Operationalizing Declarative and Procedural Knowledge

a benchmark on Logic Programming Petri Nets (LPPNs)

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

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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

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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.**

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

some connections are **terminological** **(e.g. taxonomical relations)**

other provides **causal** **meaning**

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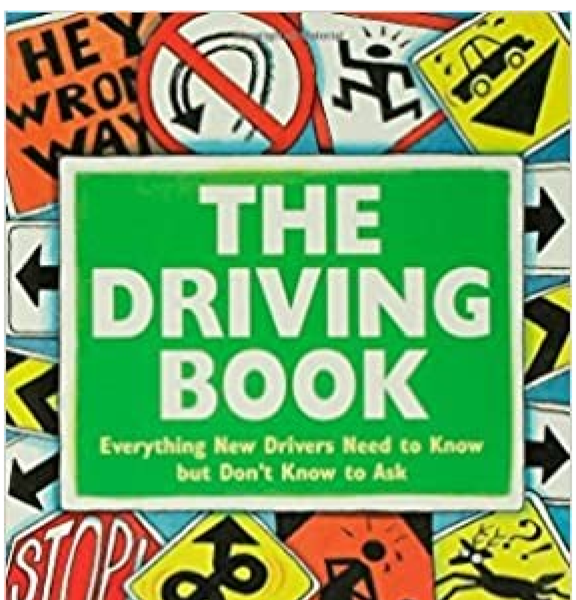
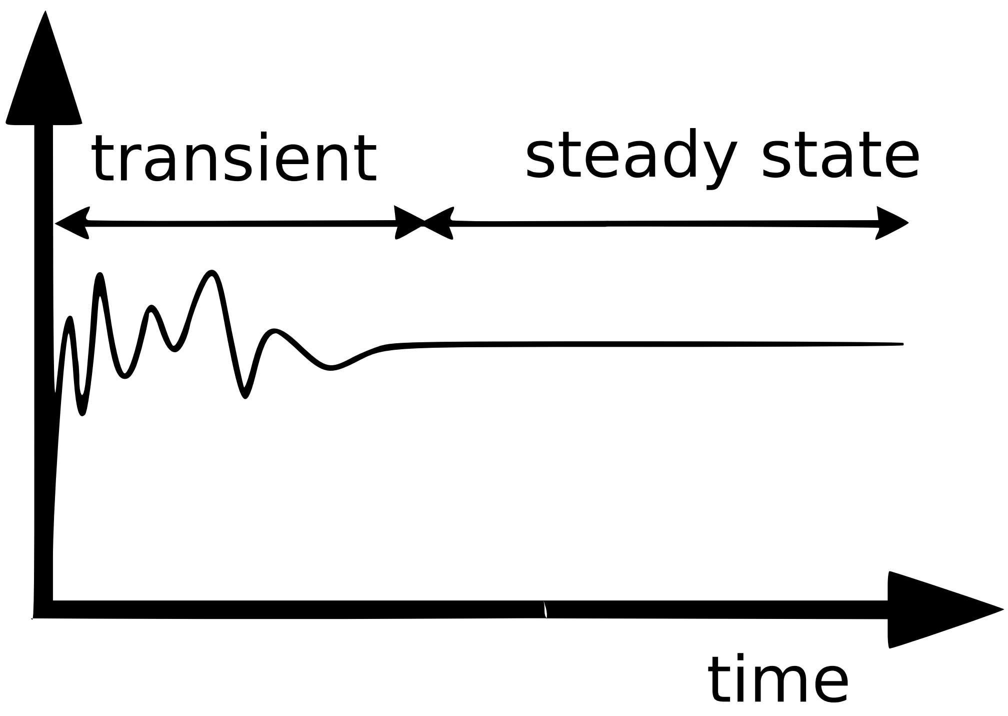
Types of Knowledge

- **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

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    - Process modelling
    - Procedural programming

focus on **What**

focus on **How**

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Petri Nets!

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Answer Set Programming

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focus on **How**

Petri Nets!

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    - Logic
    - Declarative programming
  - *transient* approach
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Answer Set Programming

focus on **What**

+

focus on **How**

logic programming petri nets

= LPPNs

Petri Nets!

