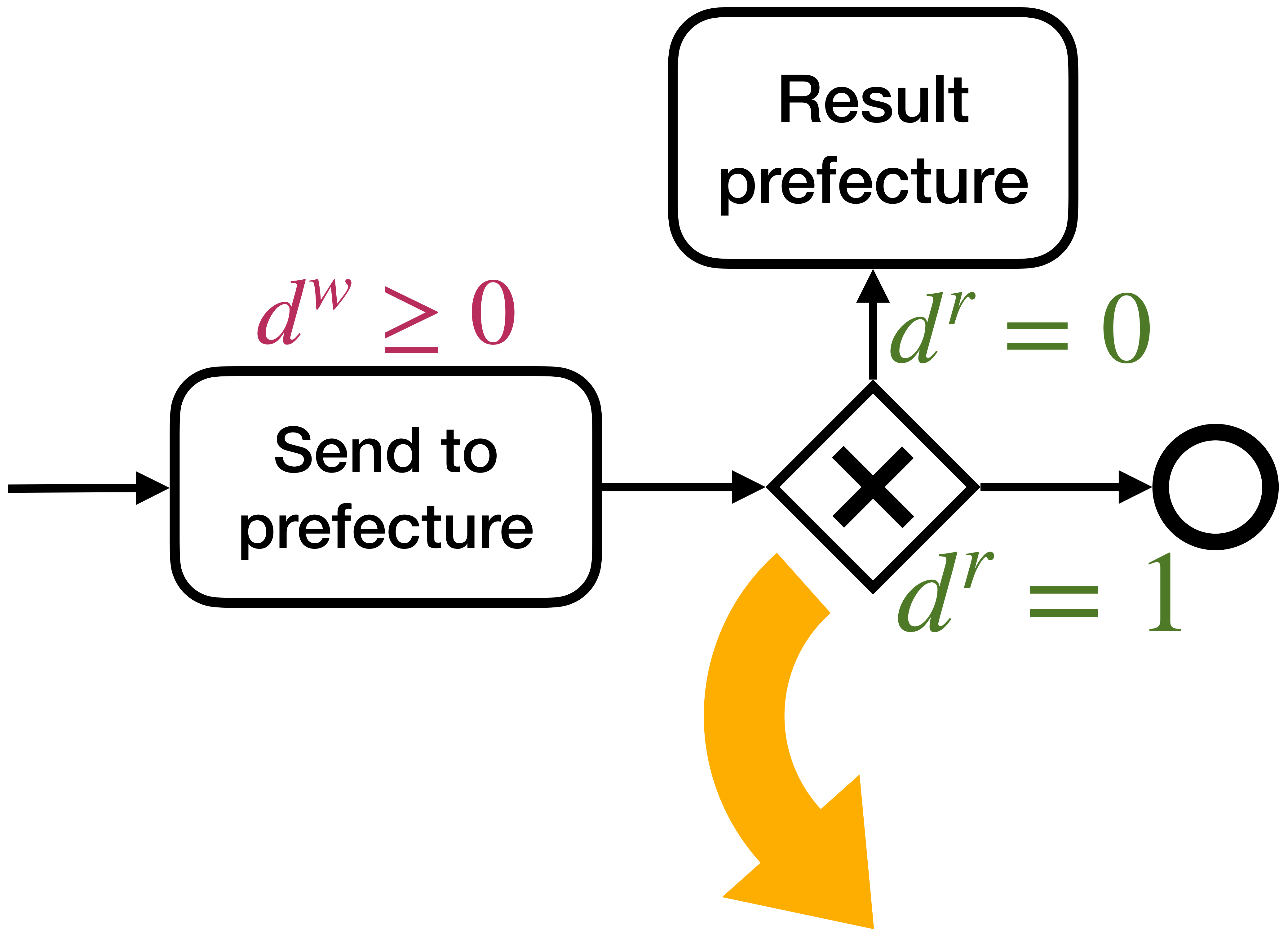
Back to the road fine example

Restriction: modify the write guard on “send to prefecture”



