Operationalizing Declarative and Procedural Knowledge

a benchmark on Logic Programming Petri Nets (LPPNs)

CAUSAL2020 Workshop on Causal Reasoning and Explanation in Logic Programming @ ICLP2020

19 September 2020

Giovanni Sileno g.sileno@uva.nl
Informatics Institute, University of Amsterdam

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Problem: reasoning with cases

- Regulations concern **systems of norms**, that in abstract, in a fixed point in time, may be approached atemporally.
- However, when applied, regulations deal with a **continuous flow of events**.
- Prototypical encounter: legal cases.
- More general but similar problem: narratives, stories.

Problem: reasoning with cases

While John was walking his dog, the dog ate Paul's flowers.

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(example of underlying norm)

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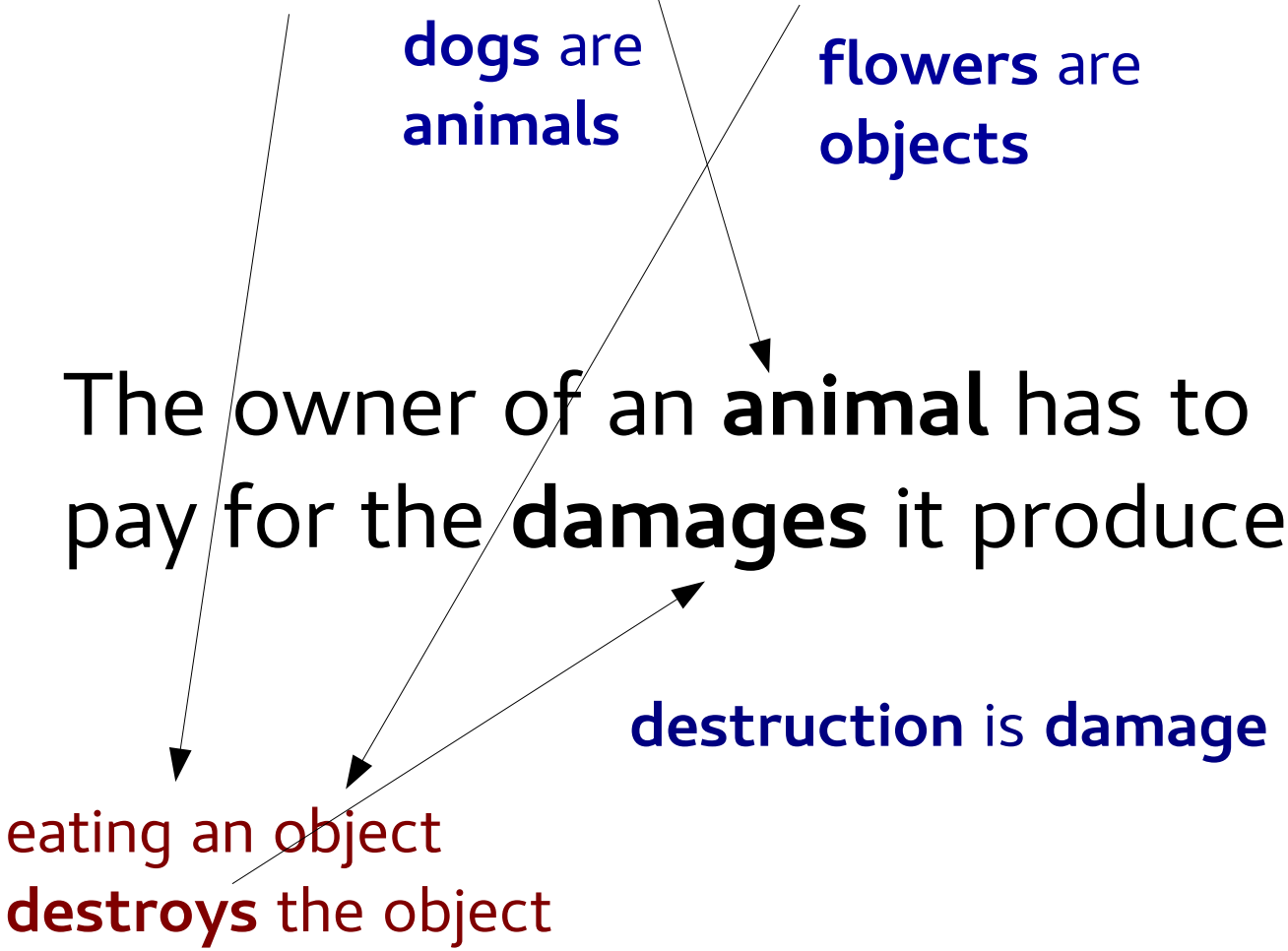
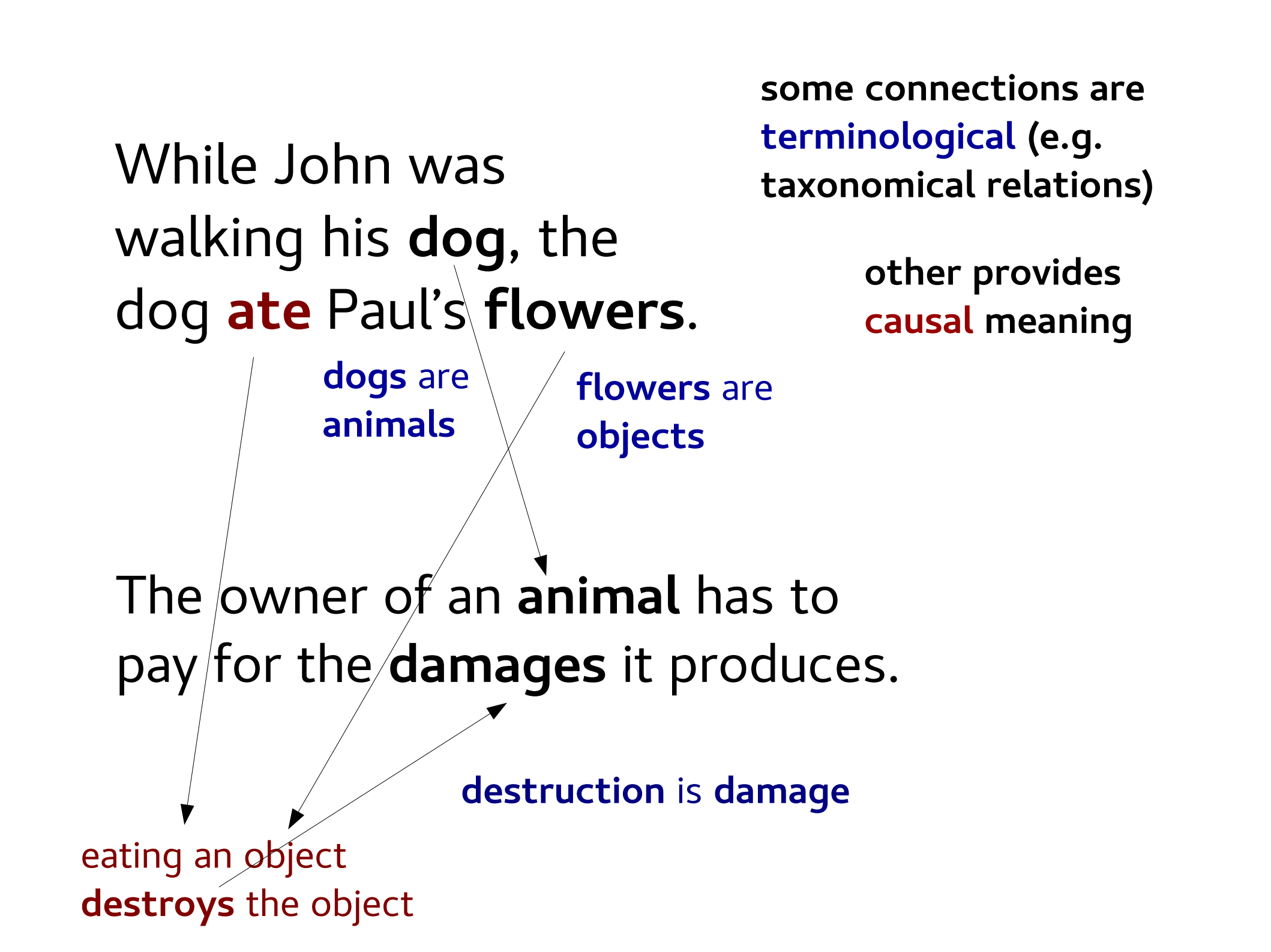
A conceptual gap exists between the concrete domain and the legal abstraction that applies on it.

