A Short Overview on Diagnosability of Patterns in Timed Petri Net

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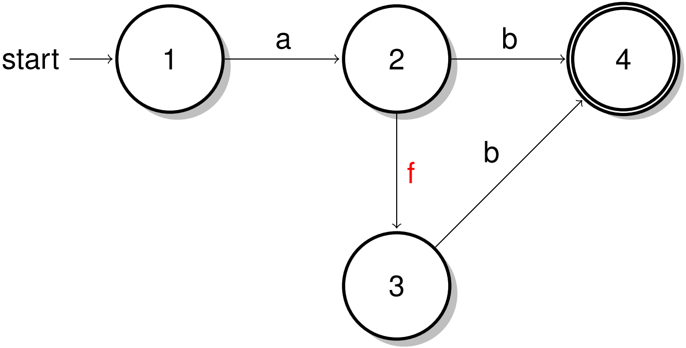
Diagnosability

Diagnosability is a basic property of Discrete Event Systems that relates to the “observability” of concealed events. Basically, it means that every failure (a distinct instance of unobservable event) can be eventually detected after a finite number of observations.



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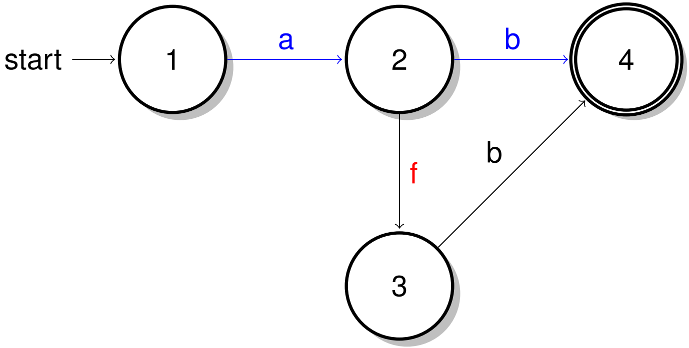

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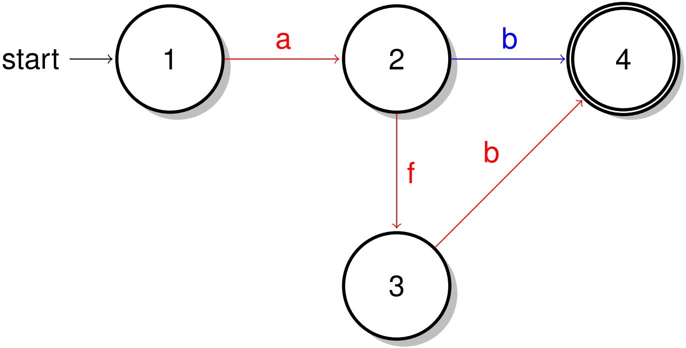
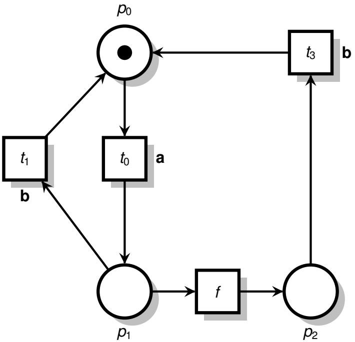


A simple (untimed) example



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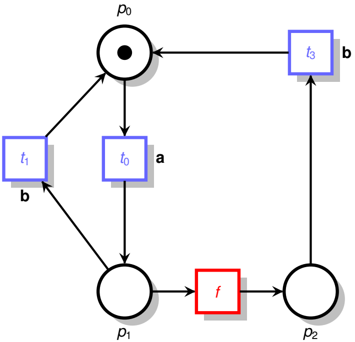