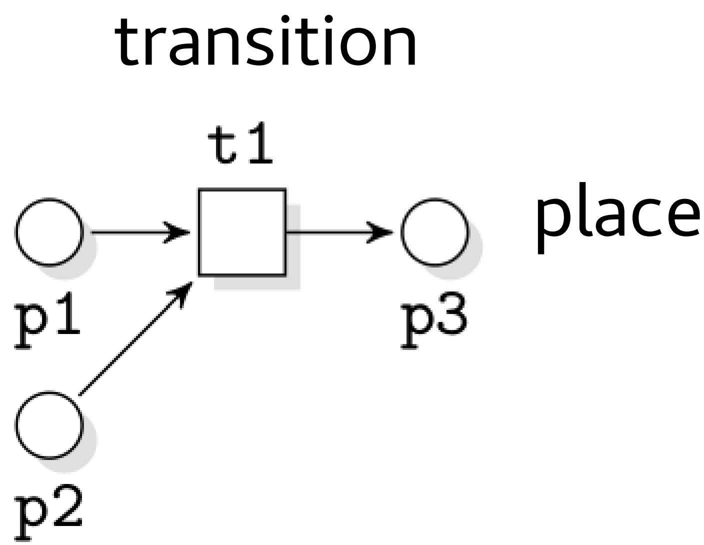
Logic Programming Petri Nets

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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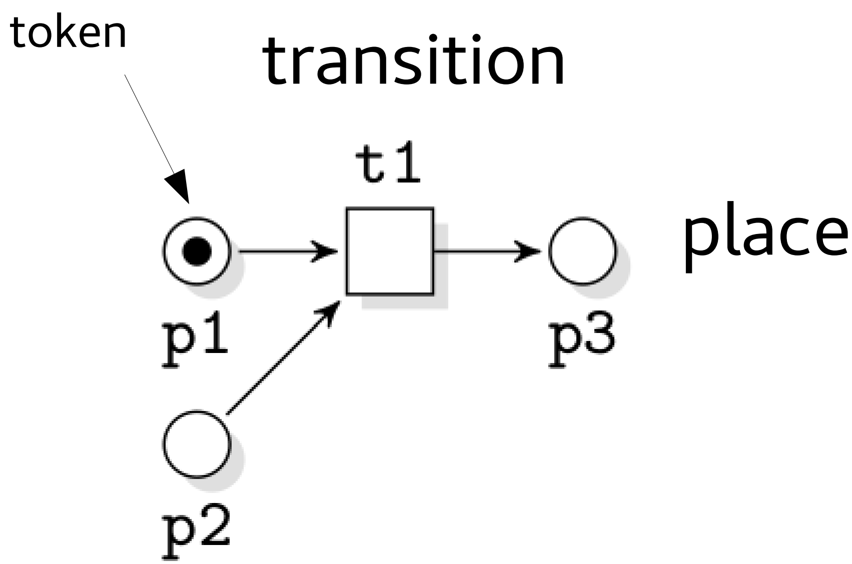
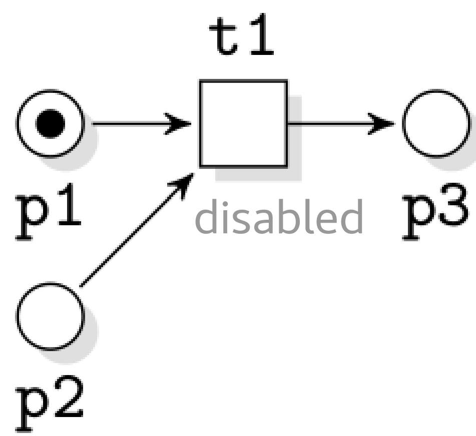


- **tokens** may occupy places.

Procedural LPPN

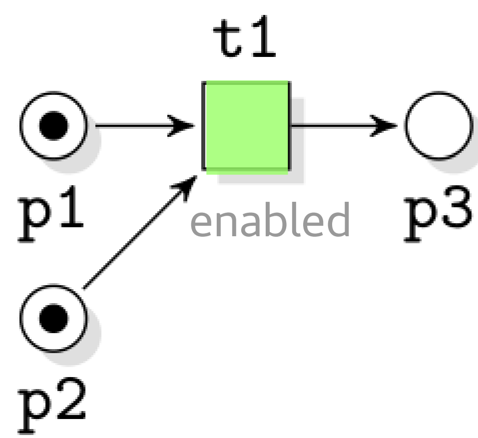
(same as Condition/Event PN)



- 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**.

Procedural LPPN

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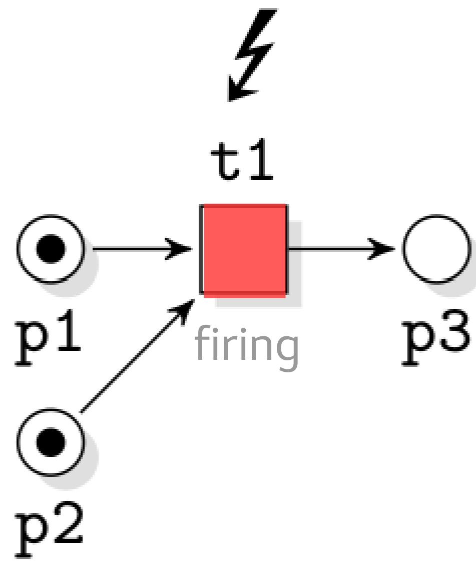

- Execution semantics *(token game)*: when the transition **fires** it will ***consume*** tokens from the ***input*** places.

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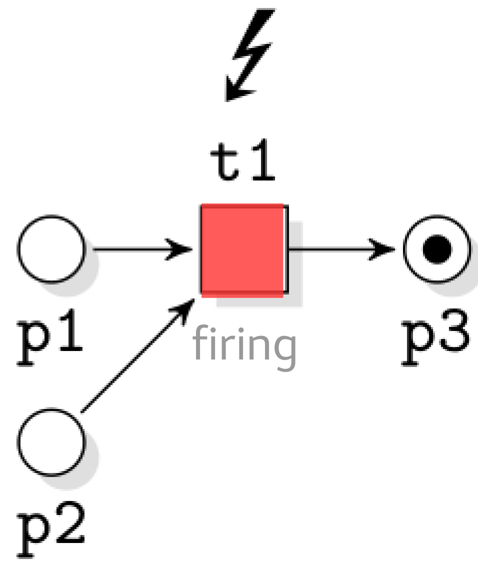
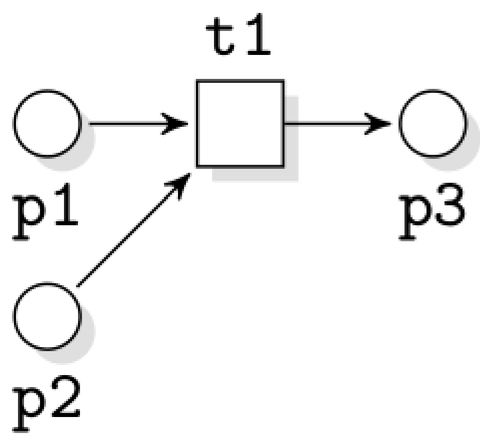


- Execution semantics *(token game)*: ...and ***produce*** tokens in the ***output*** places.

