Diagnosis (07)

Introduction to Discrete Event Systems

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1. Modelling the System by Finite State Machines
2. Other Formalisms
3. Diagnosis

1 Modelling the System by Finite State Machines

2 Other Formalisms

3 Diagnosis

Finite State Machine

Definition

A Finite State Machine is an oriented graph with a (set of) initial state(s).

Formally $\langle Q, E, T, I \rangle$:

- Q is the set of nodes
- E is the set of transition labels
- $T : Q \times E \times Q$ is the set of transitions
- $I \subseteq Q$ is the set of initial nodes (often, $\mid I \mid = 1$)

Equivalence: FSM = automaton

FSM to Model a System

A system can be modelled by an FSM $\rightarrow$ discrete event system.

- a node of the FSM represents a state of the system
- a transition between two nodes represents the evolution of the state of the system
- the label of a transition represents the event(s) that modified the state of the system (or that is/are consequence(s) or the modification of the state)
- the initial states represents the possible state at the beginning of the diagnosis

Dynamics

- Time Driven Systems
- Event Driven Systems

Observations

- Partial observation of the state ([Largouët & Cordier, DX 2001])
- Generally, observation of the transitions
  - Viewer [Lamperti & Zanella, 2003]: $T \rightarrow O \cup \{NonObs\}$
  - Generally, simplified: $O \subseteq E$

Faulty Behaviours

What we want to detect

- Is the current state faulty $s \in F \subseteq Q$?
- Did the faulty event $f \in F \subseteq E$ occur ?
- Was the faulty transition $t \in F \subseteq T$ triggered ?
  Lamperti & Zanella's ruler
- Did the faulty behaviour represented by the specified automaton A occur ?

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STRIPS-like representation

Definition

$\langle V, E, R, I \rangle$

- V is a set of Boolean variables and I an assignment of the variables,
- E is a set of events, and
- R is a set of rules (precondition + effects).

A state is an assignment $S : V \rightarrow \{0, 1\}$.
A STRIPS-like representation can be easily translated into an automaton.
Existing algorithm do not take benefit from such a representation.

Petri Nets

Definition

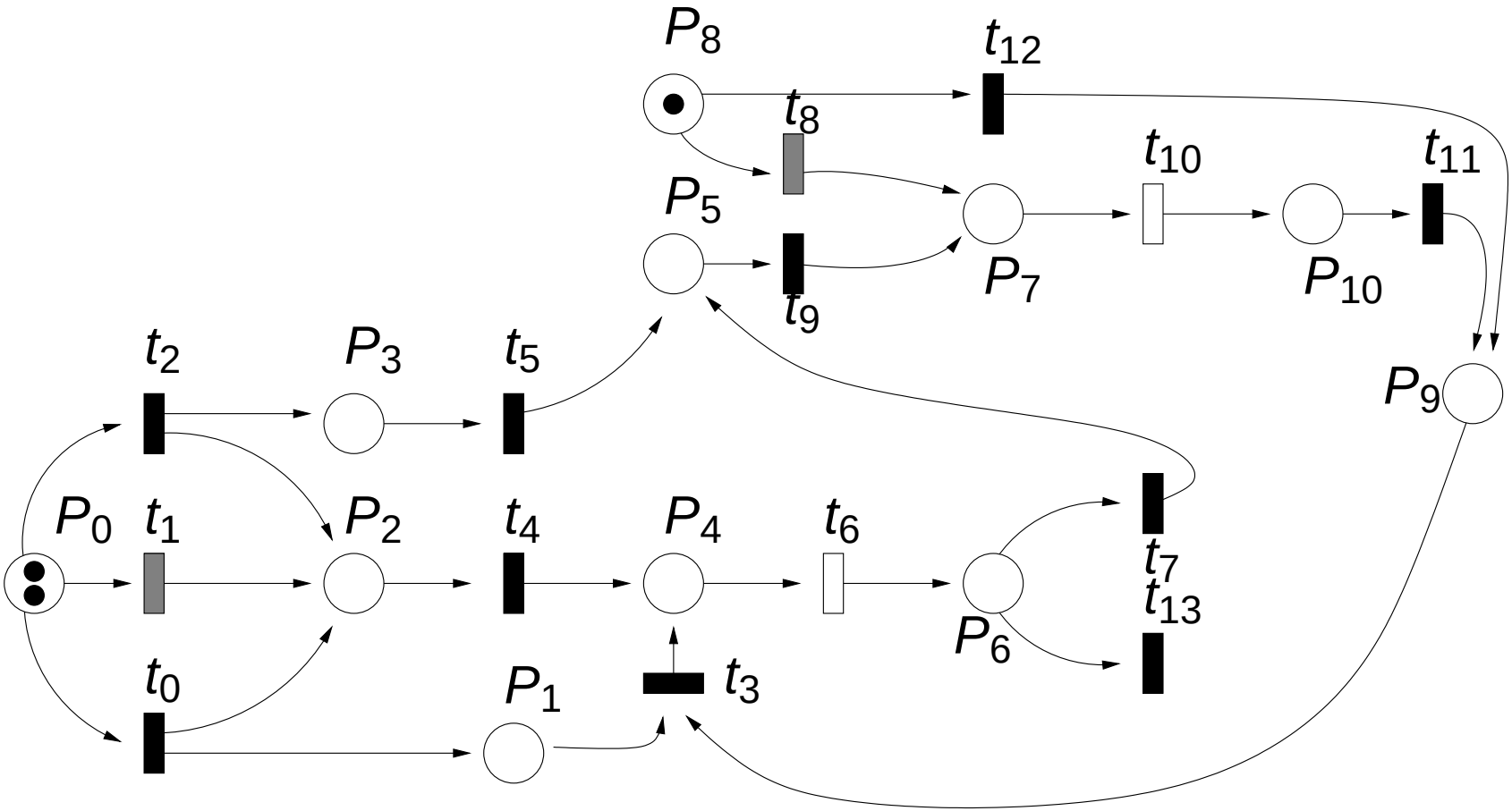
"Petri Nets: Properties, Analysis and Applications" [Tadao Murata, 89]