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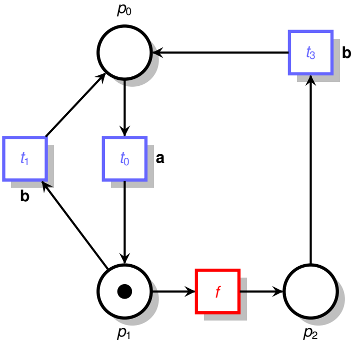
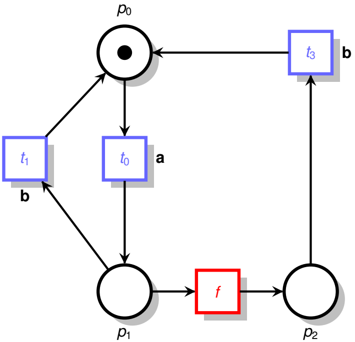


Possible executions:

$t_0 \ldots / \; a \ldots$

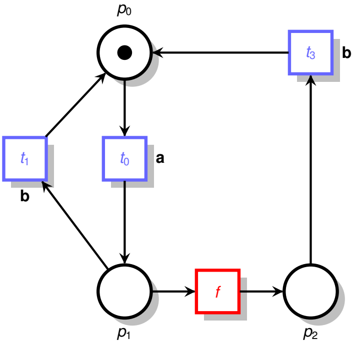
A simple (untimed) example



Possible executions:

$t_0\, t_1\ \ldots / \, a\, b\ \ldots$

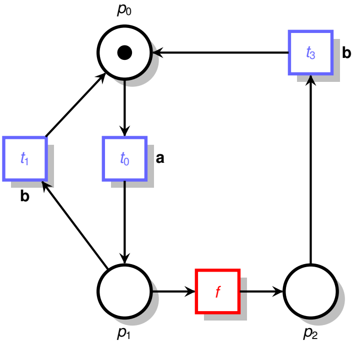
A simple (untimed) example



Possible executions:

$t_0\ t_1\ t_0\ t_1\ \ldots\ /\ a\,b\,a\,b\ \ldots$
$t_0\ f\ t_3\ t_0\ t_1\ \ldots /\ a\,b\,a\,b\ \ldots$

A simple (untimed) example

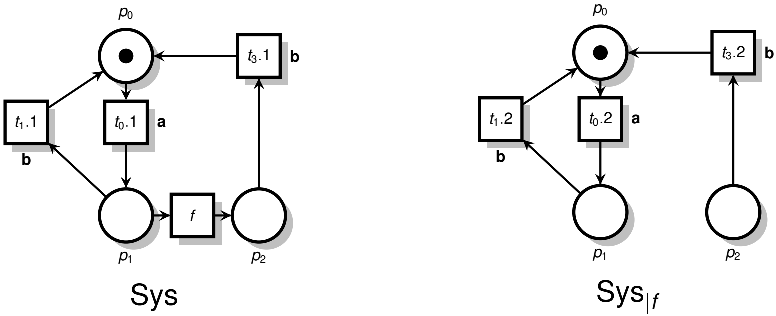


Possible executions:

$t_0\ t_1\ t_0\ t_1\ \ldots\ /\ a\,b\,a\,b\ \ldots$
$t_0\ f\ t_3\ t_0\ t_1\ \ldots /\ a\,b\,a\,b\ \ldots$

Language: $(ab)^*$

A simple (untimed) language

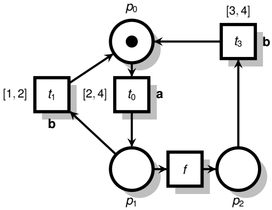


$$[\![\mathrm{Sys}]\!] \cap [\![\mathrm{Sys}_{|f}]\!] \approx [\![\mathrm{Sys} \parallel \mathrm{Sys}_{|f}]\!]$$

Time Petri Nets

TPN are composed of :

- a Petri net
- an initial marking
- timing constraints $\mathbf{I}_s(t)$ (*aka* static time interval) that constrains the time at which t can fire.



System

Possible executions:

$2.1\ t_0\ 2\ t_1\ \ldots\ /\ 2.1\ a\ 2\ b\ \ldots$
$2.1\ t_0\ 1\ f\ 3\ t_3\ \ldots\ /\ 2.1\ a\ 4\ b\ \ldots$

Language: $(ab)^*$

Composition of TPN

Analysing the “intersection” of TPN is hindered by two problems:

1. State Space is infinite

That is because in this case time delays δ can be arbitrarily small. $[x,y]$ timing constraint can be cut in an infinity δ.