Procedural LPPN

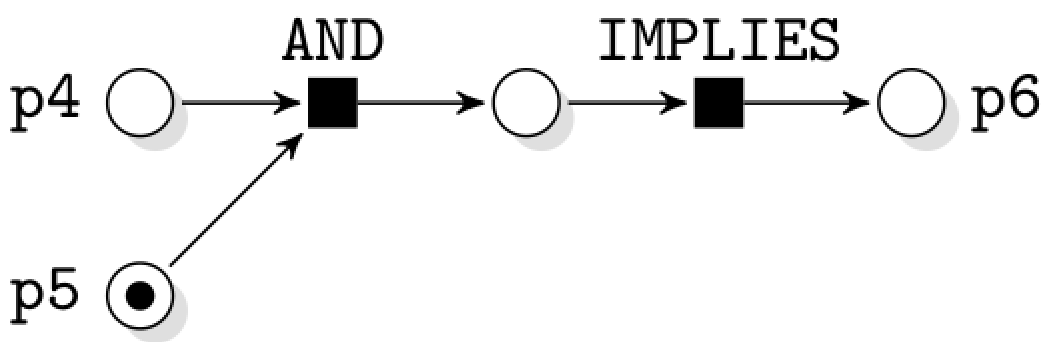
(same as Condition/Event PN)



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

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

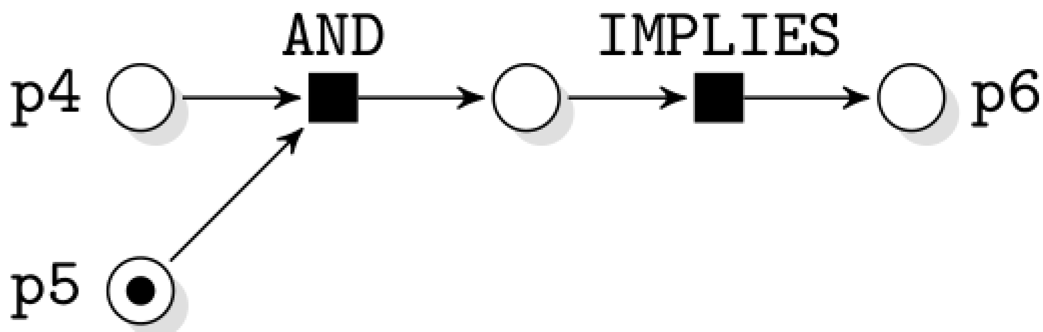
Declarative LPPN for places



- Constructed from the ASP program:

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

Declarative LPPN for places



- Equivalent to

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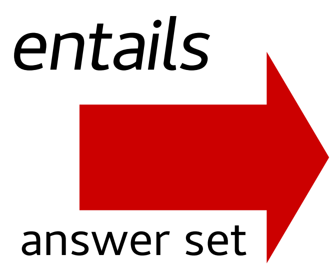
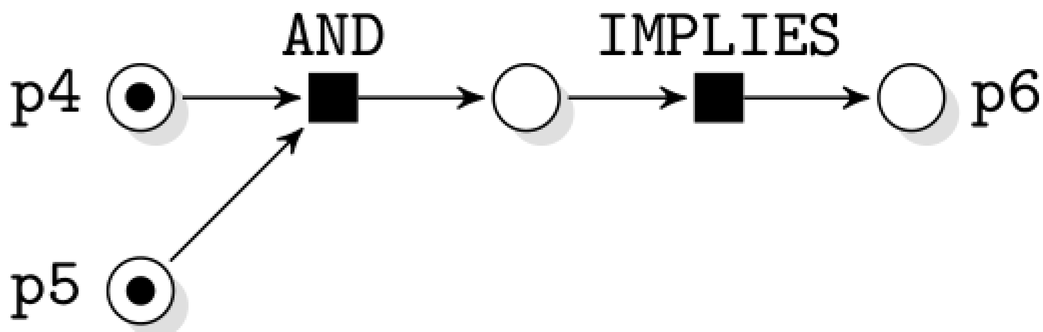
```