Back to the road fine example

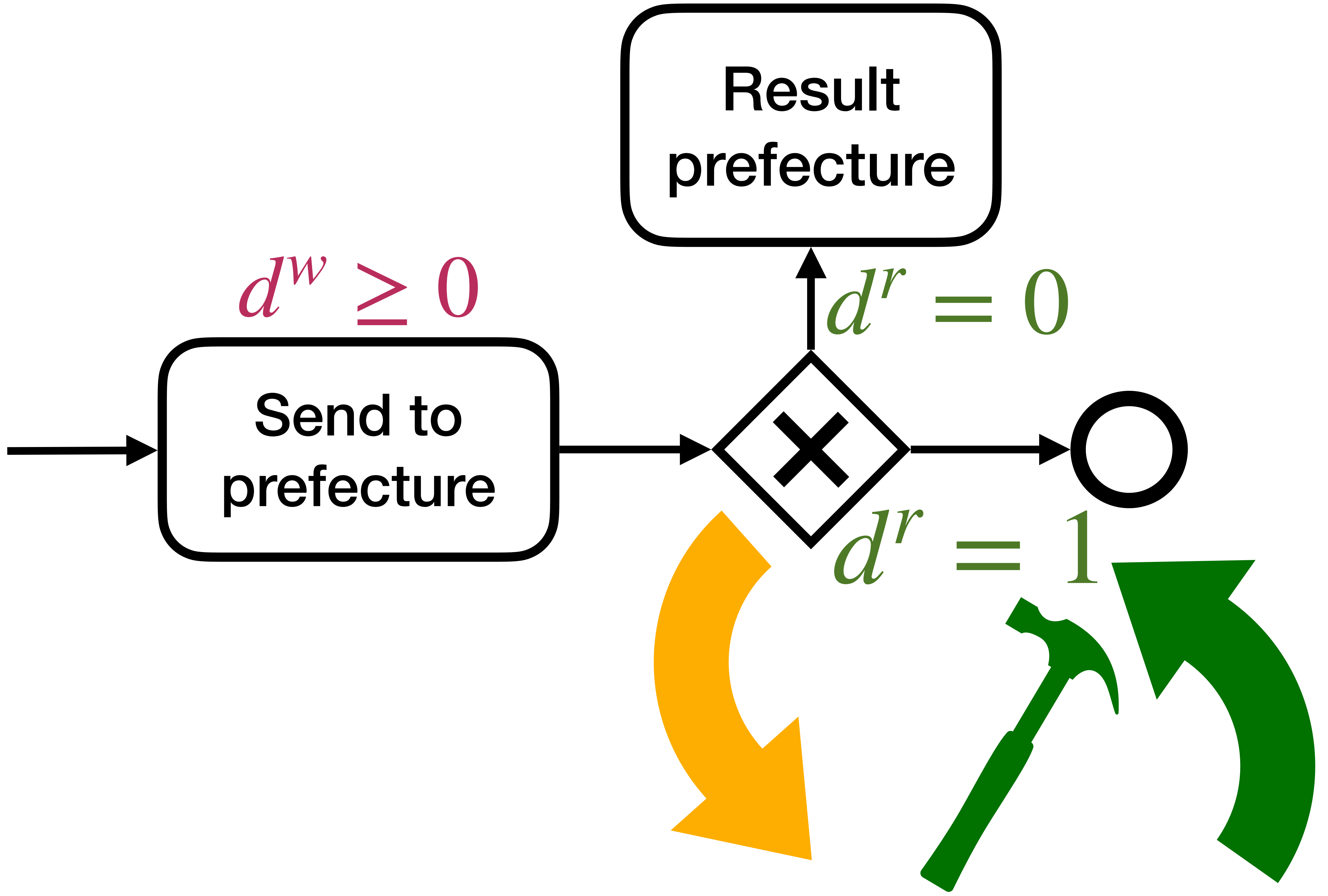
Extension: nondet. pick one of the two choice guards and fix it



