Combining Free choice and Time in Petri Nets

S Akshay, Loïc Hélouët, R Phawade

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S.Akshay[a], L. Hélouët[b], R. Phawade[a]

[a] IIT Bombay, India

[b] INRIA Rennes, France

TRENDS Sept. 9th 2017   [TIME'16]

Model Time constrained unbounded concurrent systems
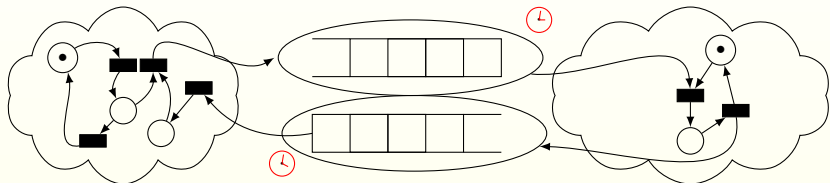
Desired features

- Latency : messages take at least 10 ms to reach their destination
- Timeout/urgency : a message not consumed after 200ms is lost
- Rates : a message is received every γ t.u,...

Standard questions

- Reachability : is marking M reachable from initial marking M_0?
- Coverability : Given a marking M, is there a marking M' reachable from M_0 such that $M'(p) > M(p)$ for every place p?
- Boundedness : is there a bound K such that for every reachable marking, every place p, $M(p) \leq K$?
- Firability : is there an execution in which transition t is fired?

Objectives

- Decidability for these questions
- Efficient algorithms

φ_{17} : Transition t_{17} (a major failure) is not firable.
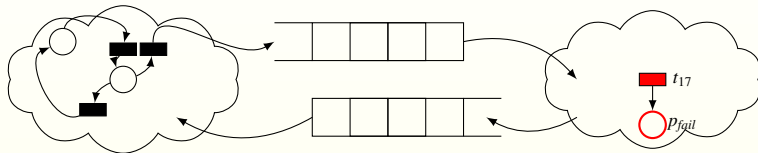
<u>What if :</u>
- time is measured with some imprecision
- clocks tend to have some drift/jitter/delay, ...

Robustness : reasonning with idealized time representation

Assume a class of properties Φ, a model for time imprecision $[\![.]\!]_\delta$

Given a model $\mathcal{M}$, and a value $\delta \in \mathbb{R}$, check that :
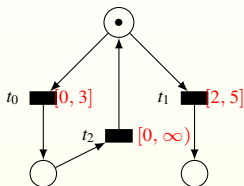$$\forall \varphi \in \Phi, \mathcal{M} \models \varphi \iff [\![\mathcal{M}]\!]_\delta \models \varphi$$

Given a model $\mathcal{M}$, check if :
$$\exists \Delta, \forall \delta \leq \Delta, \forall \varphi \in \Phi, \mathcal{M} \models \varphi \iff [\![\mathcal{M}]\!]_\delta \models \varphi$$

Time vs Timed Petri nets
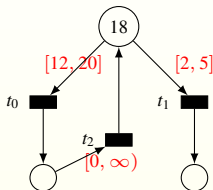
Time Petri nets [Merlin74]

Pros :
- time
- Urgency
- unbounded places
- Expressive power

Cons : Undecidability

Time_d Petri nets [Walter83]

Pros :
- time
- unbounded places
- Ages
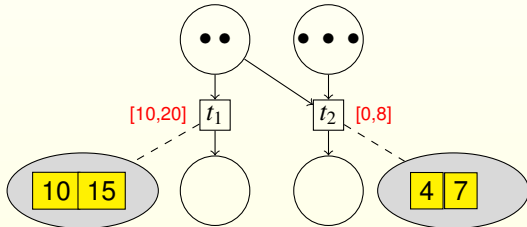- WSTS ≡ decidability of coverability, boundedness,...