```
p5.
```

Declarative LPPN for places



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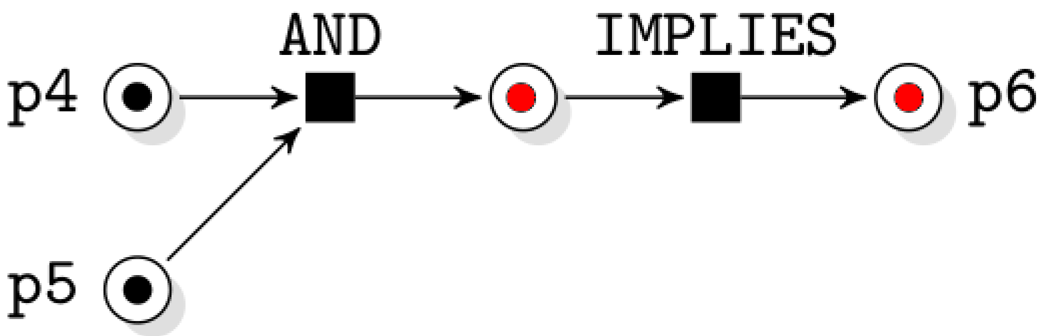
Declarative LPPN for places



- Equivalent to

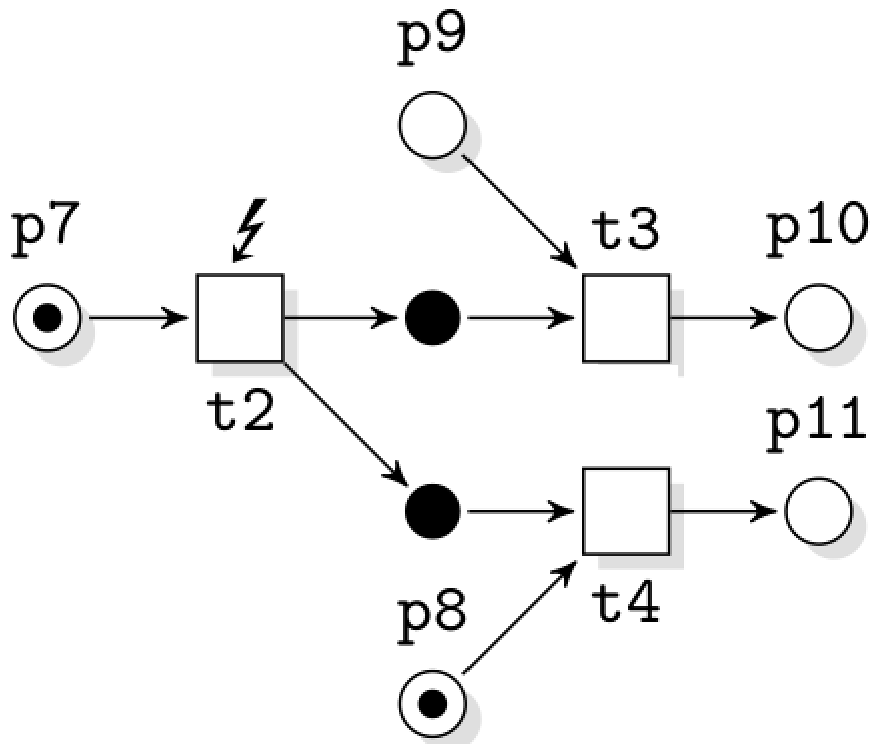
```
p6 :- p4, p5.
p4. p5.
```

entails

answer set

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

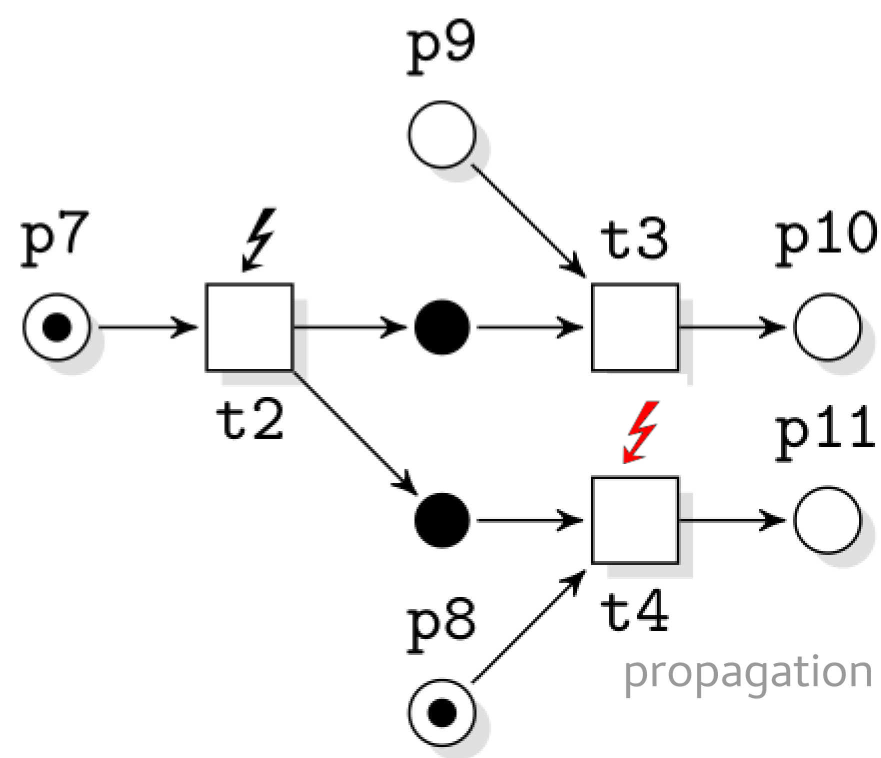
Declarative LPPN for transitions



- Equivalent to

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

Declarative LPPN for transitions



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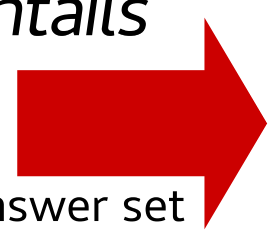
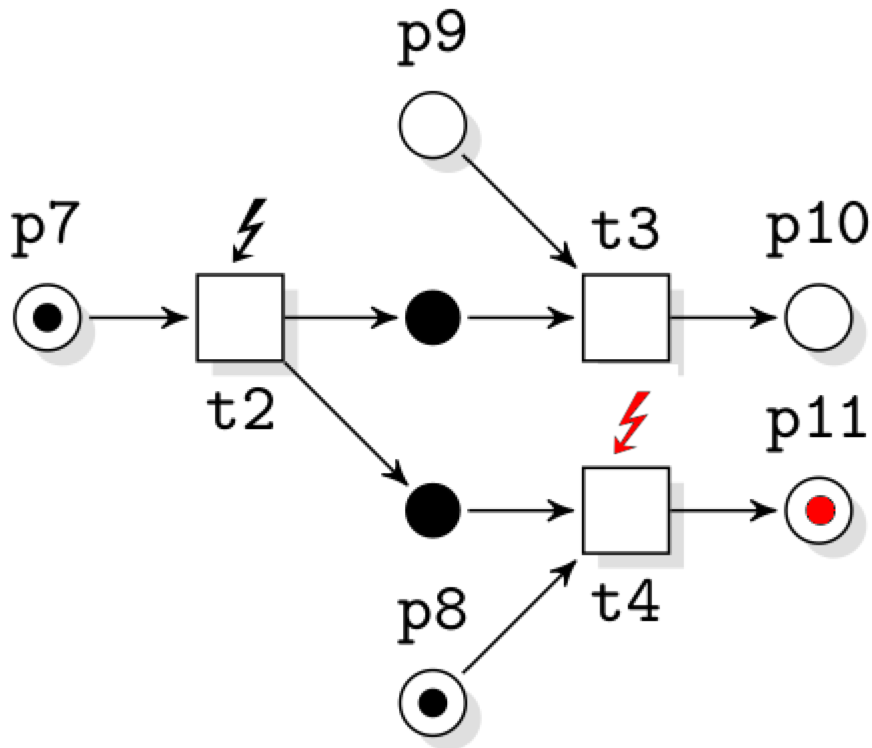