Composition of TPN

Analysing the "intersection" of TPN is hindered by two problems:

1. State Space is infinite
2. Composability problem

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A quick state of the art

Problem 1

The problem of State Space?

- A solution was proposed in [Berthomieu 83], where the authors define a state space abstraction based on State Class Graph (SCG).
- Basically, a state class captures a convex set of constraints on the time at which transitions can fire. This approach is used in several model-checking tools, such as Tina [Berthomieu 04].

Problem 2

Composition problem?

- Some works address the diagnosability of TPN [Lieu - 14, Wang - 15, Basile - 17].
- While they propose substantially different method, they all rely on a variation of the SCG construction of [Berthomieu 83].

Our approach: intersection of TPN languages

What we know Computing intersection of TA is simple $\Rightarrow$ decidable on TPN (using TA $\gtrsim$ TPN [Bérard et al. - 05]).

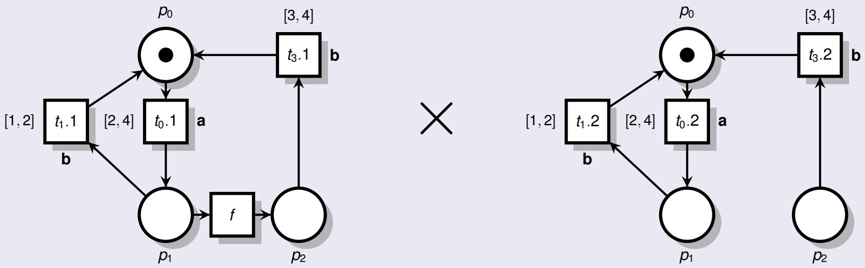
Problem: does not give an efficient method.

Idea: adapt State Class construction [Berthomieu - 83] to "product" of TPN

PTPN

Idea: use a product, $N_1 \times N_2$, and force transitions with same label (e.g. $t_3.1 \in N_1$ and $t_1.2 \in N_2$) to fire “synchronously”.

Example

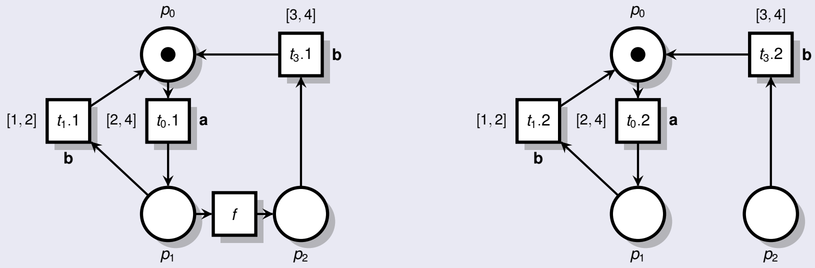


PTPN

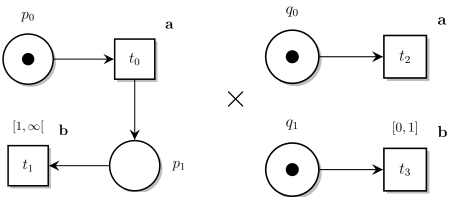
More intuitively, we can always interpret a PTPN as the set of transitions which must be fired together, at the same time. For exemple:

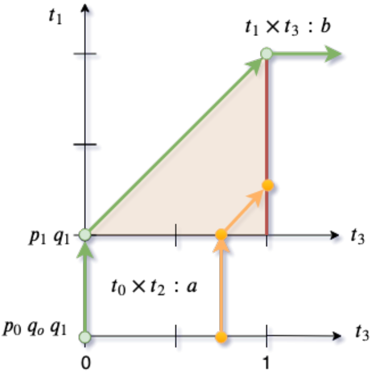
$$\{\{t_0.1, t_0.2\}, \{t_1.1, t_1.2\}, \{t_3.1, t_1.2\}, \{f\}\}$$

Example



PTPN: example of behaviour





Time elapse as in “classical” TPN $\Rightarrow$ must fire t_0 before 1 initially.