Cons : no urgency

- Free-choice Multiserver Time Petri nets
- Processes and their relation to untimed nets
- Firability
- Robustness
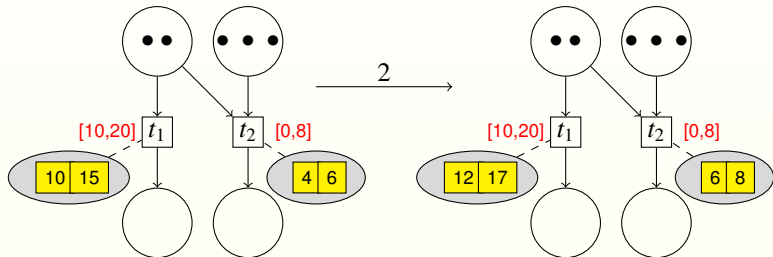
Configuration (`Threshold Semantics`)

$$C = (M, mem)$$

- M : marking, enables transitions several times
- mem : remembers for each enabling instance of a transition for how long it has been enabled

$M(p_0) = 2; M(p_1) = 3; M(p_3) = 0; M(p_4) = 0$

$mem(t_1) = \{10; 15\} \ mem(t_2) = \{4; 7\}$

TPN Multiserver Semantics : timed move

Timed Move : $C \xrightarrow{\delta} C'$

Let a duration δ elapse = update memorized durations

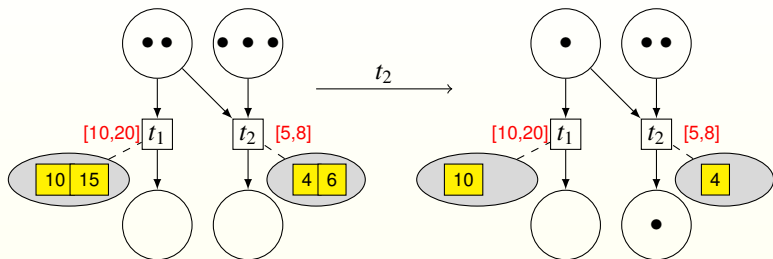## Urgency of a transition t in $C = (M, mem)$

Let t be a transition such that :

- $I(t) = [l, u]$
- t has been enabled for u t.u,   i.e., $\max mem(t) = u$

then, t is urgent.

Time **cannot** progress, a discrete move must occur.
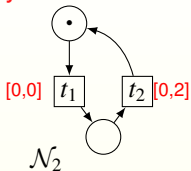
Discrete firing : $C \xrightarrow{t_i} C'$
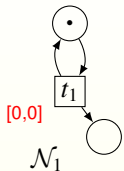
- $I(t_i) = [l, u], \max(mem(t_i)) > l$ (t_i need not be urgent)
- modification of memory for transitions in competition with t_i
- Other enabling instances remain untouched

Behaviors of a net

- Labeled Transition System : $(\mathcal{C}, \longrightarrow, C_0)$
- $Lang(\mathcal{N}) \subseteq T \times \mathbb{R}$:
  set of timed words of $\mathcal{N}$: $w = (t_1, d_1)(t_2, d2) \dots$

Forbid nets that can force zero-delay behaviors.

$\mathcal{N}_1$

$\mathcal{N}_2$

Free choice PN and free choice TPN

(FC-PN) $\mathcal{U} = (P, T, F)$ is free choice if $\forall t, t' \in T, {}^\bullet t \cap {}^\bullet t' \neq \emptyset \implies {}^\bullet t = {}^\bullet t'$.

(FC-TPN) $\mathcal{N} = (\mathcal{U}, M_0, I)$ is a free choice TPN if $Untime(\mathcal{N}) = \mathcal{U}$ is free choice.

The cluster of transition t is $Cl(t) = \{t' \in T \mid {}^\bullet t \cap {}^\bullet t' \neq \emptyset\}$
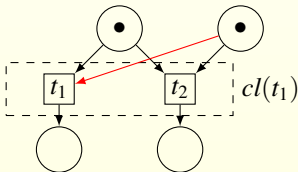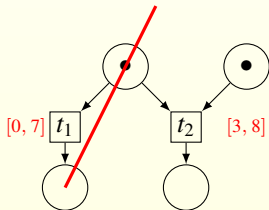
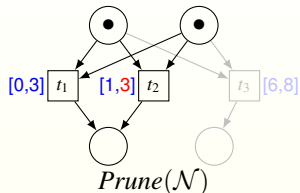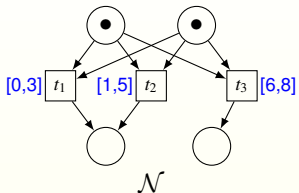Some transitions in FC-TPNs will obviously never fire !