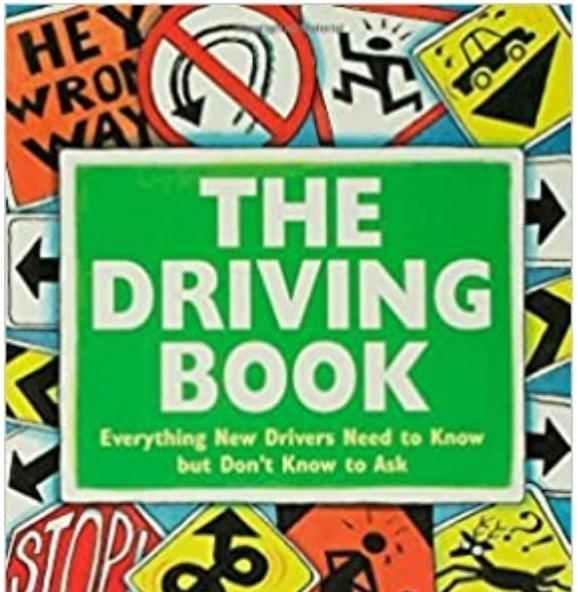
While John was walking his **dog**, the dog **ate** Paul's **flowers.**




some connections are terminological (e.g. taxonomical relations)
other provides causal meaning
While John was walking his dog, the dog ate Paul's flowers.
dogs are animals
flowers are objects
The owner of an animal has to pay for the damages it produces.
destruction is damage
eating an object destroys the object

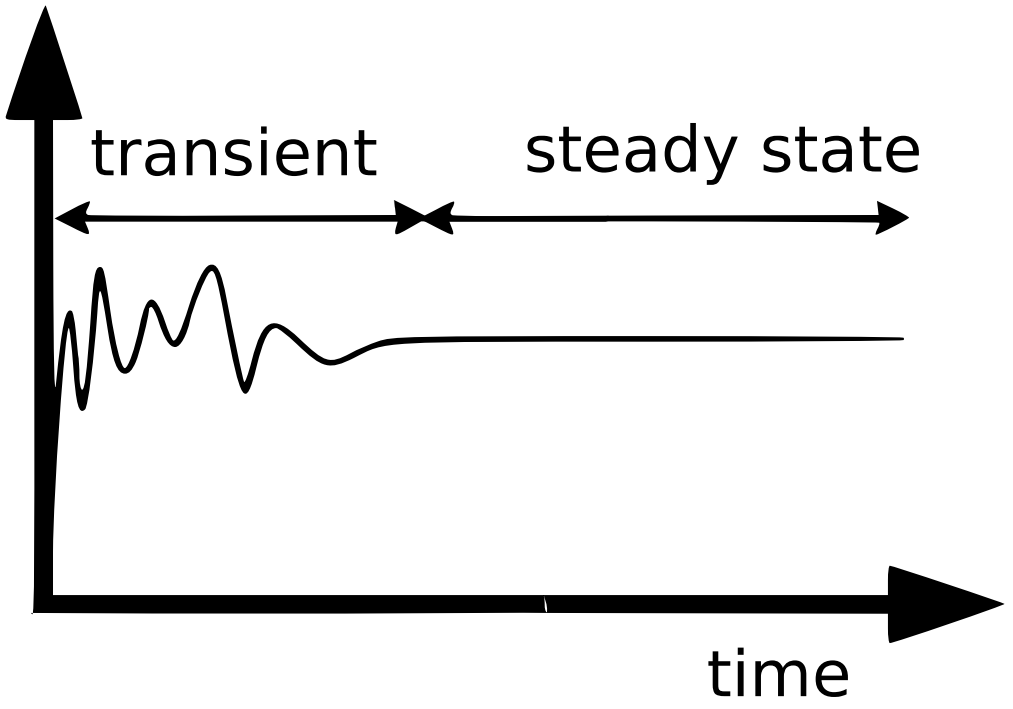
Types of Knowledge

- **Declarative knowledge**, concerning objects (physical, mental, institutional) and their logical relationships—typically reified by means of symbols
- **Procedural knowledge**, concerning patterns of events/actions, mechanisms, or processes (involving objects)—often tacit, internalized



Perspectives on Modelling

- Physical systems can be approached from **steady state** (equilibrium) or **transient** (non-equilibrium, dynamic) perspectives



- Steady states descriptions **omit** transient characteristics

  ex. Ohm's Law. V = R * I

Specifying transients and steady states

- Possible analogies:
  - *steady state* approach with
    - Logic
    - Declarative programming

focus on **What**

Specifying transients and steady states

- Possible analogies:
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    - Declarative programming
  - *transient* approach
    - Process modelling
    - Procedural programming

focus on **What**

focus on **How**

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Answer Set Programming

focus on **What**

focus on **How**

Petri Nets!

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    - Logic
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  - *transient* approach
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Answer Set Programming

focus on **What**

+

focus on **How**

logic programming petri nets

= LPPNs

Petri Nets!