```
#t2. p7. p8. #t4.
```

Declarative LPPN for transitions



p11.

produces

- Equivalent to

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

entails

answer set

#t2. p7. p8. #t4.

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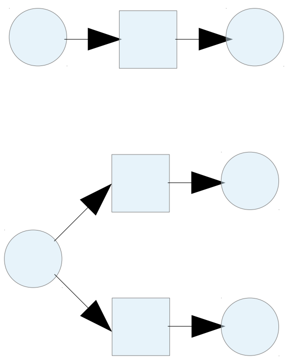
Question: how they compare in terms of computational performance? *Why they should differ?*

Experiment

Experiment

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

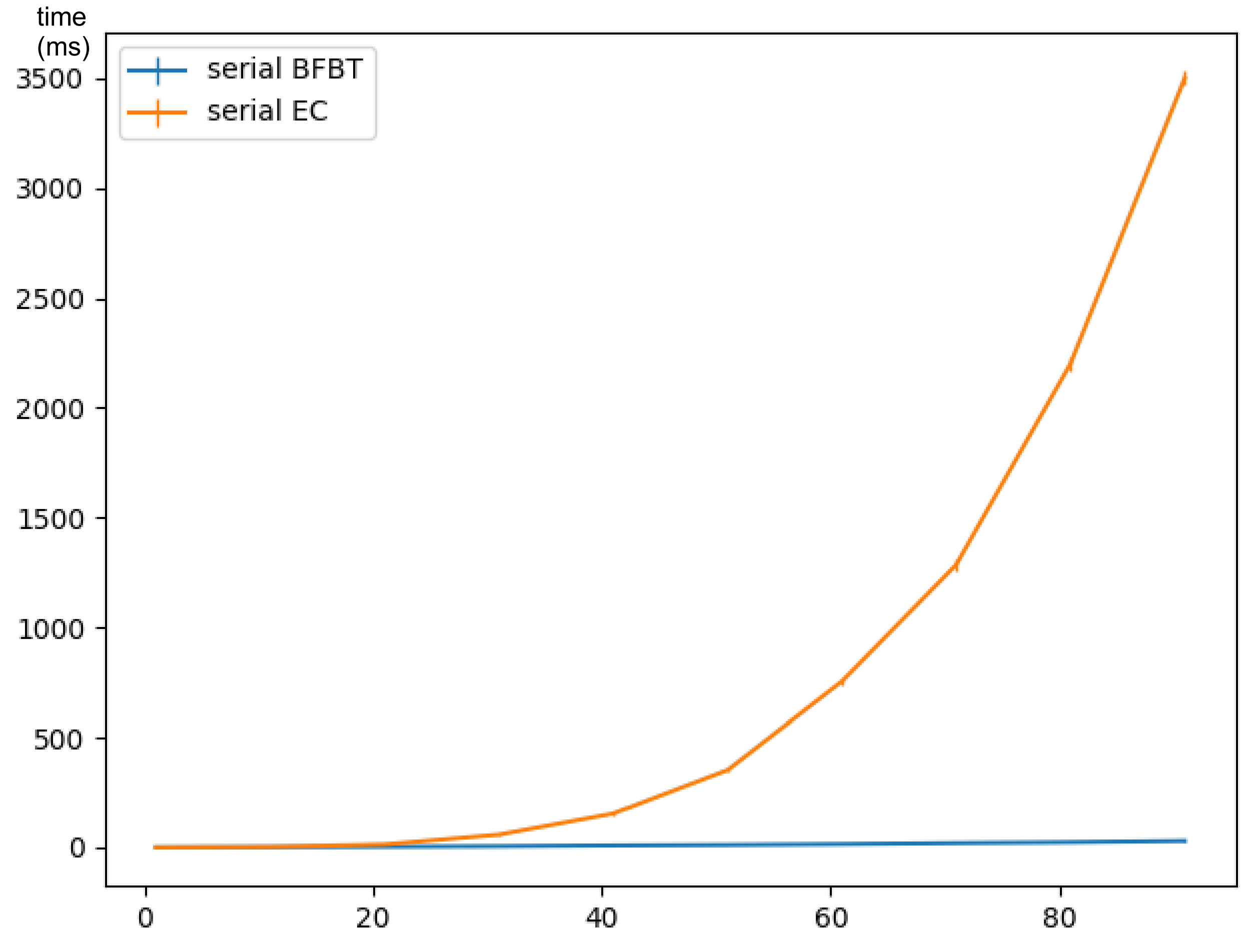


- We executed a benchmark on nets obtained by iterating these basic structures, with one token in the initial place
