Modular fault diagnosis in discrete-event systems with a CPN diagnoser

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Introduction

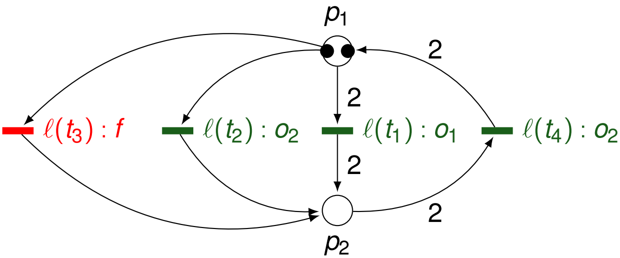
- Fault diagnosis in discrete event systems
  - Given a discrete event system and its model, a set of anticipated faults and a sequence of observations of the system
  - Determine whether a set of faults occurred in the system
- Problem initially introduced within the automaton formalism
- **Contrib 1 :** Starting from a Petri net model :
  - how to compute a Petri net Diagnoser :
  - as efficient as the diagnoser automaton of [Sampath 95]
  - as precise (belief state + fault)
  - that is not any kind of reachable marking graph
  - and smaller (a proper Petri Net)
- **Contrib 2 :** Application : how to design a modular diagnosis system with help of this Petri net diagnoser.
- Use of Coloured Petri Net (CPN)

Initial model : Labelled Bounded Petri Net

A DES is modelled here as :

$$S = \langle P, T, A, \ell, \Sigma, M_0 \rangle$$

- $\langle P, T, A, M_0 \rangle$ is a marked Petri net ;
- Σ is the set of transition labels ;
- $\ell : T \rightarrow \Sigma$ is the label mapping.



Diagnosis problem

- S be a model of a discrete event system,
- $\sigma = \sigma'.o, \sigma' \in \Sigma_o^*, o \in \Sigma_o$ be an observable sequence of the system,
- the diagnosis of σ in S, denoted $\Delta(S, \sigma)$ is the maximal set $\{(M_1, F_1), \dots, (M_n, F_n)\}$ such that :
  1. if σ is empty, $\Delta(S, \sigma) = \{(M_0, \varnothing)\}$;
  2. if σ is not empty, then for any $i \in \{1, \dots, n\}$ there exists at least a firable sequence

     $$M_o \xrightarrow{t_{1i}} \cdots \xrightarrow{t_{ki}} M_i$$

     such that

     $$\bigcup_{j=1}^{k} \ell(t_{ji}) \cap \Sigma_f = F_i$$

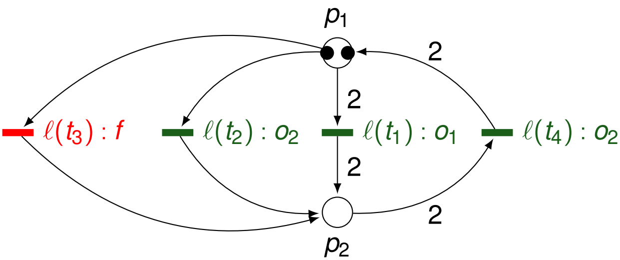
     and

     $$\mathbb{P}(\ell(t_{1i}).\ell(t_{2i}) \dots \ell(t_{ki})) = \sigma$$

     with $\ell(t_{ki}) = o$.

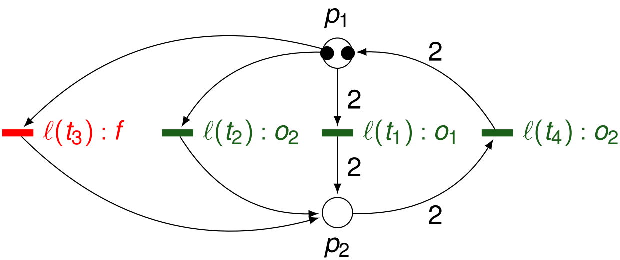
This problem is equivalent to the one of [Sampath 1995] but based on
nded Petri nets.