$$\varphi_{blocked} = d > 0 \wedge d \neq 0 \wedge d \neq 1$$

Back to the road fine example

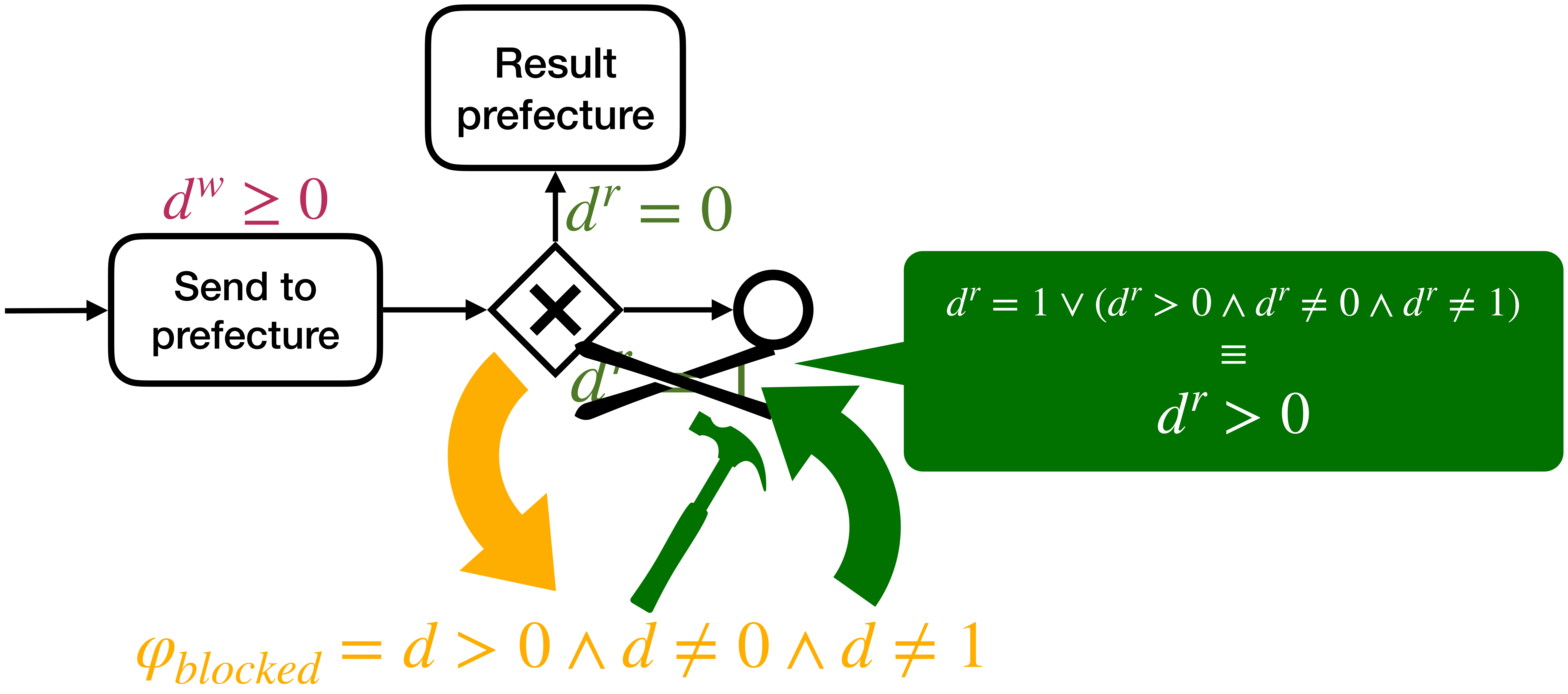
Extension: nondet. pick one of the two choice guards and fix it