  - for N iterations = 1, 11, ..., 91 (serial)
  - for N iterations = 1, 2, ..., 10 (forking)

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

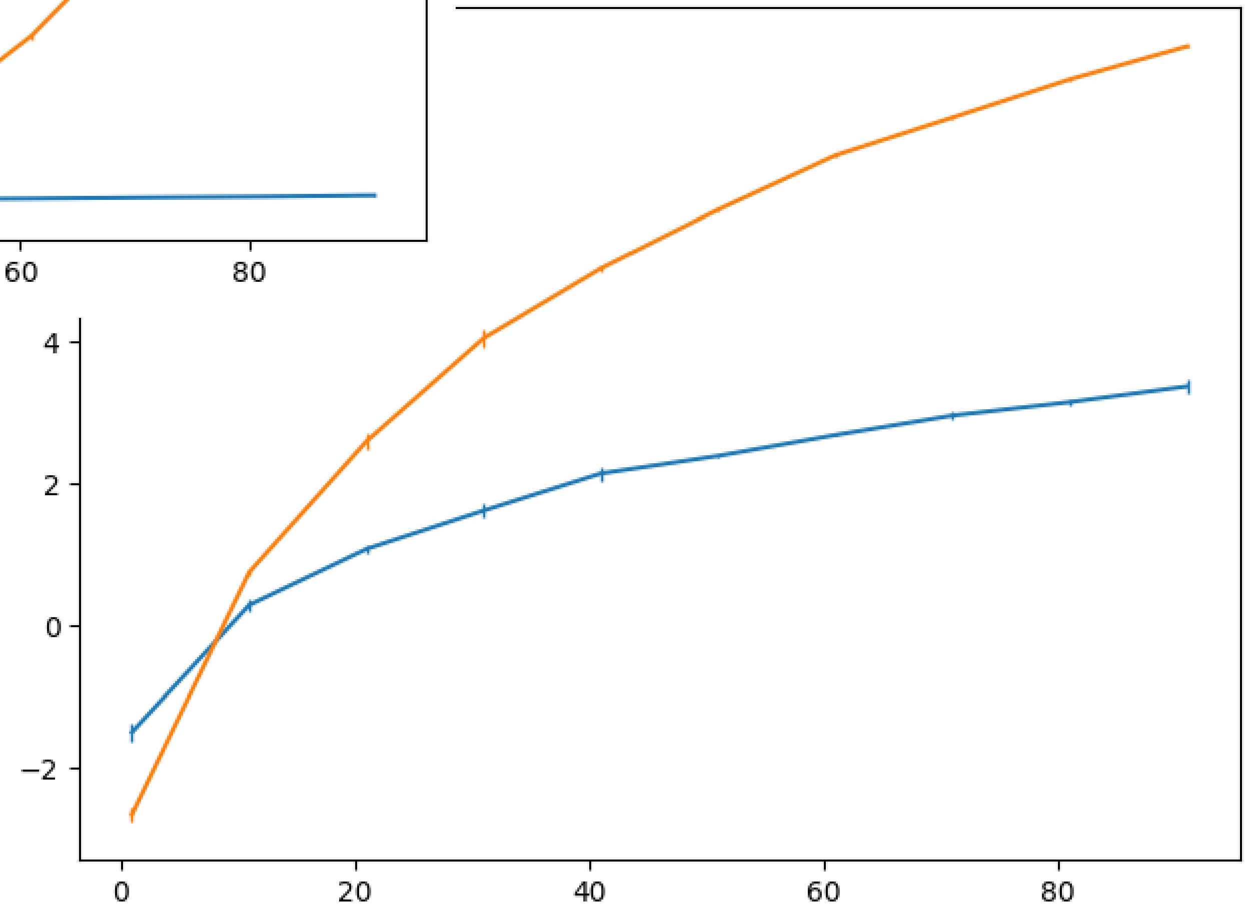
Results

Serial composition



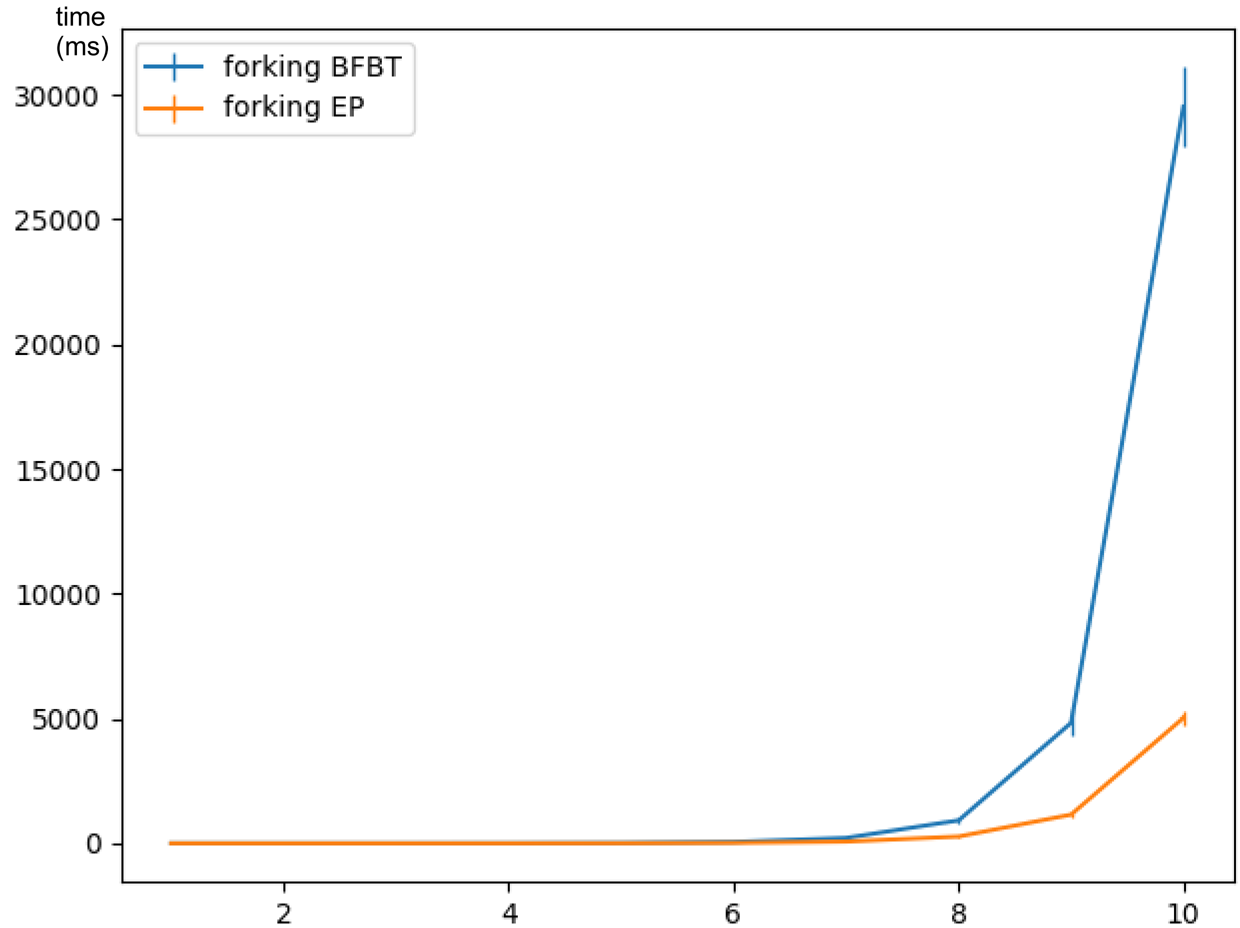
Linear scale

Log scale



Results

Forking composition