Examples



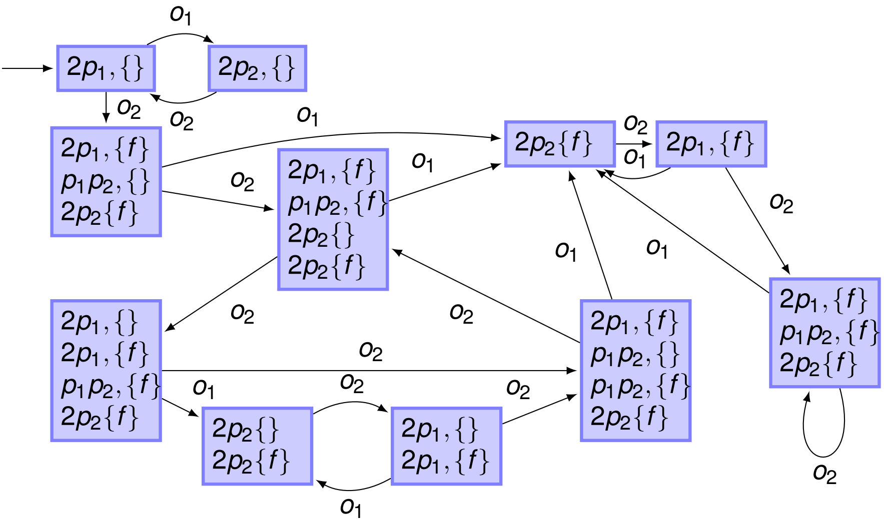
- $\Delta(S, \varepsilon) = \{(2p_1, \emptyset)\}$,
- $\Delta(S, o_1) = \{(2p_2, \emptyset)\}$,
- $\Delta(S, o_2 o_2) = \{(2p_2, \{f\}), (2p_2, \emptyset), (2p_1, \{f\}), (p_1 p_2, \{f\})\}$.

Examples : extended version



- $\Delta^+(S, \varepsilon) = \{(2p_1, \emptyset), (p1p2, \{f\}), (2p2, \{f\}\},$
- $\Delta^+(S, o_1) = \{(2p_2, \emptyset)\},$
- $\Delta^+(S, o_2 o_2) = \{(2p_2, \{f\}), (2p_2, \emptyset), (2p_1, \{f\}), (p_1 p_2, \{f\})\}.$

Classical diagnoser [Sampath 95]



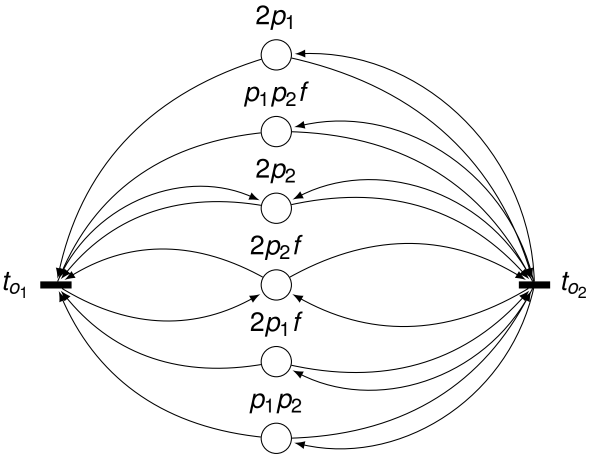
How to get a proper Petri-net diagnoser ?

- Classical diagnoser : a deterministic automaton based on the reachable marking graph of the model. Combinatorial Explosion.
- Petri-diagnoser :
  - is it possible to design a proper Petri net that solves the diagnosis problem
  - as precise as the Sampath's diagnoser (belief state + possible faults)
  - as efficient as the Sampath's diagnoser (one observable = one triggering of transitions)

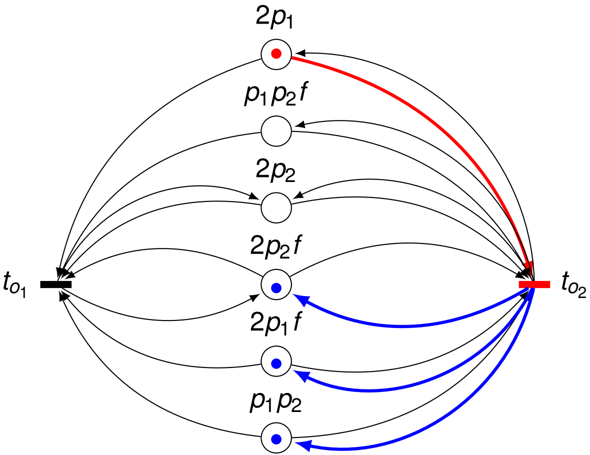
Our proposal : a CPN diagnoser

- one place = one diagnosis candidate (belief state + faults)
- one structural transition = one observation type
- colours : encoding of belief state transitions