$PN = (P, T, F, W, M_0)$:

- P is a set of places,
- T is a set of transition so that $P \cap T = \emptyset$,
- $F \subseteq (P \times T) \cup (T \times P)$ is the set of arcs,
- $W : F \times \mathbf{N}^+$ is a weighting function, and
- $M_0 : P \rightarrow \mathbf{N}$ is the initial marking.

A state is a marquing $M : P \rightarrow \mathbf{N}$

Petri Nets – Example



Advantages – Drawbacks

- Compact: the size of an equivalent automaton has an exponential number of states
- Same expressivness as automata
- Very efficient to model flow of resources
- Dedicated algorithms (unfolding)

- However, it is often required to use methods equivalent to automata

- R. Boël, A. Benveniste

Languages

- Given an alphabet Σ, a language is a set of words: $\mathcal{L} \subseteq \Sigma^*$.
- A word $s \in \mathcal{L}$ represents a possible evolution of the system.
- The language is prefix-closed.
- A language is more expressiv than an automaton.

- . . . but a language is actually generally represented by an automaton.

Temporal Aspects

Timed Automata [Alur, 1992]

- A set of clocks is associated with the system.
- A state of the system is modelled by a state of the automaton + an assignment in $\mathbf{R}^+$ of all the clocks.
- Transitions and states are guarded by conditions on the clocks.
- Clocks can be reset on transitions.
- A (non empty) amount of time slip by between two transitions.

Manipulation Timed Automata

- Basically identical to classical automata (but more complex)
- Notion of clock regions
- Difference Bound Matrices

Automata with Parameters

- Similar to timed automata
- A set of variables is associated with the system.
- A state of the system is modelled by a state of the automaton + an assignment of all the variables.
- Transitions (not states) are guarded by conditions on the variables.
- The value of the variables can be modified by transitions.

Manipulating these Automata

- Identical to classical automata (this is only a compact representation).

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Simplifying Hypotheses

- The model is an automaton.
- The transitions are labeled by a single event.
- Some events are observable: $O \subseteq E$; the number of unobserved transitions trigerred is not known.
- Some events are faulty: $F = F_1 \uplus \cdots \uplus F_f \subseteq E$.
- The observations are received in the order they are emitted.

Diagnosis

- Given the model
- Given a flow of observations
- What possible fault modes did occur ?

Sampath Diagnoser

Sampath et al. 1996

- Off-line compilation of the model
- A state of the Sampath diagnoser is a set of pairs $\langle s, fm \rangle$ where
  - s is a state of the system
  - $fm \subseteq \{F_1, \ldots, F_f\}$ is a fault mode
- The semantics of $\{\langle s_1, fm_1 \rangle, \langle s_2, fm_2 \rangle, \langle s_3, fm_3 \rangle, \langle s_4, fm_4 \rangle, \langle s_5, fm_5 \rangle\}$ is that
  - the state after the last observation is s_1 and the set of faults that occurred is fm_1, or
  - the state after the last observation is s_2 and the set of faults that occurred is fm_2, or
  - etc.

