Random generator of k-diagnosable discrete event systems

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Introduction

- Classical problem of fault diagnosis of discrete event systems
- Need of independent discrete event system benchmarks
  - For testing diagnosis algorithms
  - For testing diagnosability algorithms
- Two types of benchmarks (see SAT community)
  - Real-world benchmarks
    - Pros : validate an algorithm on a real case
    - Cons : are they really real ? hard to get (industry) ? hard to show (confidentiality) ?
  - Random benchmarks
    - Pros : as many as we like, parametrized
    - Cons : how far it is from real case ? any uncontrolled bias ? does not valid any real-world solution
- Question : is it better to have an algorithm that solves one real case (and only one) or to have an algorithm that solves many random non-real problems ?

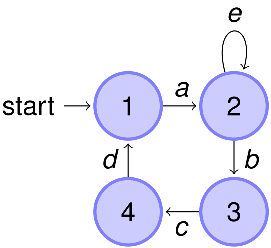
Motivation for this work

- Creation of random DES benckmarks with the help of a specific software
- The generated DES are *diagnosable*.
- Why diagnosability :
  - Worst-case of a diagnosability checker is usually when a system is diagnosable
  - Some diagnosis algorithms require that the system is diagnosable
- Identification of parameters of systems that have influence on the complexity of the algorithms to validate
- Looking at diagnosability from a different viewpoint :
  - usually, a checker looks for the reason why a system is not diagnosable
  - here, we look at the reasons why a system is diagnosable.

DES Model : finite state automaton

$\mathrm{SD} = (Q, \Sigma, T, q_0)$ where :

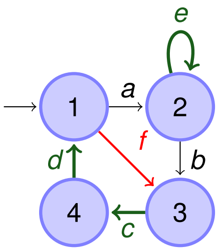
- Q is a finite set of states ;
- Σ is a finite set of events ;
- $T \subseteq Q \times T \times Q$ is a finite set of transitions ;
- q_0 is the initial state of the system.



Diagnosis problem and solution

- Observable events Σ_o, Unobservable events Σ_{uo}, $\Sigma = \Sigma_o \oplus \Sigma_{uo}$
- Fault : a non-observable event $f \in \Sigma$
- Observations OBS : a sequence σ of observable events
- Diagnosis problem : $(\mathrm{SD}, \mathrm{OBS}, \mathrm{FAULTS})$

  Find the set of active faults $F \subseteq \mathrm{FAULTS}$ that could have occurred in the system based on the model SD and the observations OBS.



$$\Delta(eee) = \{\varnothing\}$$
$$\Delta(ec) = \{\varnothing\}$$
$$\Delta(cdc) = \{\{f\}, \varnothing\}$$

Diagnosability

- f is diagnosable in a system S if :

$$\exists n \in \mathbb{N}^+, \mathit{Diagnosable}(n)$$

where $\mathit{Diagnosable}(n)$ stands for :

$$\begin{gathered}\forall \tau_1.f \in \mathscr{L}(S), \forall \tau_2 : \tau_1.f.\tau_2 \in \mathscr{L}(S) \\ |P_{\Sigma_o}(\tau_2)| \geq n \Rightarrow \\ (\forall \tau \in \mathscr{L}(S), (P_{\Sigma_o}(\tau) = P_{\Sigma_o}(\tau_1.f.\tau_2) \Rightarrow f \in \tau)).\end{gathered}$$

Intuition : once f has occurred, the next n observable events are always sufficient to diagnose f with certainty :

$$\Delta(P_{\Sigma_o}(\tau_1.f)P_{\Sigma_o}(\tau_2)) = \{F_1, F_2, \ldots, F_n\}, f \in F_i$$

k-Diagnosability

A fault f is k-diagnosable if :

$$Diagnosable(k) \wedge \neg Diagnosable(k-1)$$

k is the minimal number of observable events after the occurrence of a fault that are always sufficient to diagnose f with certainty.

- k-diagnosable $\Rightarrow$ diagnosable
- diagnosable $\Rightarrow \exists k$, k-diagnosable

This k is a property of the system.

Objectives of the proposed generator

- Random generation of k-diagnosable models
  - for a given k.
  - for a given number of states n.
  - for a given maximal state output degree deg
  - deterministic models

Generation based on the notion of fault signature.