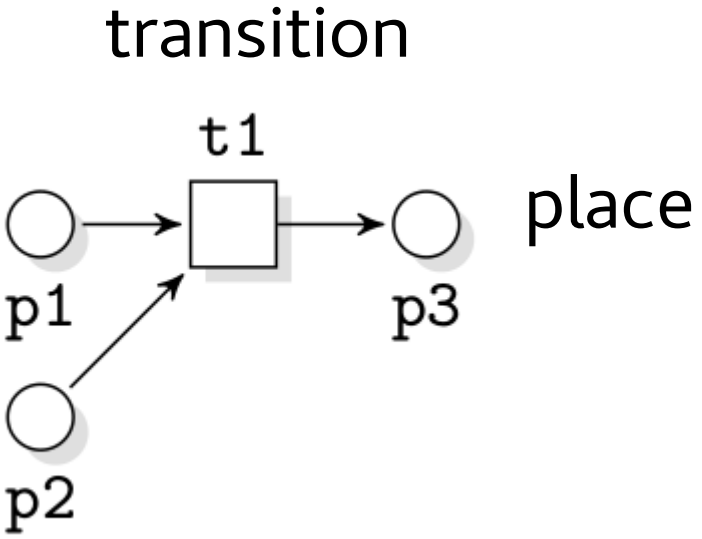
Logic Programming Petri Nets

Logic Programming Petri Net (LPPN)

- An LPPN consists of three components:
  - a procedural net (places, transitions) ← **causal mechanisms**
  - a declarative net for places ← **logical dependencies between objects**
  - a declarative net for transitions ← **logical dependencies between events**

Procedural LPPN

(same as Condition/Event PN)



- Petri net: bipartite directed graph made of **places** (circles) and **transitions** (boxes).

Procedural LPPN

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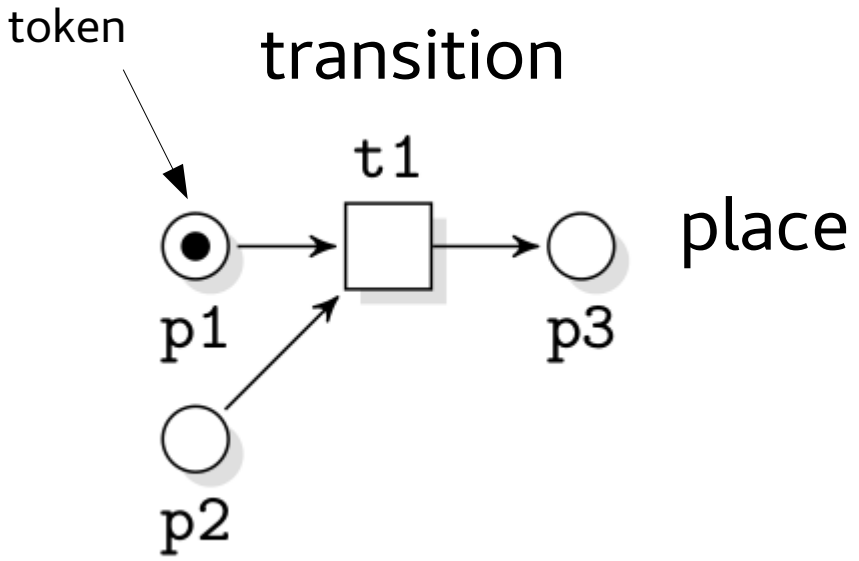
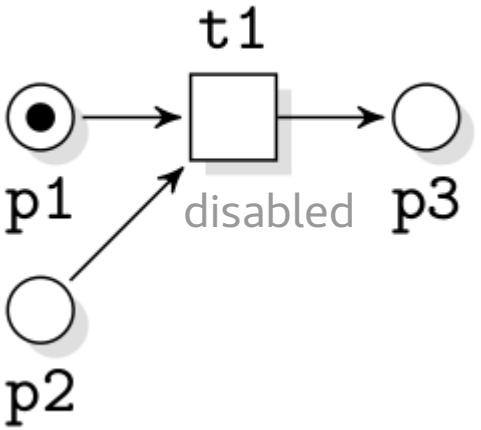


- **tokens** may occupy places.

Procedural LPPN

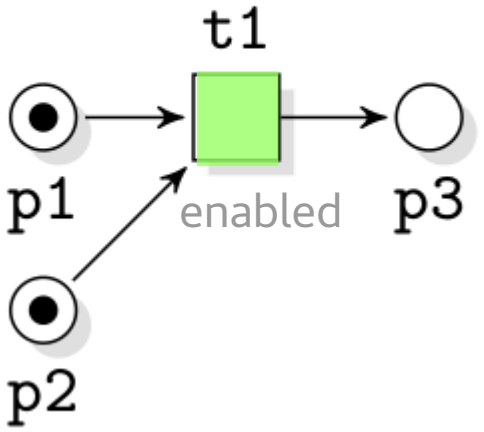
(same as Condition/Event PN)



- Execution semantics *(token game)*: if any of its input places is not occupied, the transition is **disabled**. It cannot **fire**.

Procedural LPPN

(same as Condition/Event PN)



- Execution semantics *(token game)*: if all of its input places are occupied, the transition is **enabled**. It can **fire**.

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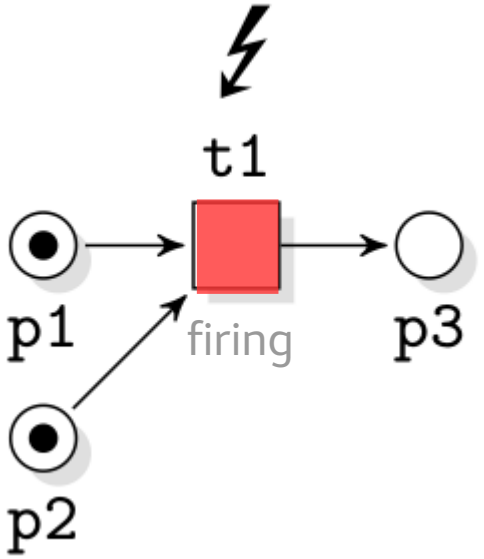
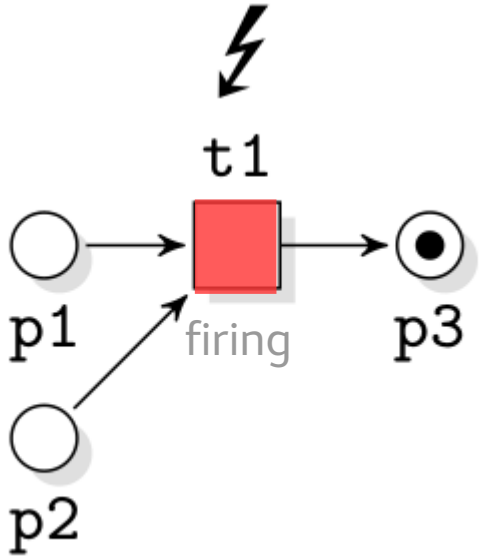


- Execution semantics *(token game)*: when the transition **fires** it will ***consume*** tokens from the ***input*** places.

Procedural LPPN

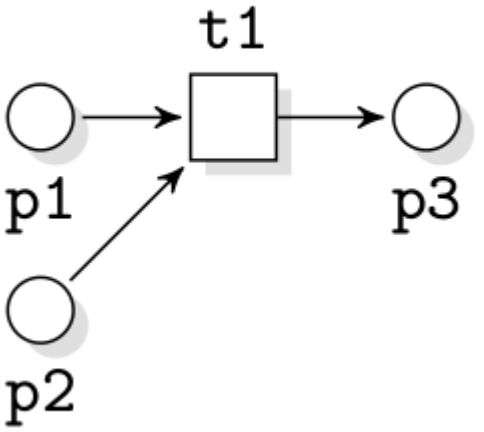
(same as Condition/Event PN)



- Execution semantics *(token game)*: …and ***produce*** tokens in the ***output*** places.

