Decentralized Diagnosis of Discrete Event Systems Using an Arborescent Architecture

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Outline

1. Introduction
   - Discrete event systems (DES)
   - Diagnosis

2. Decentralized diagnosis of DES
   - Principle
   - Basic decentralized diagnosers
   - Inference-based diagnosis

3. Arborescent architecture
   - Principle of diagnosis decomposition
   - Diagnosis tree
   - Example

4. Conclusion
   - Contribution
   - Future work
Discrete event systems
- described by possible sequences of discrete events
- modeled by finite state automata
Basics of diagnosis

**Input**
- **Plant**: DES with its *desired* and *undesired* behaviors
- **Specification**: *desired* part of the plant

```
1 --a--> 2 --b--> 3
    \sigma/    \sigma/  
     4        5
```

**Objective**: to detect *undesired* behaviors of the Plant
- detection must be done in a *bounded* future

**Approach**: Use of a diagnoser that
- Observes *partially* the behavior of the plant
- Tries to determine whether the plant is in its *desired* or *undesired* part
Decision computation, languages $\mathcal{F}$ and $\mathcal{H}$

The language of the plant is split into $\mathcal{F}$ and $\mathcal{H}$:
- $\mathcal{F}$ contains the undesired traces of the plant
- $\mathcal{H}$ contains the desired traces of the plant

**Example**: $\mathcal{F} = \{ab\sigma\}$ and $\mathcal{H} = \{a\sigma, ab\}$ for:

```
1 → a → 2 → b → 3
σ ↓ 4
```

The diagnoser observes the evolution of the plant and, after each observation, generates a decision 1, 0 or $\phi$:
- 1: the diagnoser is certain that the plant is in $\mathcal{F}$
- 0: the diagnoser is certain that the plant is in $\mathcal{H}$
- $\phi$: the diagnoser is unsure whether the plant is in $\mathcal{F}$ or $\mathcal{H}$
**Plant**: diagnosed by local diagnosers and a fusion module

**A local diagnoser** $D_i$, for each site $i$:
- makes local observations of events
- makes local decisions $(1, 0, \phi)$

**A fusion module** computes:
- a global decision $(1, 0, \phi) = \text{combination of all local decisions}$
**F-diagnoser**

**Local decision** of each $D_i$ is:
- 1, when it is certain that the plant is in $F$;
- 0, otherwise.

**Global decision** is disjunctive, i.e.:
- global decision $= \bigvee$ of all local decisions

**Intuition**: the plant is determined as nonfaulty when none of the local diagnosers is certain of faultiness

**Condition of applicability of F-diagnoser**
- $\bigcap_{i \in I} P_i^{-1} P_i(H) \cap F = \emptyset$
Local decision of each $D_i$ is:
- 0, when it is certain that the plant is in $\mathcal{H}$;
- 1, otherwise.

Global decision is conjunctive, i.e.:
- global decision $= \bigwedge$ of all local decisions

Intuition: the plant is determined as faulty when none of the local diagnosers is certain of non-faultiness

Condition of applicability of NF-diagnoser
- $\bigcap_{i \in I} P_i^{-1} P_i(\mathcal{F}) \cap \mathcal{H} = \emptyset$
Principle of inference-based diagnosis

**Local decisions:**
- Each local diagnoser $D_i$ computes:
  - a local decision $c_i$
  - an ambiguity level $n_i$
- Computation of $c_i$ and $n_i$ is:
  - quite complex and nonintuitive
  - based on iterative languages $\mathcal{F}[k]$ and $\mathcal{H}[k]$

**Global decision** =
- local decision with the smallest ambiguity level
Applicability of inference-based control

$\text{Inf}_N^\text{F}$-diagnosis denotes:
- Inference-based diagnosis s.t. $N$ is the maximum ambiguity level which is computed

Languages $\mathcal{F}[k]$ and $\mathcal{H}[k]$:
- Basis:
  - $\mathcal{F}[0] = \mathcal{F}$
  - $\mathcal{H}[0] = \mathcal{H}$
- Inductive step: for $k \geq 0$
  - $\mathcal{F}[k + 1] = \mathcal{F}[k] \cap \bigcap_{i \in I} P_i^{-1} P_i(\mathcal{H}[k])$
  - $\mathcal{H}[k + 1] = \mathcal{H}[k] \cap \bigcap_{i \in I} P_i^{-1} P_i(\mathcal{F}[k])$

Let $\mathcal{F}^m$ consisting of the traces of $\mathcal{F}$ that remain undesired even if we remove their last $m$ events

Condition of applicability of $\text{Inf}_N^\text{F}$-diagnosis
- $\exists m \geq 0$ s.t. $\mathcal{F}^m \cap \mathcal{F}[N + 1] = \emptyset$
Generality of inference-based diagnosis

- $\text{Inf}_{N+1}$-F-diagnosis is more general (i.e. applicable to more languages) than $\text{Inf}_N$-F-diagnosis
- $\text{Inf}_0$-F-diagnosis is the basic (and most restrictive) inference-based diagnosis
Step 1

Diagnosis of 
(F, H)

Diagnosis decision

Step 2k+2

Diagnosis of 
(F[2k+1], H[2k])

Diagnosis decision

Diagnosis of 
(F[2k+1] \ F[1], H)

Diagnosis decision

NF-diagnosis of 
(F[2k+1], H[2k] \ H[2k+2])

Diagnosis of 
(F[2k+1], H[2k+2])

Step 2k+3

Diagnosis of 
(F[2k+1], H[2k+2])

Diagnosis decision

F-diagnosis of 
(F[2k+1] \ F[2k+3], H[2k+2])

Diagnosis of 
(F[2k+3], H[2k+2])

Diagnosis decision

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Arborescent Decentralized Diagnosis of DES
Arborescent diagnosis of \((\mathcal{F}, \mathcal{H})\)

- F-diagnosis of \((F \setminus F[1], H)\)
- NF-diagnosis of \((F[1], H \setminus H[2])\)
- F-diagnosis of \((F[1] \setminus F[3], H[2])\)
- NF-diagnosis of \((F[3], H[2] \setminus H[4])\)
- ...
Example of arborescent diagnosis

Diagnosis of \((F, H)\)

- **F-diagnosis of** \((F \setminus F[1], H)\)
- **NF-diagnosis of** \((F[1], H \setminus H[2])\)
- **Inf\(_0\)-F-diagnosis of** \((F[1], H[2])\)

Diagnosis of \((F[1], H)\)
### Example of arborescent diagnosis

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<th>$P_1(\lambda)$</th>
<th>$P_2(\lambda)$</th>
<th>$X_1 \lor X_2 = X$</th>
<th>$Y_1 \land Y_2 = Y$</th>
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Arborescent Decentralized Diagnosis of DES 15/17
**Contribution**: We show that:

- Inference-based diagnosis $\equiv$ arborescent combination of basic diagnoses: F-diagnosers, NF-diagnosers, and 1 $\text{Inf}_0$-F-diagnosis
Future work:

- Study arborescent diagnosis when inference-based diagnosis is unapplicable (in progress)
- Apply arborescent diagnosis to real-life applications
- Adapt arborescent diagnosis to prognosis