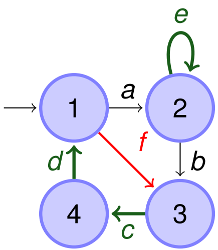
Signatures

- The signature of an event f into a system S is the language $Sig(f) \subseteq \Sigma_o^\star$ such that

$$Sig(f) = \{\sigma_\tau | \tau = \tau_1.o.\tau_2 \in \mathscr{L}(S), f \in \tau_1, o \in \Sigma_o, \tau_2 \in \Sigma^\star, \sigma_\tau = P_{\Sigma_o}(\tau)\}$$

- The signature of the absence of f into a system S is the language $Sig(\neg f) \subseteq \Sigma_o^\star$ such that

$$Sig(\neg f) = \{\sigma_\tau | \tau = \tau_1.o \in \mathscr{L}(S), f \notin \tau_1, o \in \Sigma_o, \sigma_\tau = P_{\Sigma_o}(\tau)\}$$



$Sig(f) =$
$\{c, cde^*, cde^*c, cd(e^*cd)^+, cd(e^*cd)^+c\}$

$Sig(\neg f) = \{e, e^*c, (e^*cd)^+, (e^*cd)^+e^*c\}$

Ambiguous signatures

- Any observable trace σ that belongs to $Sig(f)$ AND $Sig(\neg f)$ is ambiguous

$$\forall \sigma \in Sig(f) \cap Sig(\neg f), \Delta(\sigma) \text{ is ambiguous.}$$

- To be diagnosable, the number of observable continuations of an observable ambiguous trace must be finite
- Twin-plant method : checking whether there exists in $Sig(f) \cap Sig(\neg f)$ an unbounded continuation of an observable trace $\sigma \in Sig(f) \cap Sig(\neg f)$.
- To be k-diagnosable, for any $\sigma \in Sig(f) \cap Sig(\neg f)$:
  - for any $\sigma \in Sig(f) \cap Sig(\neg f)$, any continuation σ' of σ such that $\sigma\sigma' \in Sig(f) \cap Sig(\neg f)$ must be such that :

$$|\sigma\sigma'| - |\sigma| \leq k - 1$$

  - there exists at least a couple σ, σ' such that

$$|\sigma\sigma'| - |\sigma| = k - 1$$

Principle of the benchmark generator

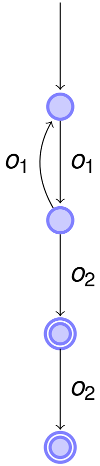
Given *n* a number of states, *k* parameter, *deg* allowed number of output transitions

1. Computation of a random ambiguous signature *AmbSig*
2. Parsing of the ambiguous signature and random generation of the system.

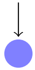
Example : Ambiguous signature

Very simple example :

$$Sig(f) \cap Sig(\neg f) = \{o_1 o_2,\ o_1 o_2 o_2,\ o_1 o_1 o_1 o_2,\ o_1 o_1 o_1 o_2 o_2, \ldots\}$$



Example : Generated system



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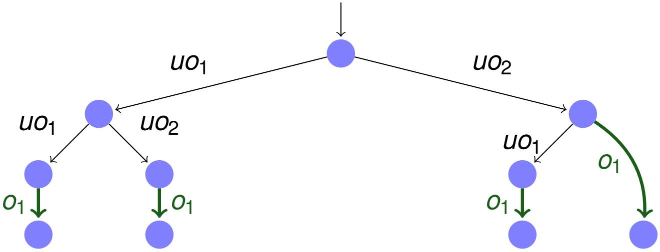

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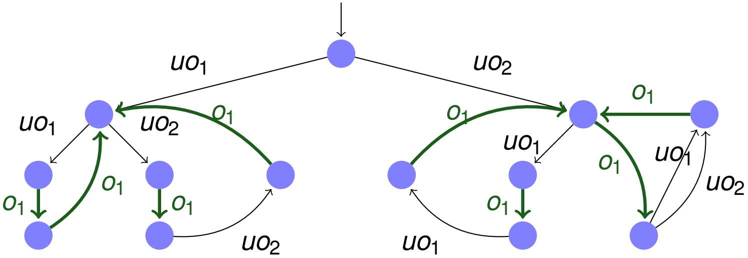