Procedural LPPN

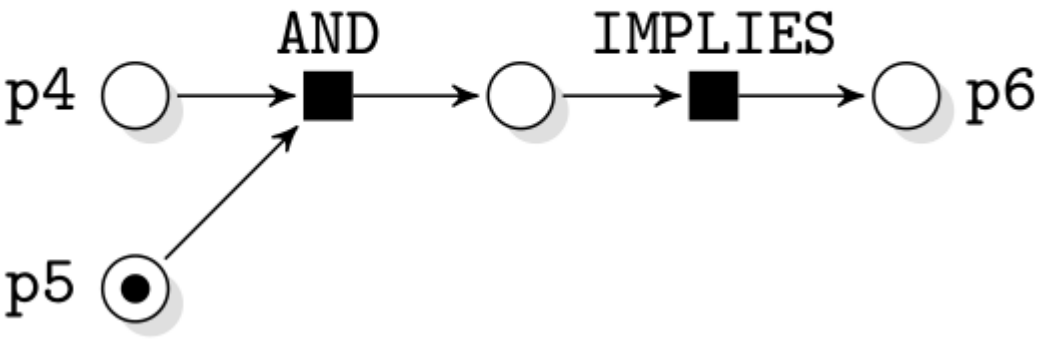
(same as Condition/Event PN)



- For our purposes, this maps to a reactive rule (ECA):

```
#t1 : p1, p2 => -p1, -p2, +p3.
```

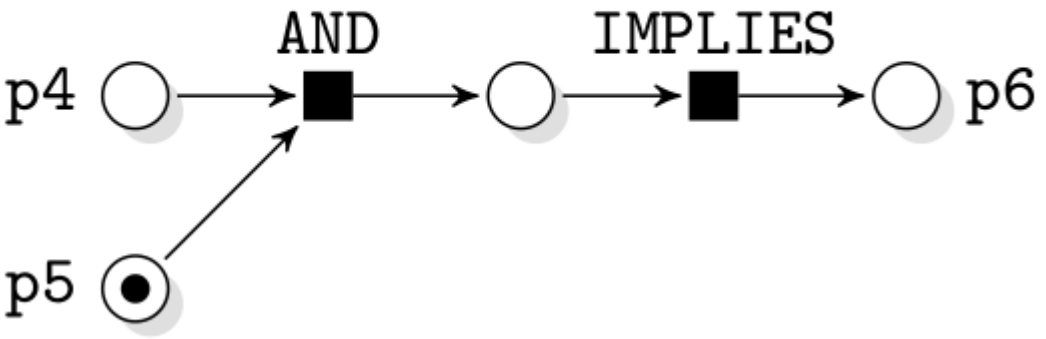
Declarative LPPN for places



- Constructed from the ASP program:

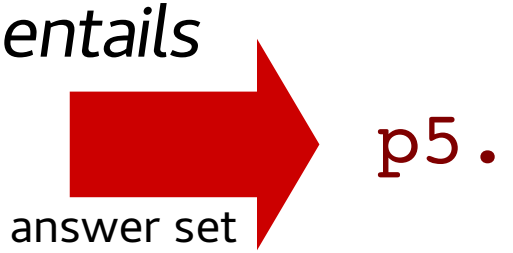
```
p6 :- p4, p5.
p5.
```

Declarative LPPN for places

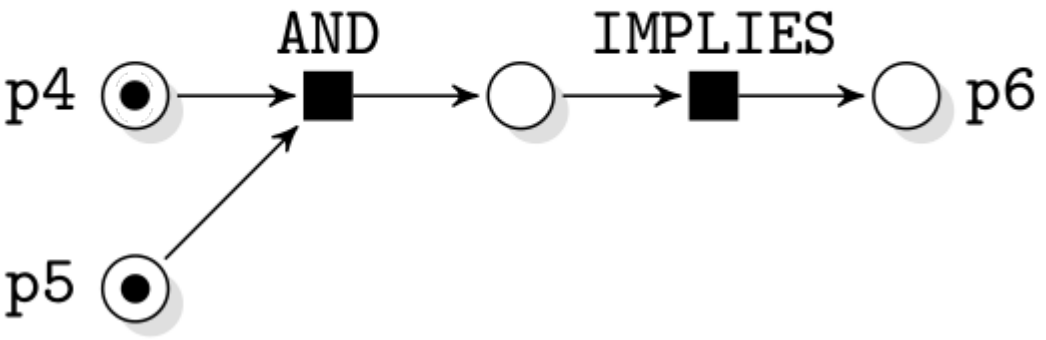


- Equivalent to

```
p6 :- p4, p5.
p5.
```



Declarative LPPN for places



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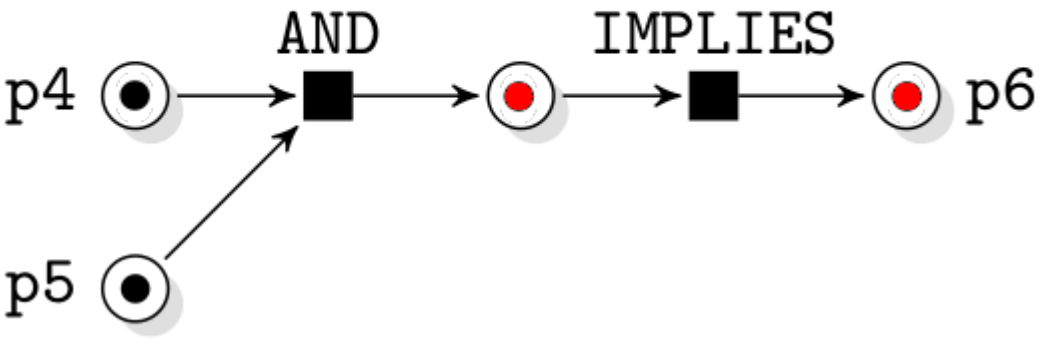
Declarative LPPN for places