$\mathcal{N}$

$Prune(\mathcal{N})$

To obtain a Pruned FC-TPN

- remove unfirable transitions :
  $t : I(t) = [a, b] \wedge \exists t', I(t') = [c, d]$ with $d < a$
- Associate to remaining transition possible values for intervals
  $I(t) = [a, b] \Rightarrow I'(t) = [a, \max_{t \in Cl(t)} (lft(t'))]$

Pruning Lemma : Let $\mathcal{N}$ be a FC-TPN, then

the transition systems associated with $\mathcal{N}$ and $Prune(\mathcal{N}))$ are isomorphic.
(not true outside FC-TPNs)

Causal processes
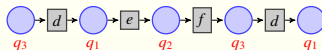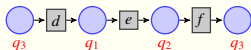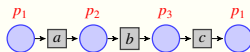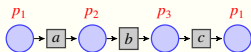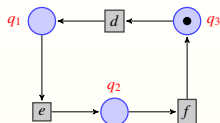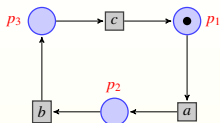
Untimed causal processes ON_1 and ON_2

Causal processes

- A partial order representation of executions
- **Principle :** Unfold the net by glueing transitions/places occurrences one after another starting from the initially marked places

Still an untimed setting !

Timed causal processes
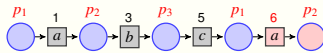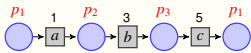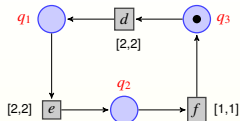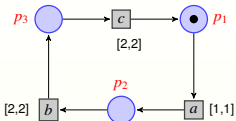
TON_3

TON_4
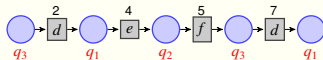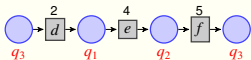
Advantages of Timed Causal processes

- Partial order timed representation of timed executions
- URGENCY is considered : if d occurs at date 7 in *TON*, all urgent transitions before d also occur in *TON*.

Relation between Timed causal Processes and timed languages

Let $\mathcal{P}$ be the set of timed causal processes of $\mathcal{N}$. Then,

$$Lang(\mathcal{N}) = \bigcup_{N \in \mathcal{P}} Lang(N)$$

Theorem 1 : Inclusion of untimed prefixes

Let $\mathcal{N} = (\mathcal{U}, M_0, I)$ be a pruned FC-TPN (w.o. forced 0-delay sequences). U be an (untimed) causal process of $\mathcal{U} = \textit{Untime}(\mathcal{N})$.

Then there exists a timed causal process N of $\mathcal{N}$ such that $U \leq \textit{Untime}(N)$.
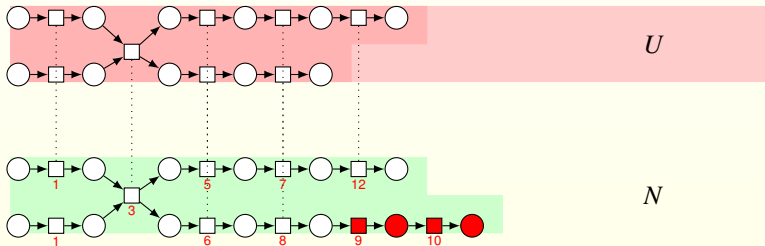
Decidability

Theorem 2 : Fireability

Let $\mathcal{N} = (\mathcal{U}, M_0, I)$ be an FC-TPN (w.o. forced 0-delay).
Checking fireability of a transition $t \in T$ in $\mathcal{N}$ is decidable.

<u>Proof idea :</u> Firability $\sim$ coverability in untimed nets [Rack78]
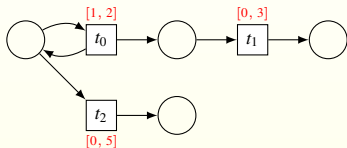
Theorem 3 : Termination

Let $\mathcal{N} = (\mathcal{U}, M_0, I)$ be an FC-TPN (w.o. forced 0-delay). It is decidable if $\mathcal{N}$ terminates.