Transitions $\{t_0, t_2\}$ and $\{t_1, t_3\}$ must fire simultaneously $\Rightarrow$ this can create “timelocks”.

PTPN: Diagnosability of a single fault

- Using the features of PTPN, we have developed an algorithm to check the diagnosability of a TPN.
- Its purpose is to detect cycles after (or with) a fault transition.

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- It is possible to extend this method to the observability of "patterns of events" [Gougam - 2017]. We define a *pattern* as a labelled Petri net, *P*, representing the set of behaviours (sequences of labels) that we want to detect.

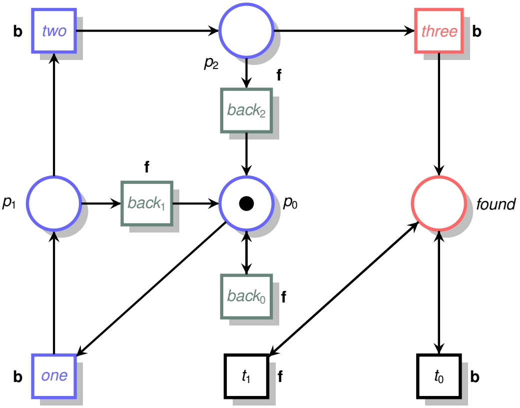


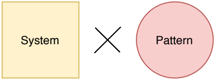
Figure: pattern for "three consecutive b without f "

We say a pattern is well-formed if it fulfils a set of hypothesis:

- Patterns are total.
- Patterns are deterministic.
- Labels *f* are unobservable.

Twin Plant Methods for patterns

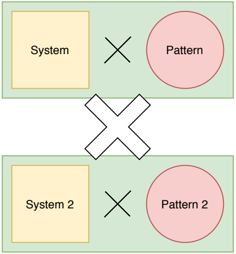
- First, we make a PTPN with the TPN and its pattern:



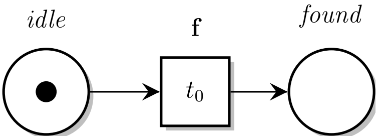
- Now we have to check for the "found" place!

Twin Plant Methods for patterns

- Now, all we have to do is to test the "diagnosability" of the transitions just before "found". To do this...We simple apply another twin-plant method for a single fault!



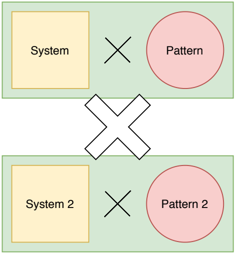
- Now the idea is to check the diagnosability via the PTPN.
- We define the single fault as a pattern we are matching with, like this:



Theorem

a TPN N is diagnosable if and only if all the maximal executions of the PTPN N.1 $\times$ N.2 satisfy the LTL formula:

$$\square(found.1 \Rightarrow \Diamond(dead \vee found.2))$$



Theorem

Assuming some well-formedness conditions on the pattern P, TPN N is diagnosable for pattern P iff all maximal executions of the PTPN $(N.1 \times P.1) \times (N.2 \times P.2)$ *satisfy the LTL formula:*

$$\Box(found.1 \Rightarrow \Diamond(dead \vee found.2))$$

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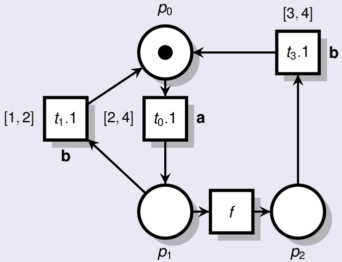
- Tool for analyzing the “product” of two Time Petri Nets (TPN).
- Another use of Twina is to check the diagnosability of a net.
- Available at `https://projects.laas.fr/twina/` with example.