- Equivalent to

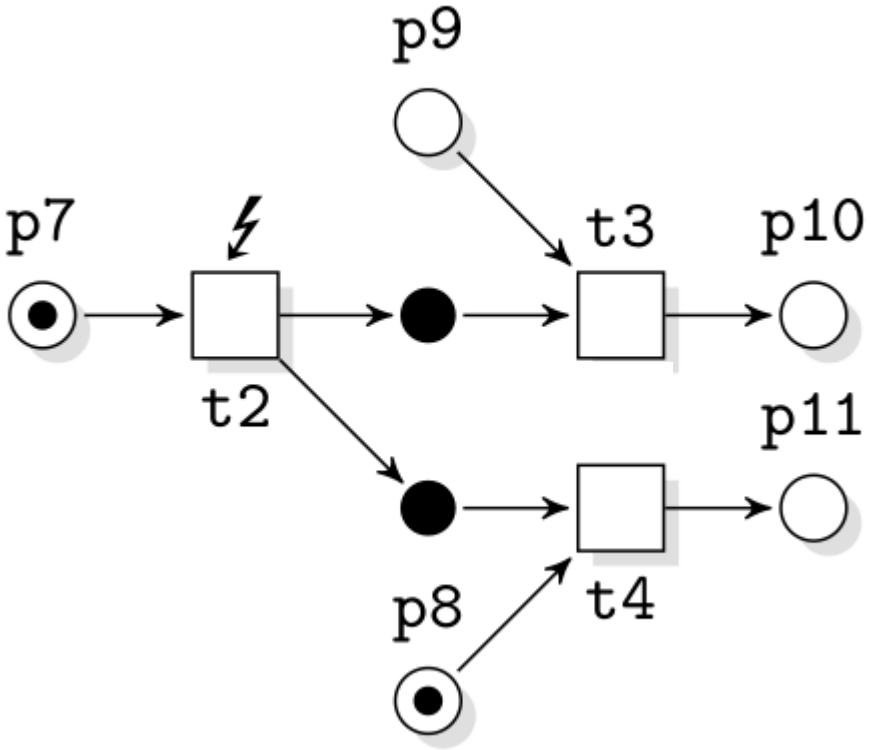
```
p6 :- p4, p5.
p4. p5.
```

entails

answer set

```
p4. p5. p6.
```

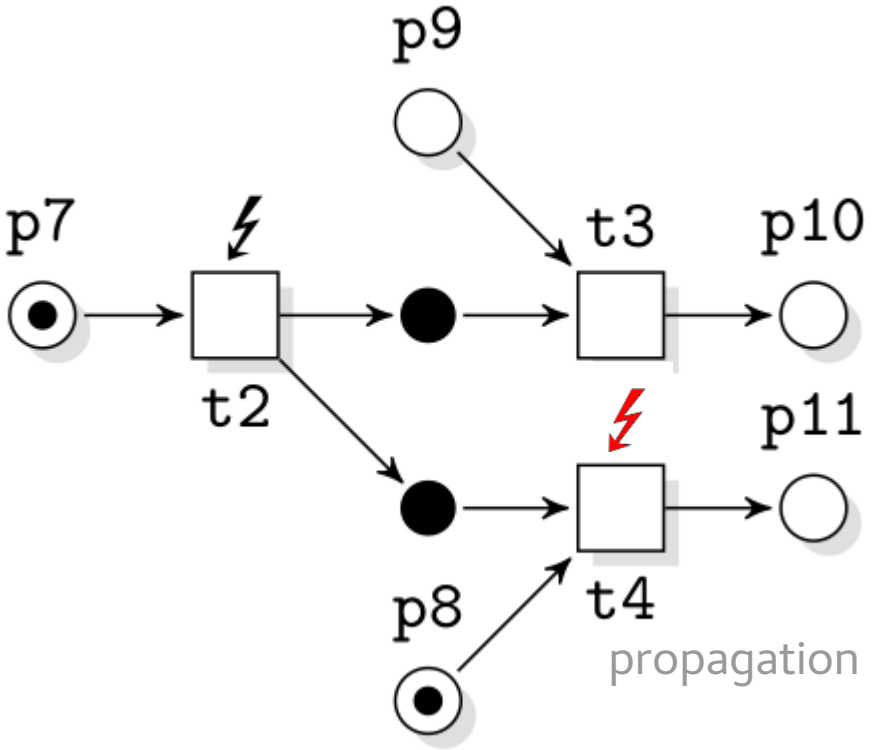
Declarative LPPN for transitions



- Equivalent to

```
#t3 :- #t2, p9.
#t4 :- #t2, p8.
#t2. p7. p8.
```

Declarative LPPN for transitions



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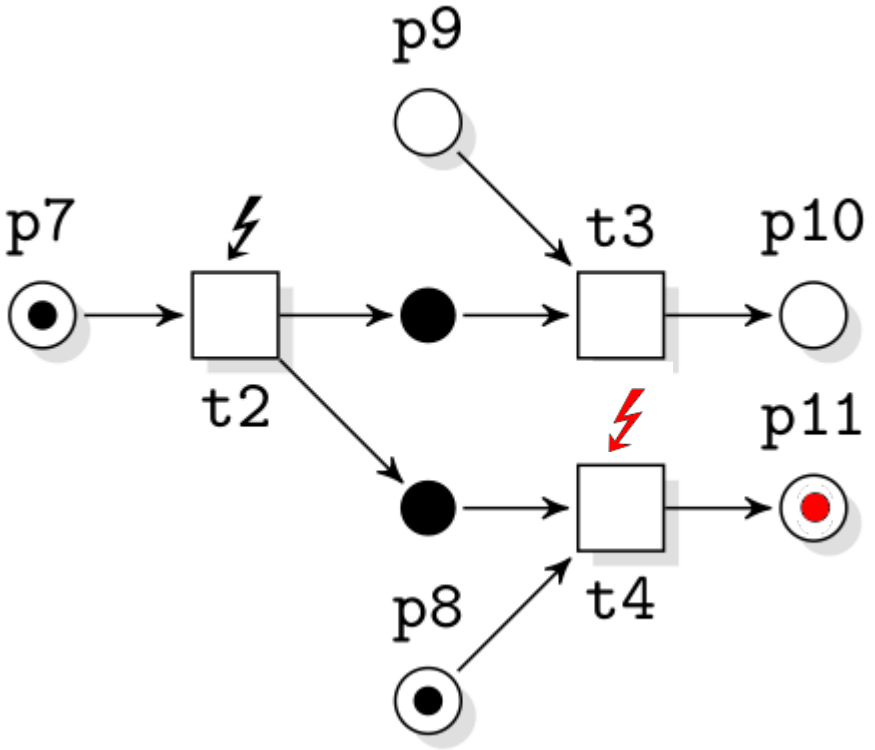
Declarative LPPN for transitions



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answer set

```
#t2. p7. p8. #t4.
```

produces

```
p11.
```

Initial example (partial model)

while John was walking his dog,
*the dog ate Paul's flowers ("**story**")*

```
dog. flower. dog-walking. #dog-eats-flower.
```

```
animal :- dog.
object :- flower.
damage :- destruction.
```

logical dependencies
at level of objects

```
#eat-object :- #dog-eats-flower.
#destroy-object :- #eat-object.
```

logical dependencies
at level of events

```
#destroy-object : object => -object, +destruction.
```

causal mechanisms

Execution semantics

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  - a **denotational semantics**, mapping causal mechanisms to ASP using *Event Calculus* → **ASP solver**

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  - a **hybrid semantics**, consisting of 4 steps:
    1. solve logical dependencies of objects → **ASP solver**
    2. select one enabled transition to fire **direct computation**
    3. solve logical dependencies of events → **ASP solver**
    4. execute the selected firing using the Petri Net **direct computation**

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Question: how they compare in terms of computational performance?