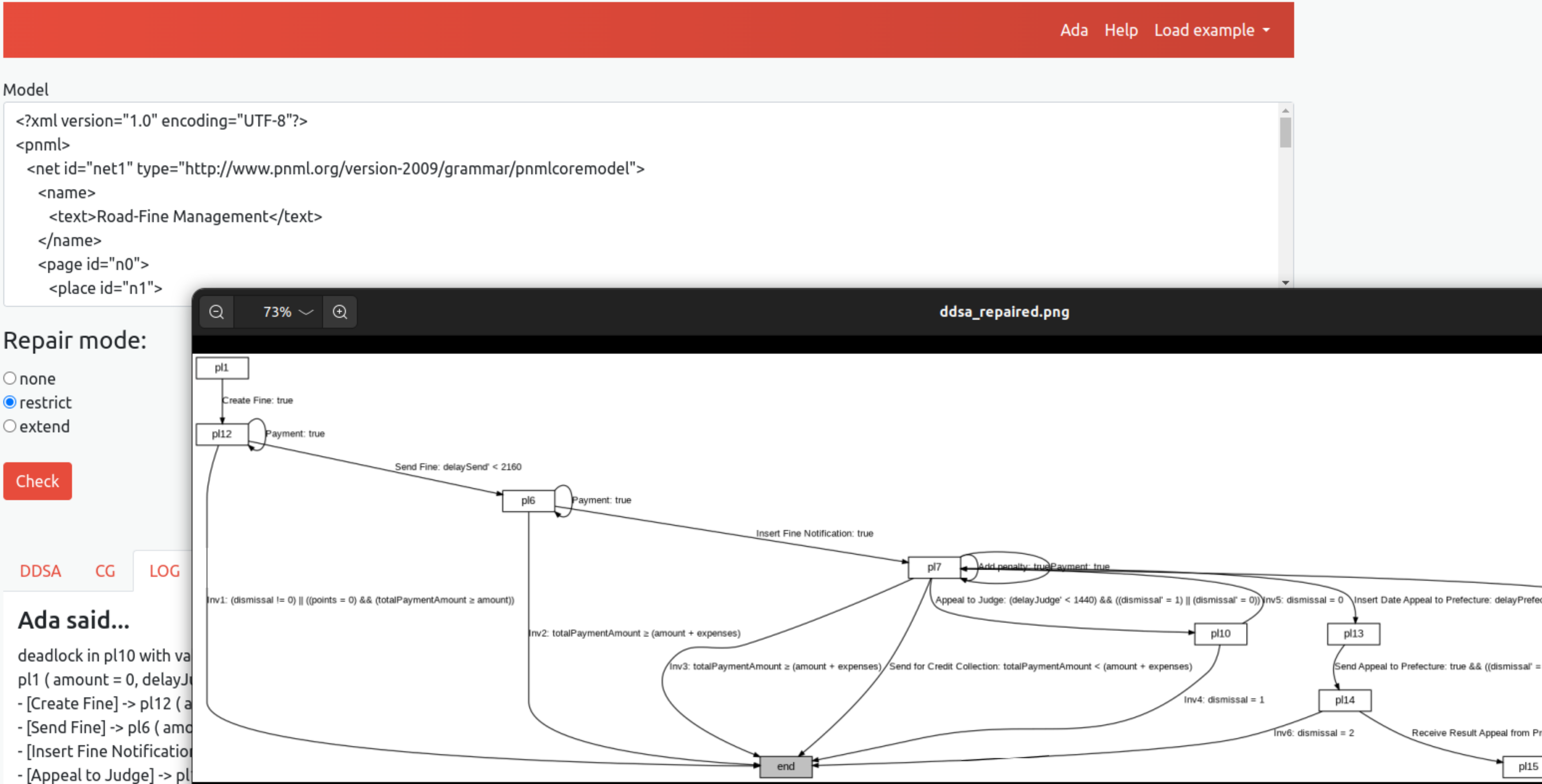
$$\varphi_{blocked} = d > 0 \land d \neq 0 \land d \neq 1$$

Back to the road fine example

Extension: nondet. pick one of the two choice guards and fix it



Fully implemented: soundness.adatool.dev



Experiments

Repair of unsound DPNs

DPN	repair/Restrict		repair/Extend	
	time	*# deadlocks*	*time*	*# deadlocks*
(a) road fines normative [MannhardtLRA16]	50s	2	71s	2
(b) road fines mined [Mannhardt18]	24s	1	22s	1
(c) dig. whiteboard/transfer [Mannhardt18]	2.1s	1	3s	1
(d) package handling [Fig. 5, deLeoniFM21]	6s	0	6s	0
(e) auction [FMW22a]	8s	1	20s	1
(f) auction example	2.5s	1	2.7s	1
(g) livelock example	2.1s	1	2.4s	1

Extension takes more time (larger constraint graphs)

Conformance checking (road fines example)

	original DPN	after repair/Restrict	after repair/Extend
average distance	1.2009	1.2009	1.1305

Repair does not affect conformance negatively

Conclusions

Take home

- Need of **soundness repair** in **data-aware process mining**
- **SMT-based automatic repair** for DPNs that is **conservative on the control-flow** and **on the original behavior**
- Two repair directions: **restrict** or **extend**
- **Fully implemented**

Next steps

- **Blending** of restriction and extension, user-in-the-loop
- **Log-driven data-aware repairs**

Repairing soundness properties in data-aware processes

Paolo Felli, Marco Montali, Sarah Winkler

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