Proof Idea :
an infinite run of $\mathcal{U} = Untime(Prune(\mathcal{N}))$ has a timed counterpart in $\mathcal{N}$ and conversely. (and termination is decidable in untimed Petri nets)

A major drawback of timed models :
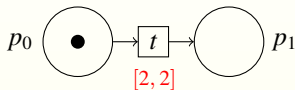

```
public class MyProgram {
    throws InterruptedException {
        Myprogram prog=new MyProgram();
        //Pause for 2 seconds
        Thread.sleep(2000);
        prog.t();
    }
}
```

What the implementation might really do :
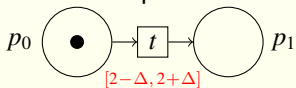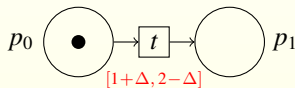
Guard enlargement   *Guard Shrinking*

Form now : $\mathcal{N}_\delta = \mathcal{N}$ with enlarged guards

Robustness

Definition (robustness problems for TPNs)

Given a TPN $\mathcal{N}$, does there exist $\Delta \in \mathbb{Q}_{>0}$ such that $\forall \delta \leq \Delta$

- *Fireable*$(\mathcal{N})$ = *Fireable*$(\mathcal{N}_\delta)$?
- $\mathcal{N}$ terminates iff $\mathcal{N}_\delta$ terminates
- $\mathcal{N}$ is bounded iff $\mathcal{N}_\delta$ is bounded...

Note : Firability, termination, boundedness are not a priori robust/non robust properties of the whole class of FC-TPNs.

Theorem 4

Let $\mathcal{N}$ be a FC-TPN without forced 0-delay time firing sequences. Then robustness of fireability is decidable. If $\mathcal{N}$ has robust fireability, bound Δ can Be effectvely computed.

Theorem 5

Let $\mathcal{N}$ be a FC-TPN without forced 0-delay time firing sequences. Then it is decidable whether temination is a robust property of $\mathcal{N}$.

If $Prune(\mathcal{N})$ and $Prune(\mathcal{N}_\Delta)$ have the same clusters, then Δ-enlargement of $\mathcal{N}$ does not modify firable transitions.

t_2 not firable t_2 firable $\forall \Delta$
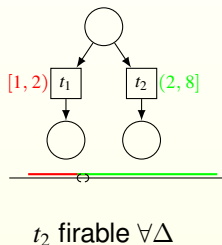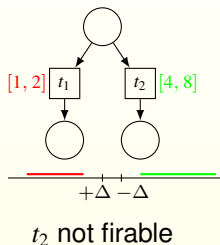
Check for each accessible cluster C whether intervals can be enlarged by some Δ_C without changing firable transitions

Conclusion

Contributions so far :

- A FC-Multiserver PN variant with its process semantics
- Decidable firability, termination
- Decidability of robustness of firability, termination, wrt enlargement (and shrinking)

Open questions :

- decidability of Coverabillity, reachability and boundedness for FC-TPNs ?
- Robustness of more properties ?
- same issues without multi-enabledness ?
- Expressiveness of FC-TPNs ?

$\mathbb{L}_{TPN^M}$: Timed languages expressible with Time Petri nets (Multiserver)
$\mathbb{L}_{TPN}$: Timed languages expressible with Time Petri nets
$\mathbb{L}_{PN}$: Untimed languages expressible with Petri nets
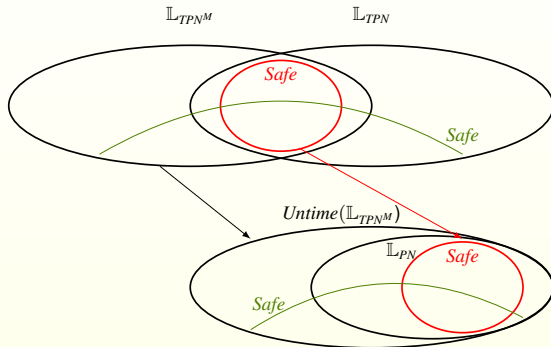
(Thm. 1) In free choice nets, timed / untimed processes tightly related
What about Languages ?

$$\mathbb{L}_{PN} \subseteq Untime(\mathbb{L}_{TPN^M}) \quad \mathbb{L}_{PN \cap Safe} = Untime(\mathbb{L}_{TPN^M \cap Safe}) \quad \mathbb{L}_{PN} \neq Untime(\mathbb{L}_{TPN^M} ??)$$

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