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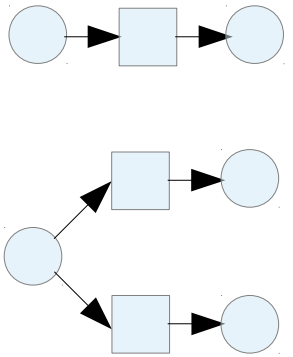
Question: how they compare in terms of computational performance? *Why they should differ?*

Experiment

Experiment

- We considered two basic reiterable structures at process level:
  - Serial composition (deterministic)
  - Forking (non-deterministic)

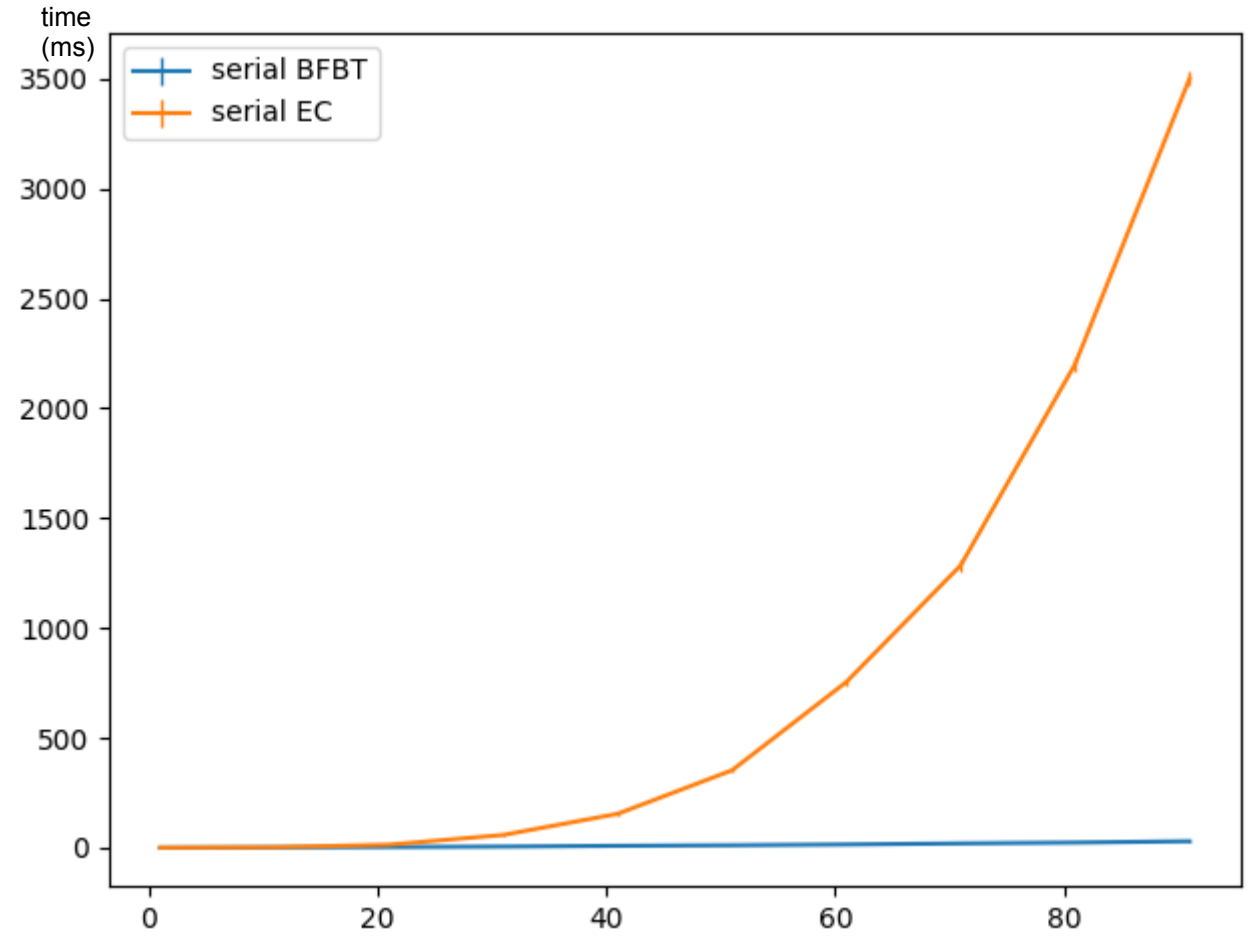


- We executed a benchmark on nets obtained by iterating these basic structures, with one token in the initial place
  - for N iterations = 1, 11, ..., 91 (serial)
  - for N iterations = 1, 2, ..., 10 (forking)