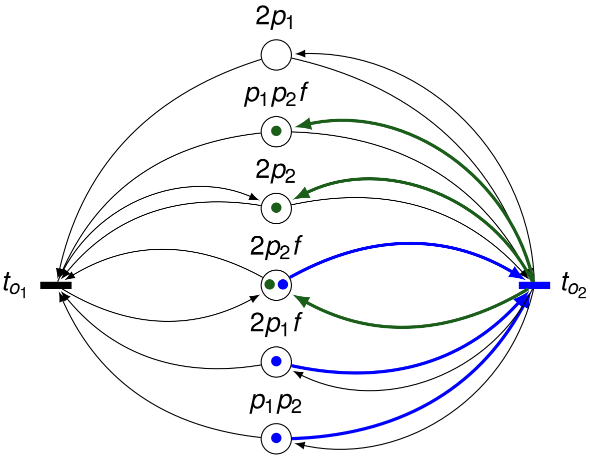
Equivalent Coloured diagnoser



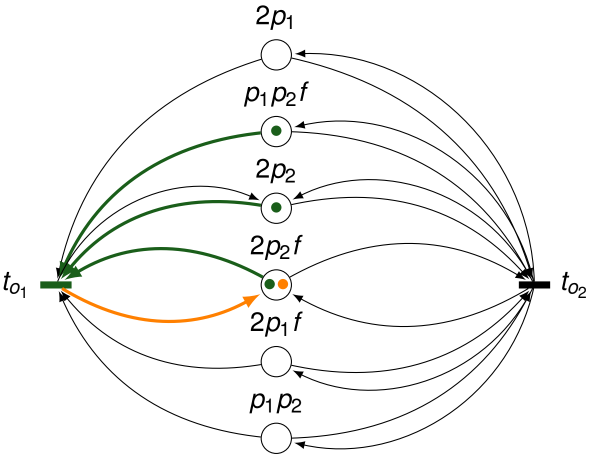
Coloured diagnoser



Coloured diagnoser



Coloured diagnoser



Comparative analysis

- The coloured diagnoser solves the same problem as the classical diagnoser with same efficiency
- Graphical viewpoint :

	Classical	Coloured
state representation :	$o(2^{2^{\|P\|}\times 2^{\|\Sigma_f\|}})$	$o(2^{\|P\|} \times 2^{\|\Sigma_f\|})$ + colours
transition representation :	$o(2^{2^{\|P\|}\times 2^{\|\Sigma_f\|}})$	$o(2^{\|P\|} \times 2^{\|\Sigma_f\|})$

- Colours : $o(2^{2^{|P|}\times 2^{|\Sigma_f|}})$.

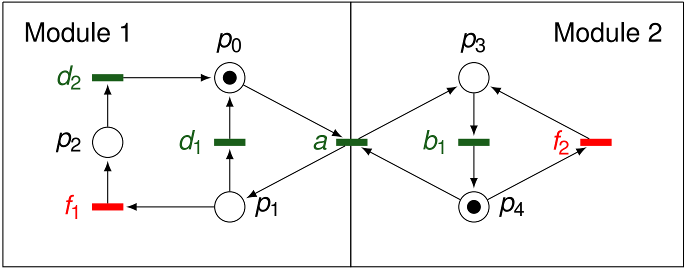
Application : modular diagnosis problem

- Modular diagnosis :
  - determine the module belief state + module faults
  - for each module
  - the module diagnosis must be globally consistent
- Usually solved with a set of automata (modular diagnosers)
- Proposal : Implementation of the modular diagnosis problem with ONE CPN