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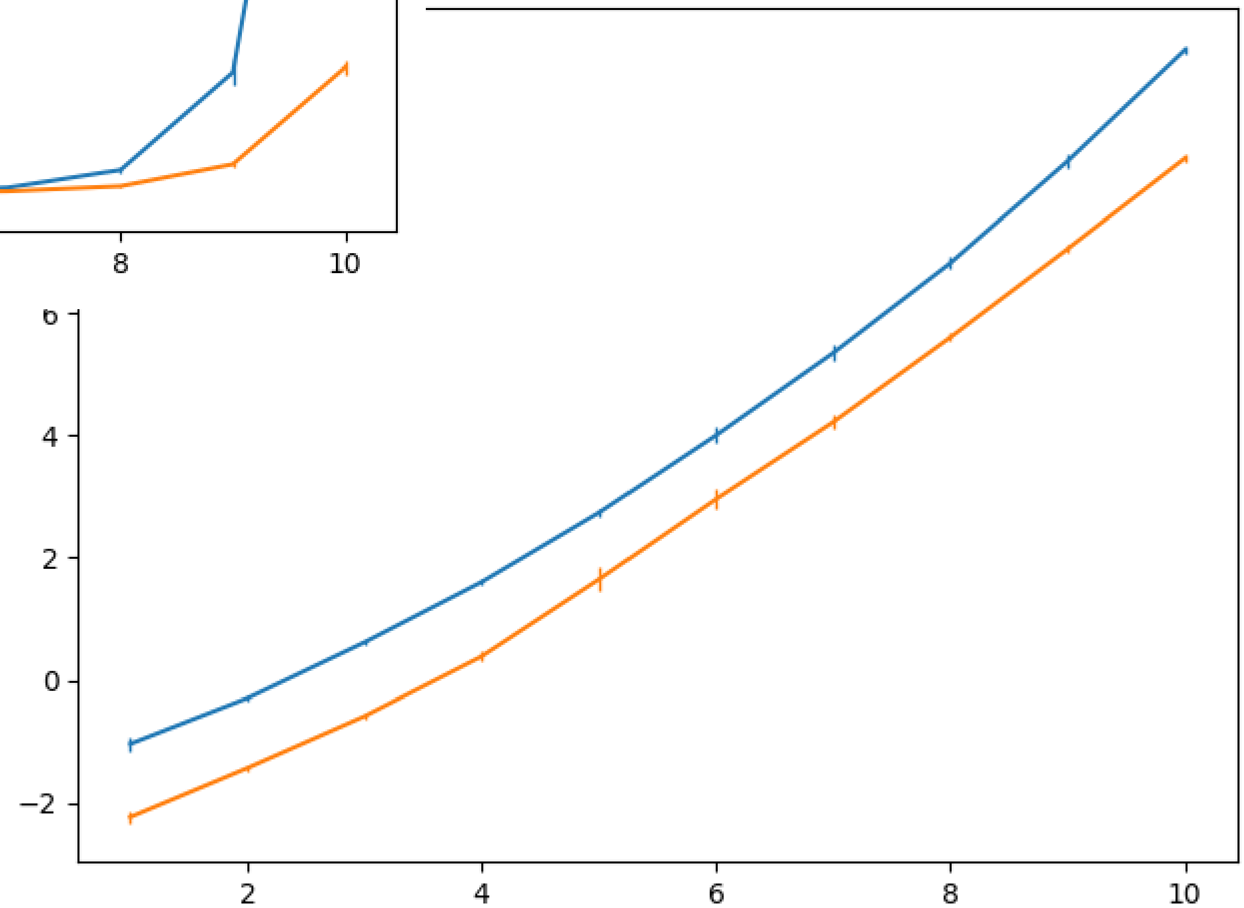
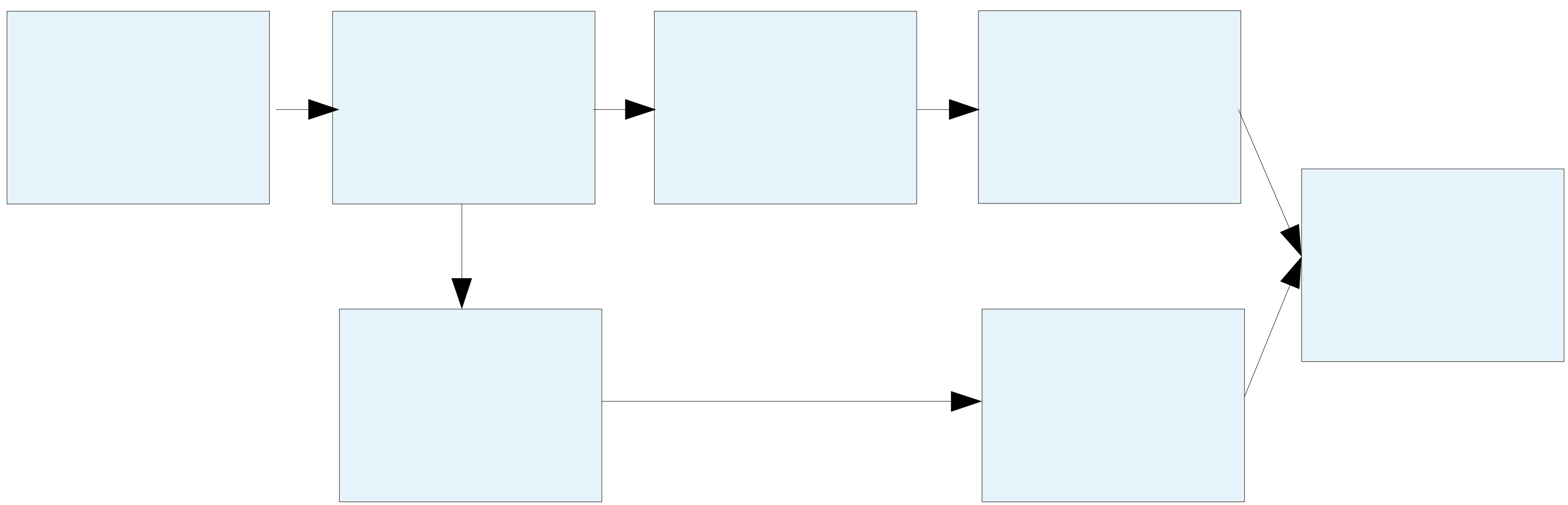


Why this difference? (intuition)

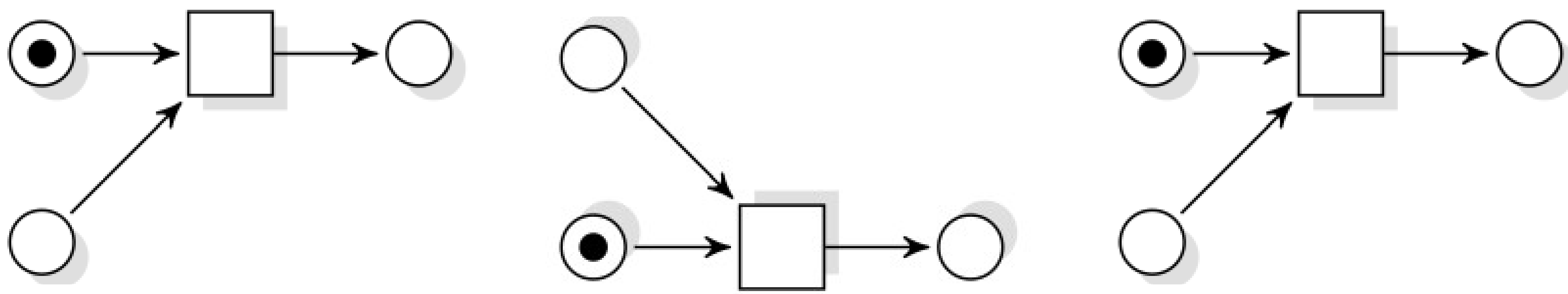
Denotational semantics: Model execution as *search*



- 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