Code available at http://github.com/s1l3n0/pypneu

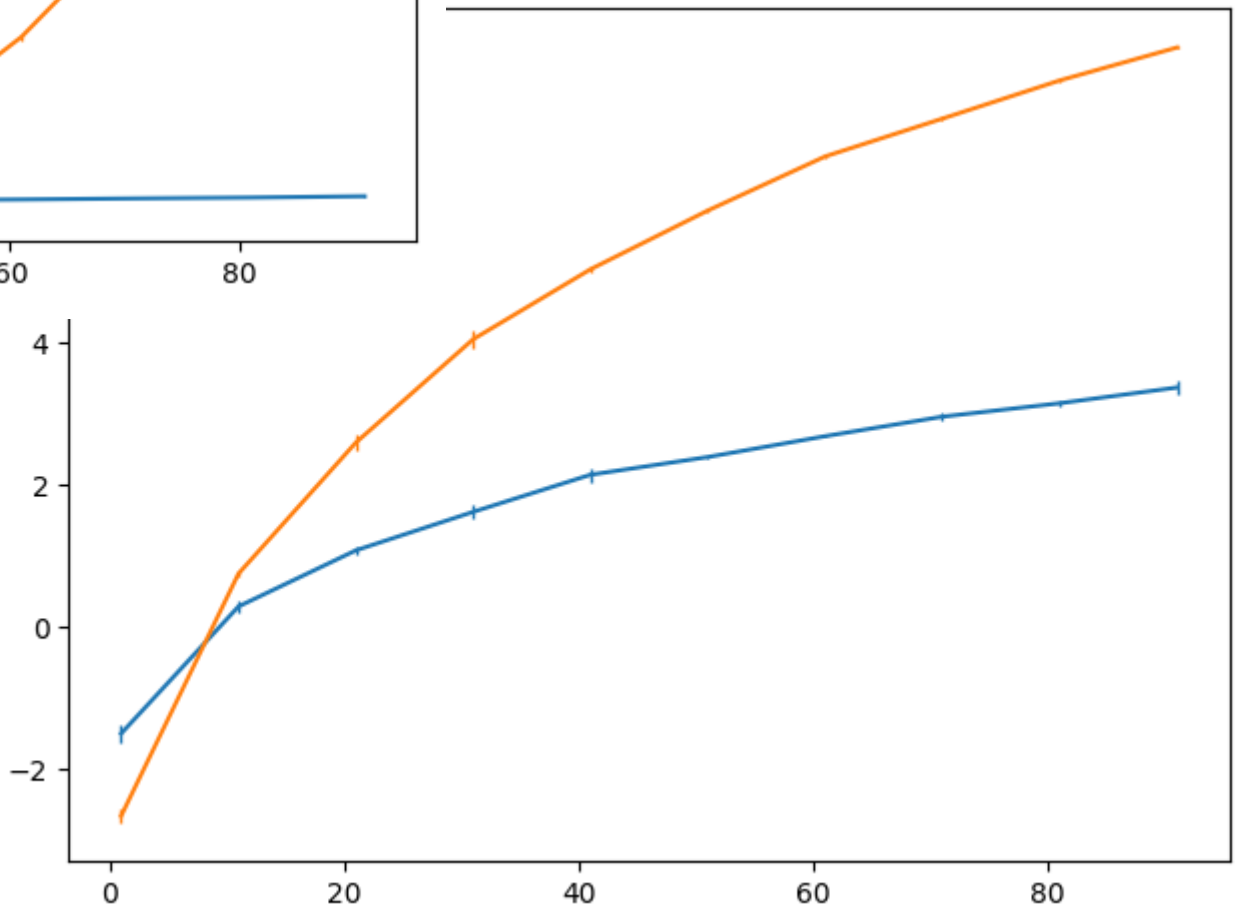
Results

Serial composition



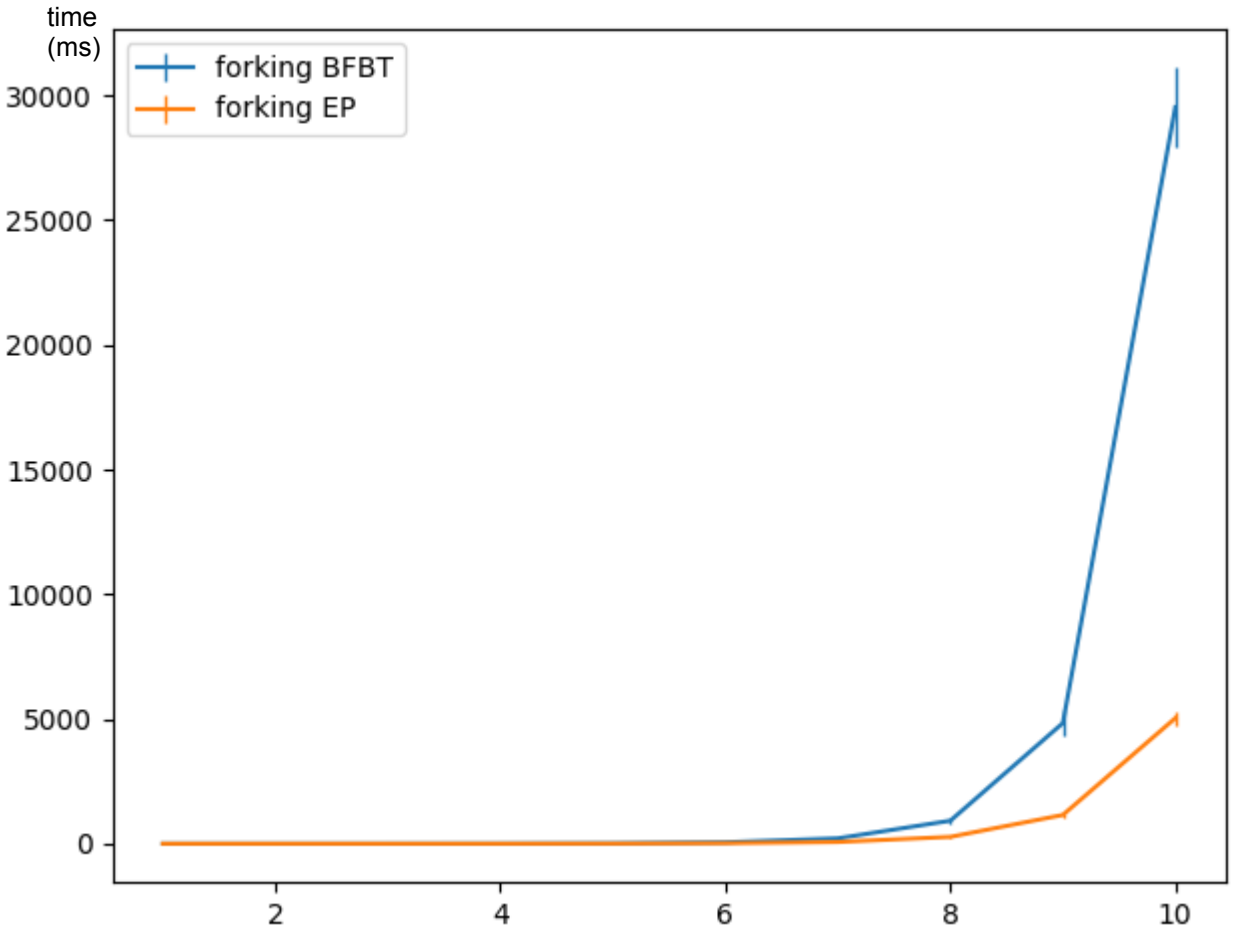
Linear scale

Log scale



Results

Forking composition



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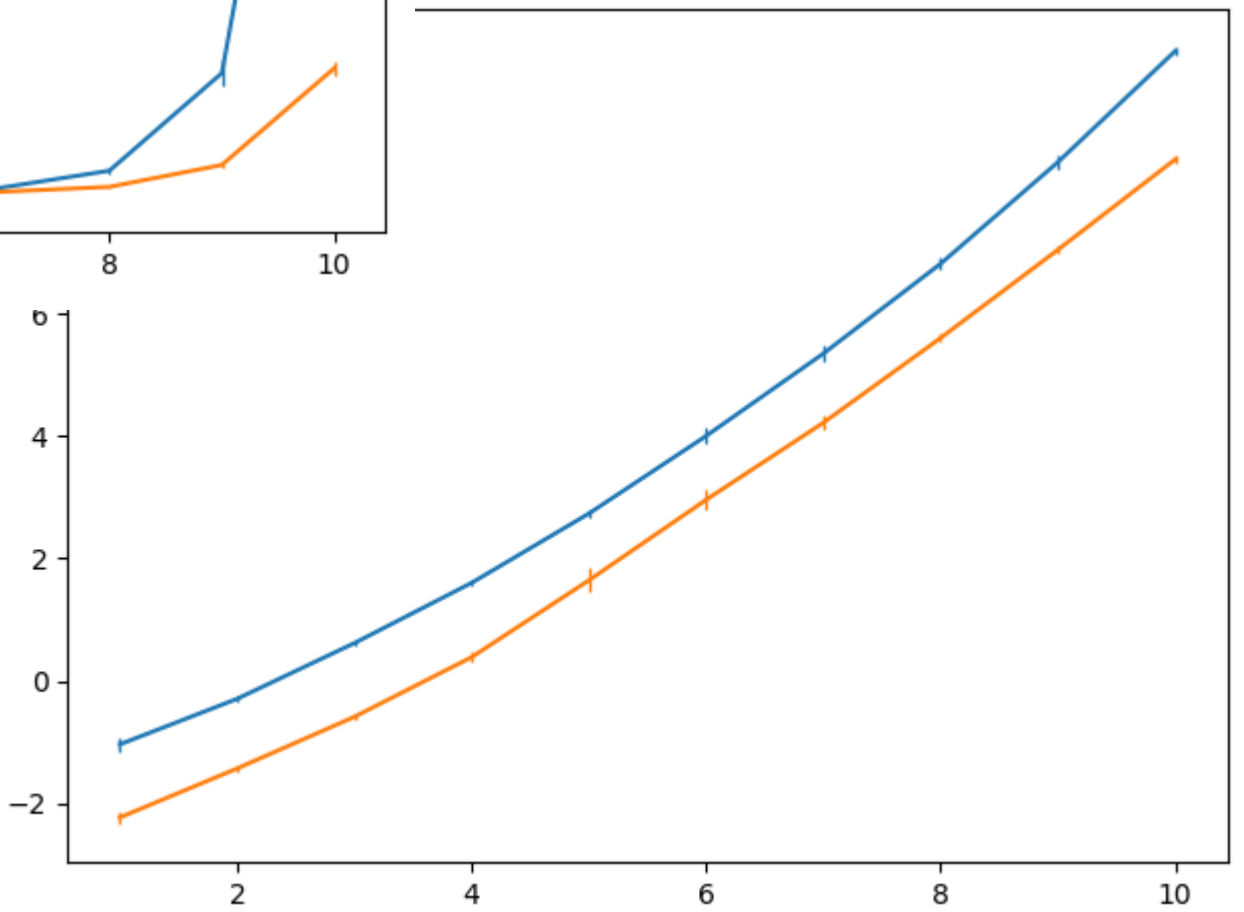
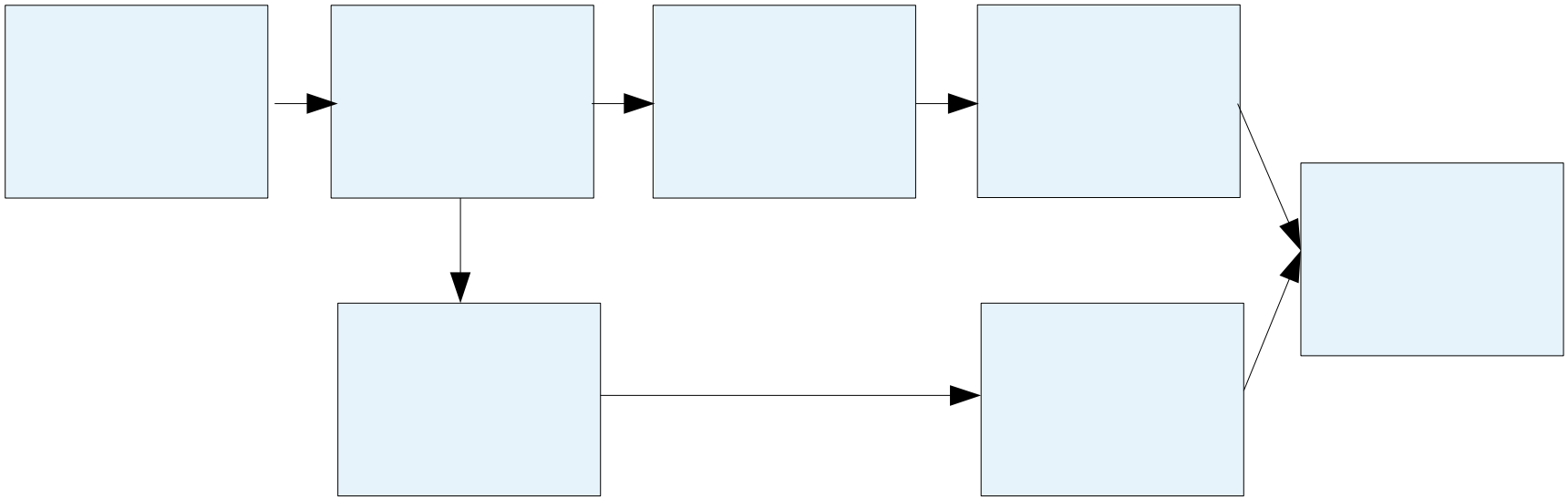


Why this difference? (intuition)

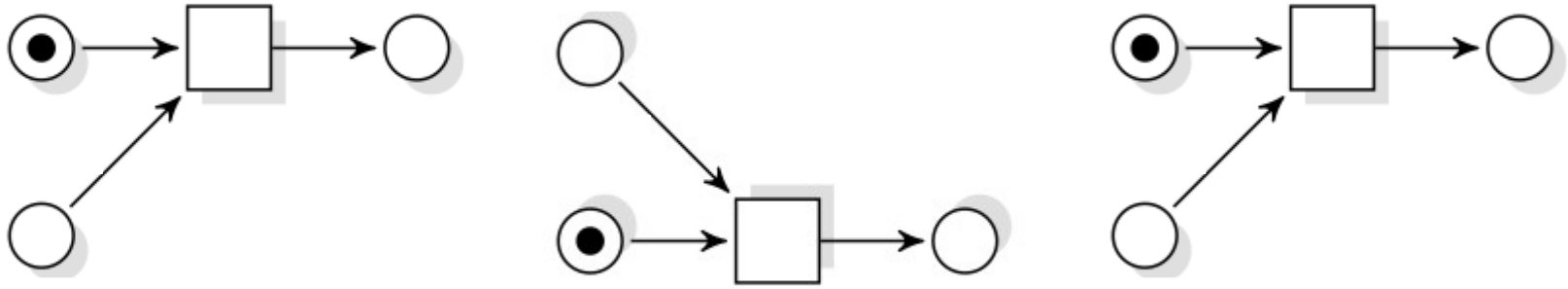
Denotational semantics: Model execution as *search*



- Situation Calculus, Event Calculus, Fluent Calculus all rely on some form of ***timestamp***.
- Causal mechanisms are mapped to logical dependences between ***timestamped snapshots***

Causation in model => Logical constraints

Hybrid semantics: Model execution as *execution*



- Petri nets do not require to reify the global state to perform execution.
- They are directly mappable to individual instructions in imperative programs, they utilize some (local) input to produce some (local) output.

Causation in model => Computational causation

Conclusion

- The paper presents an empirical experiment with LPPNs, a *logic programming-based* extension of Petri Nets.
- LPPNs were introduced with a practical goal: a visual modelling notation, relatively simple for non-experts, handling declarative and procedural aspects of the target domain.
- Here the focus has been put on their computational properties, showing that **maintaining the two levels separated** has the potential to **bring better performances**. *The benchmark needs to be extended.*

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- *Future developments*: extension to predicate logic, optimization of execution model, “canonic” models

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Commit 2 Data connecting business and science
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