Notion of modules

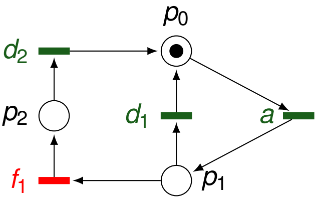
- subset of places and transitions (usually a component or a set of components)
- shared resources : transitions only (event synchronisation, communication)
- Assumption here : shared transitions are observable (to get global-consistency [Pencolé SAFE06] for free)
- Sound decomposition of the Petri model : set of modules

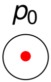
Modular system



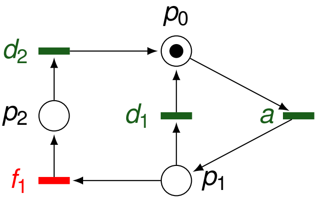
Sound decomposition

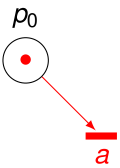
Modular diagnoser, module 1



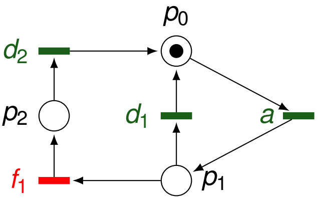


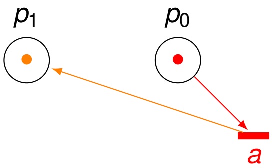
Modular diagnoser, module 1



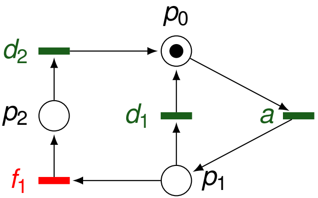


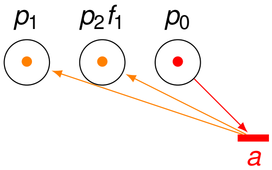
Modular diagnoser, module 1



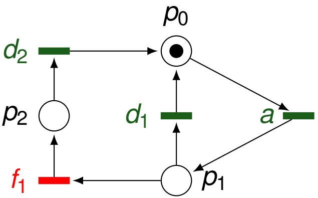


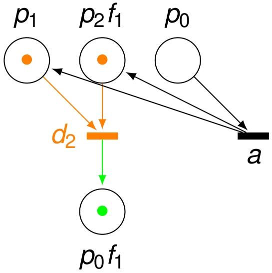
Modular diagnoser, module 1



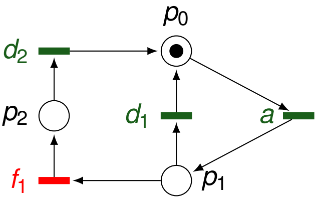


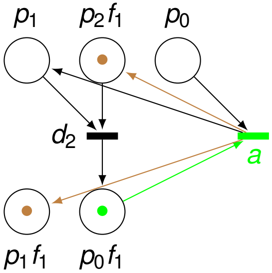
Modular diagnoser, module 1



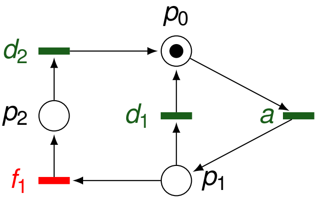


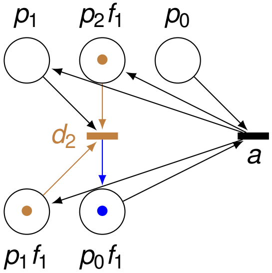
Modular diagnoser, module 1



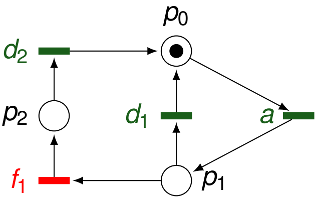


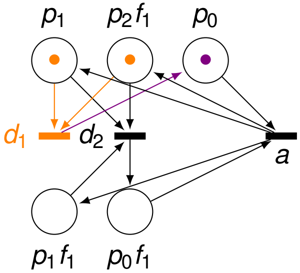
Modular diagnoser, module 1



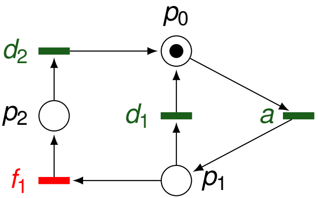


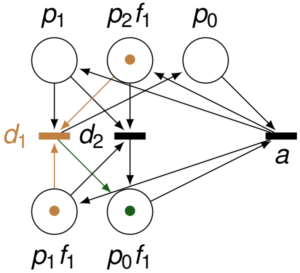
Modular diagnoser, module 1



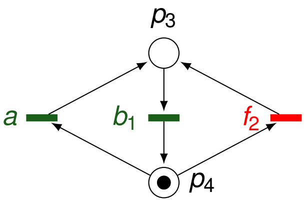


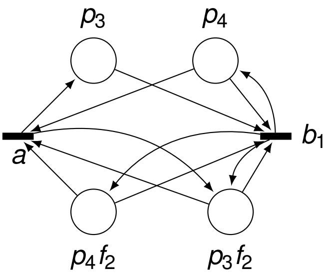