Using a Diagnoser

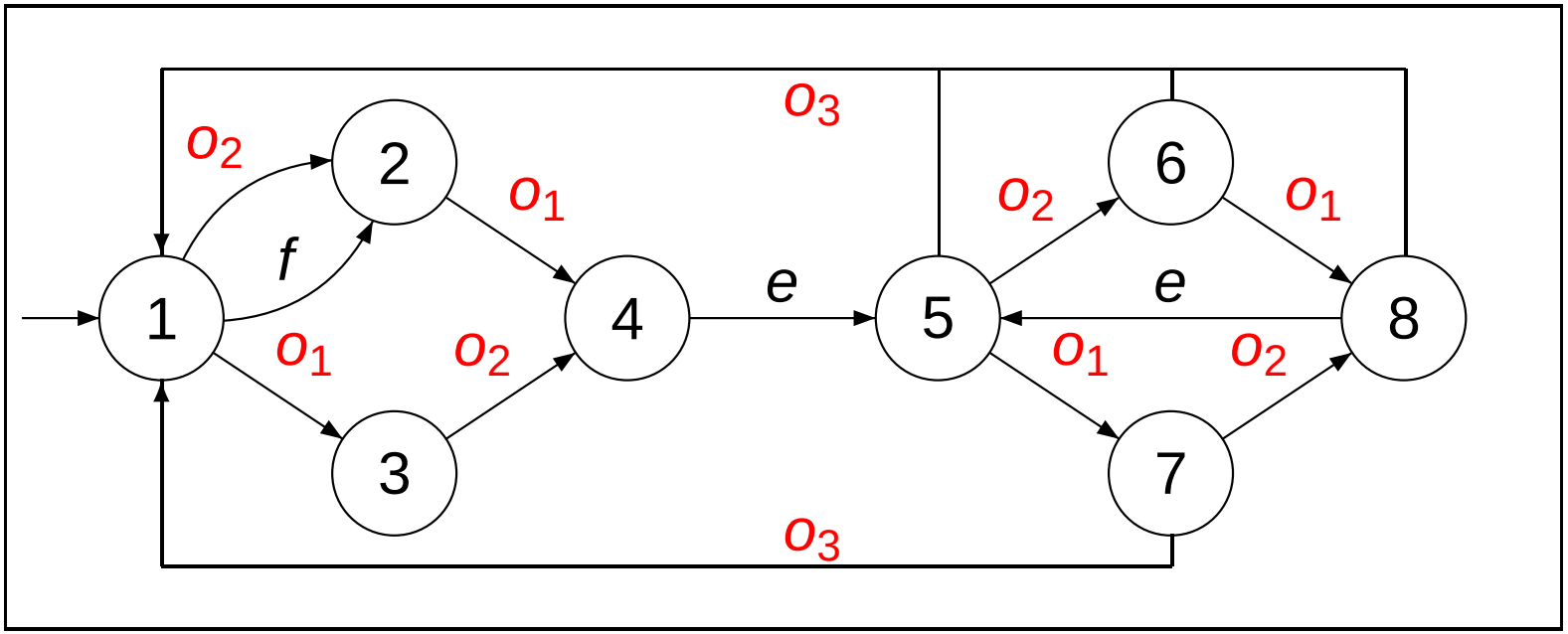
Construction of the Diagnoser

- The initial state of the Sampath diagnoser is $\{\langle s_0, \emptyset \rangle\}$
- For each state $s = \{\langle s_1, fm_1 \rangle, \ldots, \langle s_k, fm_k \rangle\}$
  - For each observable event o
    - Add a transition between s and s' labeled by o where s' contains the set of pairs $\langle s'_j, fm'_j \rangle$ so that
    - there exists a path p label with unobservable events from a state s_i to a state s''
    - $fm'_j = fm_i \oplus p$ (the fault mode is the previous fault mode added with the faults in the path),
    - there exists a transition from s'' to s'_j labeled by o

Using the Diagnoser

Given the sequence of observation, simply follow the state in the diagnoser.

Example



Discussion

Advantages

- Fast: the complexity of the diagnosis task is linear in the number of observations and does not depend on the size of the system

Drawbacks

- The worst case size of the diagnoser is $2^{|Q| \times 2^f}$: for realistic real-world systems, this method cannot be applied
- The observation must be totally ordered, or the size of the diagnoser is even worst.

Improvements

- Specialised diagnosers (Y. Pencolé et al.)
- BDD (A. Schumann et al.)