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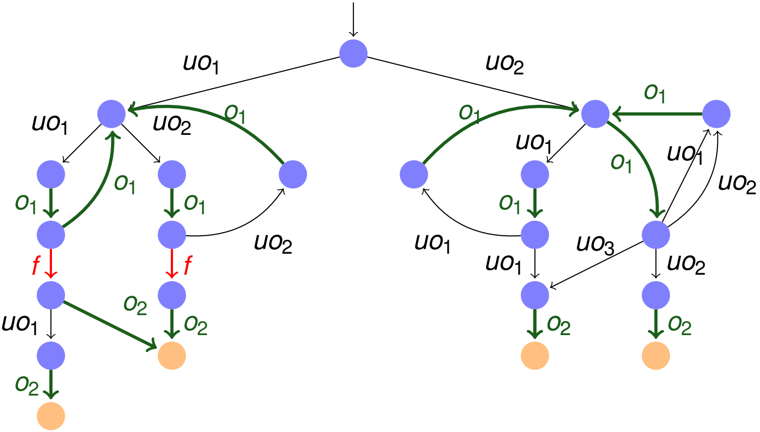

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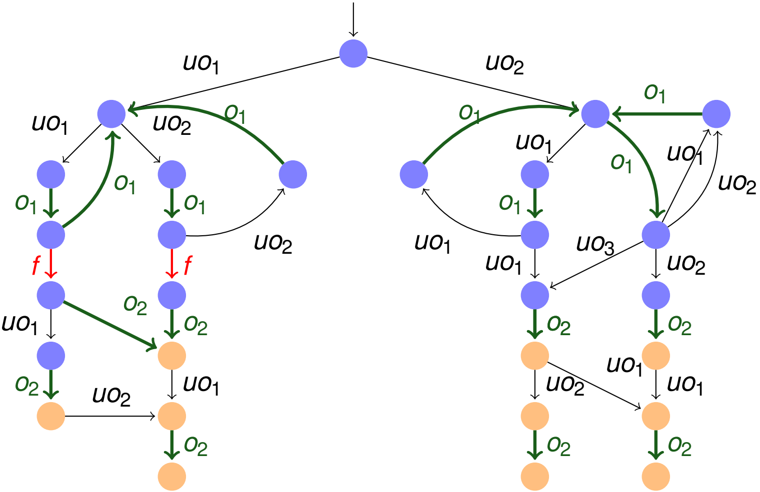

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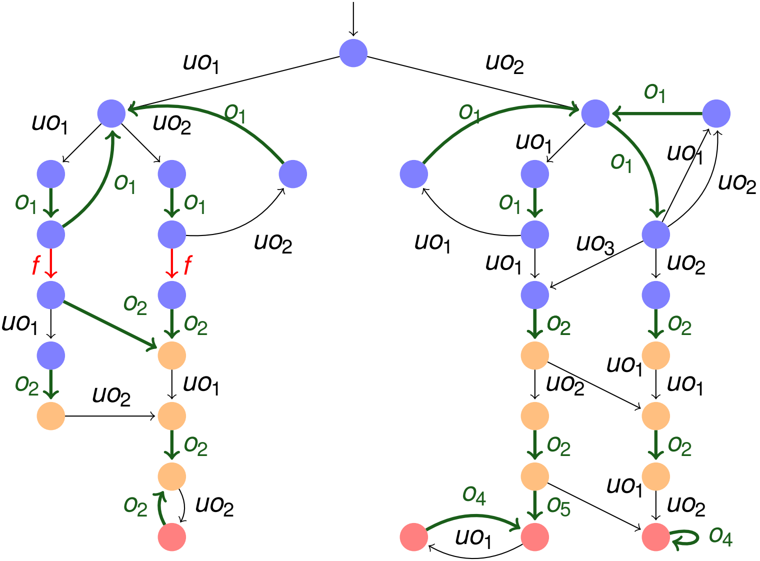