Modular diagnoser, module 1



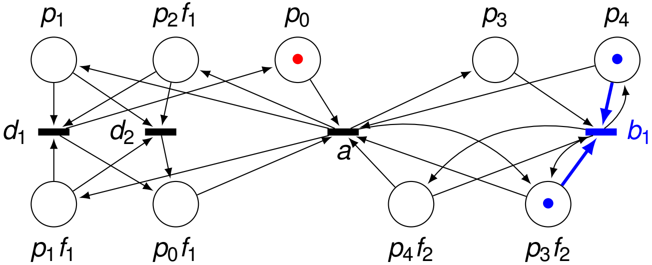


Modular diagnoser, module 2





Modular coloured diagnoser



$$\Delta^+(S,\varepsilon) = \{(p_0 p_4), (p_0 p_3, f_2)\}$$

$$\Delta_M(S,\varepsilon) = \Delta^+(S_1) = \{(p_0)\} \wedge \Delta^+(S_2) = \{(p_4), (p_3, f_2)\}$$

New observation : b_1 ?

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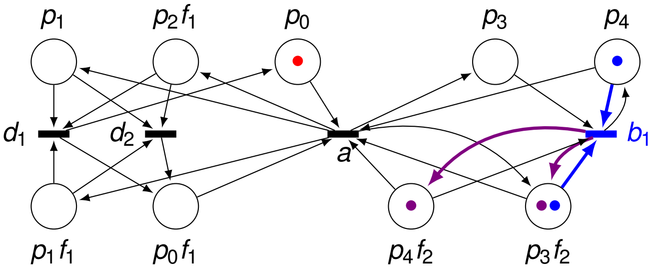
Modular coloured diagnoser

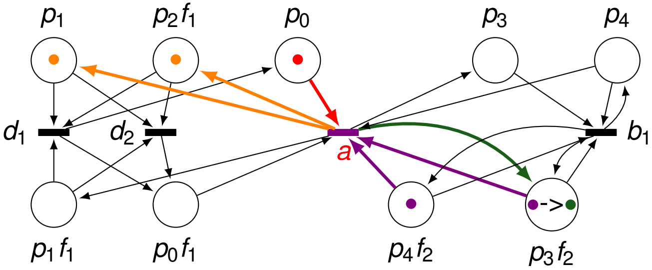


Observation : b_1

$$\Delta^+(S, b_1) = \{(p_0 p_4, f_2), (p_0 p_3, f_2)\}$$

$$\Delta_M(S, b_1) = \Delta^+(S_1) = \{(p_0)\} \wedge \Delta^+(S_2) = \{(p_4, f_2), (p_3, f_2)\}$$

Modular coloured diagnoser



Observation : b_1 followed by a

$$\Delta^+(S, b_1 a) = \{(p_1 p_3, f_2), (p_2 p_3, f_1 f_2)\}$$

$$\Delta_M(S, b_1 a) = \Delta^+(S_1) = \{(p_1), (p_2, f_1)\} \wedge \Delta^+(S_2) = \{(p_3, f_2)\}$$

Conclusion

- Design of a CPN diagnoser
- as precise, complete as the Sampath's diagnoser
- but it is still a Petri-net and can be used as it
- definitely smaller in terms of place and transition (graphical viewpoint)
- as an application, modular diagnosis system
- just by synchronising shared observable transitions
- some perspectives :
  - coordination protocols [Debouk00] with CPN diagnosers.
  - discriminability analysis of the CPN net structure.
  - problem abstractions
  - deploying and embedding on hardwares (micro-controllers...)