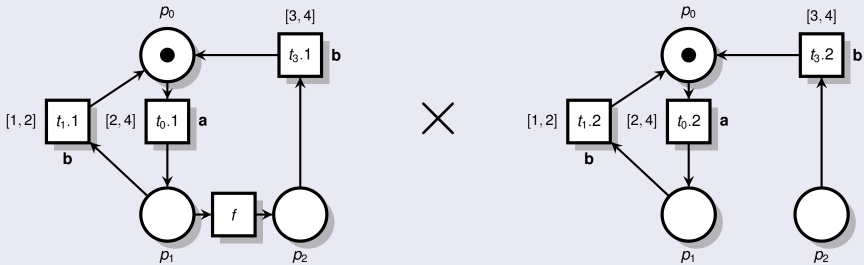
Example

TPN N



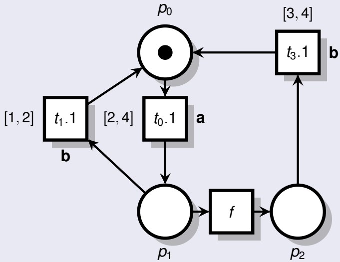
Example

PTPN NxN'



Example

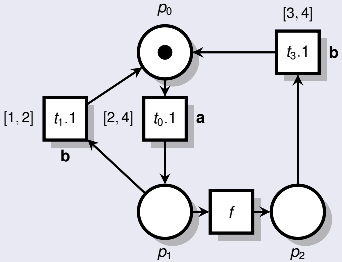
TWINA




```
elubat@cid:~/Dev/2TPN$ more ex2tpn.net
tr f : f [0,w[ p0 -> p2
tr t0 : a [2,4] p1 -> p0
tr t1 : b [1,2] p0 -> p1
tr t3 : b [3,4] p2 -> p1
pl p1 (1)
net ex2tpn
```

Example

TWINA

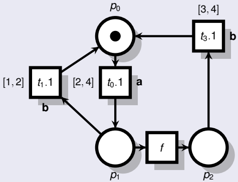



```
elubat@cid:~/Dev/2TPN$ twina -diag --fault=f ex2tpn.net

# net is diagnosable
#
# states (explored):   3
# markings:            3
# dbms:                3
0.000s
```

Example

TWINA




```
elubat@cid:~/Dev/2TPN$ twina -twin -v --fault=f ex2tpn.net
# states 3
# transitions 3

class 0
  marking: {p1.1} {p1.2}
  domain:
   2 <= {t0.1} <= 4
   2 <= {t0.2} <= 4
  successors: {t0.1}|{t0.2}/1

class 1
  marking: {p0.1} {p0.2}
  domain:
   0 <= {f.1} <  w
   1 <= {t1.1} <= 2
   1 <= {t1.2} <= 2
  successors: {f.1}/2 {t1.1}|{t1.2}/0

class 2
  marking: {p2.1} {p0.2}
  domain:
   3 <= {t3.1} <= 4
   0 <= {t1.2} <= 2
  successors:
```

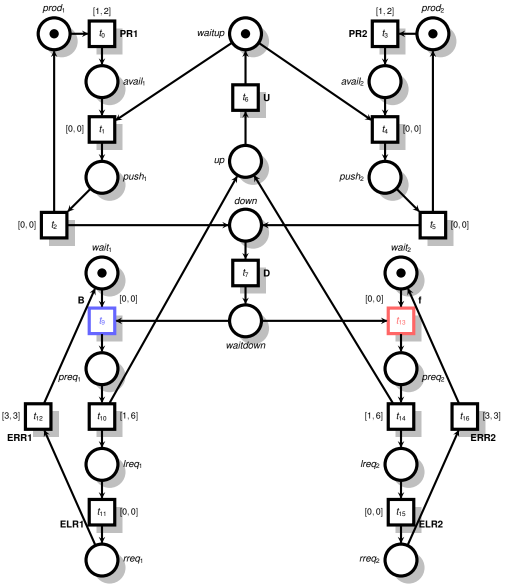


Figure: Transport timed - [Gougam 17]