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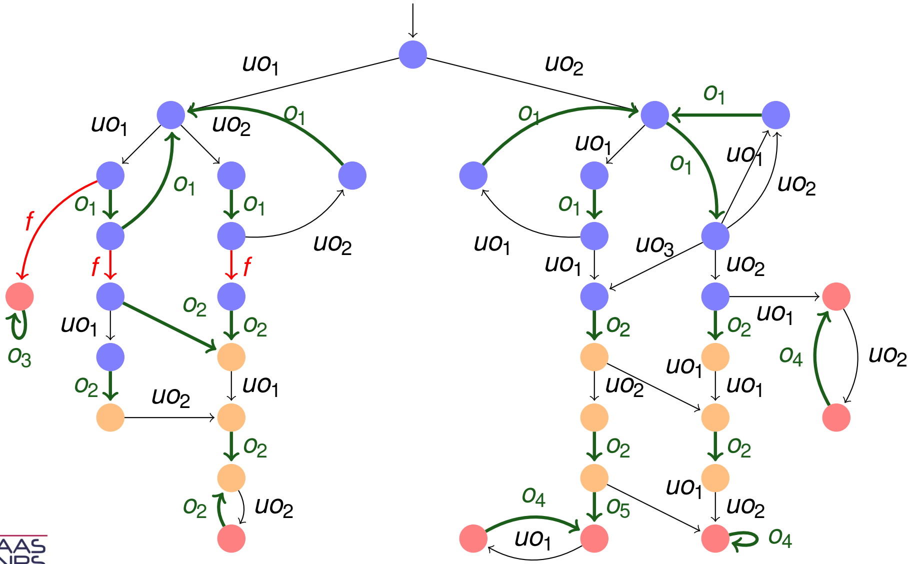

Analysis of the generated system

- By construction, the signature of f is :
  - $(o_1 o_1)^* o_3^+$
  - $o_1 (o_1 o_1)^* o_2$
  - $o_1 (o_1 o_1)^* o_2 o_2$
  - $o_1 (o_1 o_1)^* o_2 o_2 o_2^+$
- By construction, the signature of $\neg f$ is :
  - o_1^+
  - $o_1 (o_1 o_1)^* o_4^+$
  - $o_1 (o_1 o_1)^* o_2$
  - $o_1 (o_1 o_1)^* o_2 o_2$
  - $o_1 (o_1 o_1)^* o_2 o_2 (o_5 o_4^* + o_4^+)$

Analysis of the generated system

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  - $o_1(o_1 o_1)^* o_2$
  - $o_1(o_1 o_1)^* o_2 o_2$
  - $o_1(o_1 o_1)^* o_2 o_2 (o_5 o_4^* + o_4^+)$

Ambiguous signature :

$$Sig(f) \cap Sig(\neg f) = o_1(o_1 o_1)^* o_2 + o_1(o_1 o_1)^* o_2 o_2$$

Analysis of the generated system (2)

Ambiguous signature :

$$Sig(f) \cap Sig(\neg f) = o_1(o_1 o_1)^* o_2 + o_1(o_1 o_1)^* o_2 o_2$$

- $\neg f$-certainty as long as we see $o_1(o_1 o_1)^*$.
- f-certainty as soon as o_3 occurs after $o_1(o_1 o_1)^*$.
- f-ambiguity as soon as o_2 occurs after $o_1(o_1 o_1)^*$
- still f-ambiguity if another o_2 occurs after $o_1(o_1 o_1)^* o_2$
- f-certainty as soon as a 3rd o_2 occurs after $o_1(o_1 o_1)^* o_2 o_2$.
- $\neg f$-certainty is any other case

So f is 3-diagnosable.

Implementation

- Generator, part of the toolset :

  DiaDes : diagnosis of discrete event systems
- UNIX command line program : `dd-diagnosable-system-generator`
- Pure C++ implementation (C++11)

Command line

```
./dd-new-diagnosable-des-generate --help
Diades: generator of diagnosable discrete event systems

Allowed options:
  --help
  --states arg (still experimental)
  --observables arg
  --unobservables arg
  --output_degree arg
  --k arg
  --min_observable_ambiguity arg
  --ambiguity_ratio arg
  --seed arg
```

Some available benchmarks

A set of benchmarks already generated :
`http://homepages.laas.fr/ypencole/benchmarks`

- From 100-states systems to 200 000-states systems
- From $k = 1$ to $k = 5000$
- From $deg = 3$ to $deg = 100$
- At present, only `des_comp` format
- More benchmarks will be generated
- Any idea of other parameters to control ?

Perspectives

- Better control of the number of states
- Performance improvements
- Generation of component-based diagnosable system
- Automatic generation of diagnosis scenarios