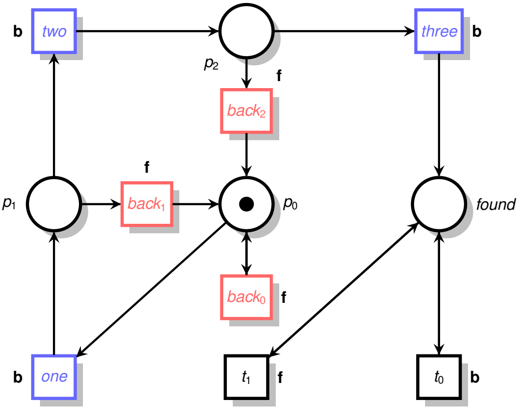


Figure: pattern for “three consecutive b without f ”

```
elubat@cid:~/Transport_timed$ time ./script_inter_tpn.sh transport_timed.net omega.net result
Debut script sur omega.net
# net {}, 72 places, 72 transitions, 240 arcs                      #
# bounded, not live, possibly reversible                           #
# abstraction        count      props      psets       dead       live #
#      states       853415         72      48395          0     153013 #
# transitions      3806808         72         72         28         32 #
FALSE
  state 0: L.scc*2874 {p0.1.1} {p0.1.2} {prod1.2.1} {prod1.2.2} {prod2.2.1} {prod2.2.2} {ptest_t0.2.1} {ptest_t0.2.2} {ptest_t1.2.1} {ptest_t1.2.2} {ptest_t11.2.1} {ptest_t11.2.2} {ptest_t12.2.1} {ptest_t
12.2.2} {ptest_t13.2.1} {ptest_t13.2.2} {ptest_t15.2.1} {ptest_t15.2.2} {ptest_t16.2.1} {ptest_t16.2.2} {ptest_t2.2.1} {ptest_t2.2.2} {ptest_t3.2.1} {ptest_t3.2.2} {ptest_t4.2.1} {ptest_t4.2.2} {ptest_t5.
2.1} {ptest_t5.2.2} {ptest_t6.2.1} {ptest_t6.2.2} {ptest_t7.2.1} {ptest_t7.2.2} {ptest_t9.2.1} {ptest_t9.2.2} {wait1.2.1} {wait1.2.2} {wait2.2.1} {wait2.2.2} {waitup.2.1} {waitup.2.2}
  -{t0.2.1} ... (preserving T)->
  state 415: L.scc*2 {avail2.2.1} {avail2.2.2} {down.2.1} {down.2.2} {found.1.1} {p0.1.2} {prod1.2.1} {prod1.2.2} {ptest_t0.2.1} {ptest_t0.2.2} {ptest_t1.2.1} {ptest_t1.2.2} {ptest_t11.2.1} {ptest_t11.2.2
} {ptest_t12.2.1} {ptest_t12.2.2} {ptest_t13.2.1} {ptest_t13.2.2} {ptest_t15.2.1} {ptest_t15.2.2} {ptest_t16.2.1} {ptest_t16.2.2} {ptest_t2.2.1} {ptest_t2.2.2} {ptest_t3.2.1} {ptest_t3.2.2} {ptest_t4.2.1}
 {ptest_t4.2.2} {ptest_t5.2.1} {ptest_t5.2.2} {ptest_t6.2.1} {ptest_t6.2.2} {ptest_t7.2.1} {ptest_t7.2.2} {ptest_t9.2.1} {ptest_t9.2.2} {rreq1.2.1} {wait1.2.2} {wait2.2.1} {wait2.2.2}
  -{t12.2.1} ... (preserving - {found.1.2} /\ - dead /\ {found.1.1})->
* [accepting] state 416: L.scc*2 {avail2.2.1} {avail2.2.2} {down.2.1} {down.2.2} {found.1.1} {p0.1.2} {prod1.2.1} {prod1.2.2} {ptest_t0.2.1} {ptest_t0.2.2} {ptest_t1.2.1} {ptest_t1.2.2} {ptest_t11.2.1} {p
test_t11.2.2} {ptest_t12.2.1} {ptest_t12.2.2} {ptest_t13.2.1} {ptest_t13.2.2} {ptest_t15.2.1} {ptest_t15.2.2} {ptest_t16.2.1} {ptest_t16.2.2} {ptest_t2.2.1} {ptest_t2.2.2} {ptest_t3.2.1} {ptest_t3.2.2} {p
test_t4.2.1} {ptest_t4.2.2} {ptest_t5.2.1} {ptest_t5.2.2} {ptest_t6.2.1} {ptest_t6.2.2} {ptest_t7.2.1} {ptest_t7.2.2} {ptest_t9.2.1} {ptest_t9.2.2} {wait1.2.1} {wait1.2.2} {wait2.2.1} {wait2.2.2}
  -{t0.2.2} ... (preserving - {found.1.2} /\ - dead)->
  state 416: L.scc*2 {avail2.2.1} {avail2.2.2} {down.2.1} {down.2.2} {found.1.1} {p0.1.2} {prod1.2.1} {prod1.2.2} {ptest_t0.2.1} {ptest_t0.2.2} {ptest_t1.2.1} {ptest_t1.2.2} {ptest_t11.2.1} {ptest_t11.2.2
} {ptest_t12.2.1} {ptest_t12.2.2} {ptest_t13.2.1} {ptest_t13.2.2} {ptest_t15.2.1} {ptest_t15.2.2} {ptest_t16.2.1} {ptest_t16.2.2} {ptest_t2.2.1} {ptest_t2.2.2} {ptest_t3.2.1} {ptest_t3.2.2} {ptest_t4.2.1}
 {ptest_t4.2.2} {ptest_t5.2.1} {ptest_t5.2.2} {ptest_t6.2.1} {ptest_t6.2.2} {ptest_t7.2.1} {ptest_t7.2.2} {ptest_t9.2.1} {ptest_t9.2.2} {wait1.2.1} {wait1.2.2} {wait2.2.1} {wait2.2.2}

real    1m58,343s
user    1m56,573s
sys     0m1,748s
```

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Motivation for our work

Fault diagnosis for Discrete Event System $\equiv$ properties on trace languages [Sampath - 95].

Addition of time constraints.

- Δ-diagnosability $\equiv$ “reachability of (non-Zeno) runs in product of TA” [Tripakis - 02]
- τ-diagnosability $\equiv$ “same” for T-TPN [Wang - 2015, Basile - 2017] (but ask for a firing sequence)

Problem boils down to checking the intersection of timed languages (Twin-plant method).

Conclusion

We talked about the diagnosability in DES with a timed context.

Our solution is available on `https://projects.laas.fr/twina/`.

The next step is to analyse opacity in TPN via the use of PTPN.

Conclusion

Thanks for your attention **!**

Any questions **?**

A quick state of the art

Overview of fault diagnosis methods based on petri net models

[Basile - 14]
System is diagnosable if we can always detect a fault in a finite number of observations.

A new approach for diagnosability analysis of petri nets using verifier nets

[Cabasino - 12]
There are several efficient methods for checking the diagnosability of single faults in PN. We can divide existing techniques in two groups:

- (1) critical pair.
- (2) “diagnoser-based” methods.

Diagnosability Analysis of Labeled Time Petri Net Systems

- In [Basile - 17] the author build a Modified SCG that over-approximate the possible (timed) executions.
- The system is diagnosable if no critical pair is found. If a critical pair is found, we have to solve a Linear Programming problems (LPP) to check whether this scenario is feasible.
- This approach has several limitations. In particular, it may require to solve a large number of LPP.

Diagnoser-based approaches

- In [Liu - 14], the authors define an Augmented State Class (ASC) graph, which are SCG augmented with diagnosability information. He then use a method to split time intervals to only keep deterministic paths in the ASC graph.
  - The interval splitting phase may create a large number of new active states that can lead to a state explosion problem.
- The approach in [Wang - 15] relies on a combination of SCG and an enumeration of all the firing sequences between active states.