Toward Computing Conflict-based Diagnoses in Probabilistic Logic Programming

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Introduction

Many human-created artifacts: most knowledge is about *normal* structure and behavior.

- Little or no knowledge is available about abnormalities.
- New systems.

Consistency-based diagnosis (CBD): malfunctioning is diagnosed mostly based on normal behavior.

- This differs from abductive diagnosis.
- SD (System Description) specifies normal behavior via logical formulas:

$$\neg \mathrm{Ab}(c) \rightarrow \mathsf{Behavior}(c)$$

- E.g. an OR-gate could behave as:

$$\neg \mathrm{Ab}(O) \rightarrow (\mathsf{In}_1(O, \mathit{true}) \rightarrow \mathsf{Out}(O, \mathit{true}))$$

Introduction

Consistency-based diagnosis (CBD):

- We are also given: observations OBS about inputs and outputs.
- We compute a **diagnosis** Δ: an assignment to each $\mathrm{Ab}(c)$ being *true* or *false*.
- **Our aim in CB diagnosis**: find Δ such that

$$\mathrm{SD} \cup \mathrm{OBS} \cup \Delta \not\models \perp$$

Δ should include the (subset-)minimal number of abnormalities.

However, there can be several candidate diagnoses.

- Probability theory has been used to *rank* diagnoses.
- **Bayesian diagnostic system** by Flesch & Lucas (2007): translated the notion of *data conflict* in Bayesian networks to probabilistic MBD.

Overview

- We generalize Bayesian diagnostic problems to probabilistic logic programs
    - enables combination of logics and probabilities for model-based diagnosis
    - allows better modeling of the structure of the diagnostic problem
- ProbLog is used to model the diagnostic problems.
- Properties of probabilistic-based diagnosis in this context are studied

Outline

1. Introduction
2. Bayesian diagnostic system
3. Diagnoses in PLP
4. Diagnoses with incomplete observations
5. Conclusions

Setting

From logical approach to probabilistic approach:

- All atoms are modeled as random variables
- We observe random variables $\Omega = \{\text{inputs and outputs}\}$.
- **Probabilistic model-based diagnosis**: we assign a probability to diagnosis candidate Δ:

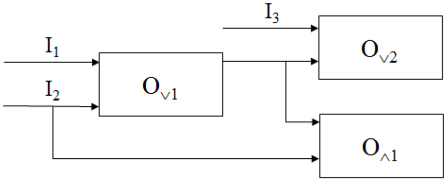
$$P(\Omega \mid \Delta)$$

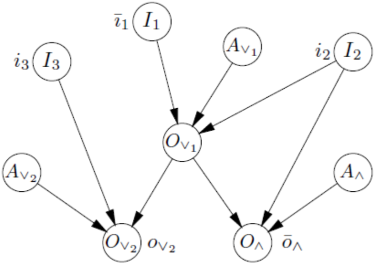
- $P(\Omega \mid \Delta)$: how likely is to obtain the observations if Δ is assumed.

Bayesian diagnostic system - Flesch & Lucas (2007)

- Bayesian network represents the SD (system description).
- Implications are modeled by direct relationships in the network
- Outputs depend on inputs and abnormality variables

Example - Bayesian diagnostic system





General assumptions

- Assumption 1: component has *deterministic* behavior if it is **not abnormal**.
- Assumption 2: component has *probabilistic* behavior if it is **abnormal**. The output does not depend on the inputs anymore.

Conflict measure in diagnosis

Logical consistency and conflict-based consistency

- If diagnosis Δ is logically consistent, we know that it is also P-consistent

$$P(\Omega \mid \Delta) \neq 0 \text{ iff } \mathrm{SD} \cup \mathrm{OBS} \cup \Delta \not\models \bot$$

- Can we say more about $P(\Omega \mid \Delta)$ in these cases?

Flesch & Lucas (2007) proposed the notion of **conflict-based diagnosis**.

- Intuition: measure how much related are I and O under Δ.

$$conf_{\Delta}(\Omega) = \log \frac{P(I \mid \Delta)P(O \mid \Delta)}{P(I, O \mid \Delta)}$$

- If $conf_{\Delta} > 0$: I and O are "conflicting".
- If $conf_{\Delta} \leq 0$: Δ is called conflict-based diagnosis.

Modeling in ProbLog

We represent a Bayesian diagnostic system as a ProbLog program.

Example 1

```
0.1::ab(C).
0.5::in1(C,true) ; 0.5::in1(C,false).
0.5::in2(C,true) ; 0.5::in2(C,false).

0.5::out(C, true) ; 0.5::out(C,false) :- ab(C).

out(o1, true)  :- \+ ab(o1), (in1(o1, true) ; in2(o1,true)).
out(o1, false) :- \+ ab(o1), in1(o1,false), in2(o1, false).

out(a1, true)  :- \+ ab(a1), in1(a1, true), out(o1, true).
out(a1, false) :- \+ ab(a1), (in1(a1, false) ; out(o1,false)).
```

Advantage is specifying *local* logical structure directly (as opposed to encode this in CPTs of Bayesian networks).

Basic properties

Property 1

There is a conflict-based diagnosis (i.e. $conf_\Delta \leq 0$) for any given diagnostic PLP and set of observations.

This is the trivial diagnosis: all components are assumed abnormal (thus, $conf_\Delta = 0$)

Now, let us assume **complete observations**, i.e., all inputs and outputs are known.

Property 2 (sketch)

If Δ is consistency-based diagnosis, then it is conflict-based.

Intuitively, this means that if Δ is a consistency-based diagnosis, then $P(I, O \mid \Delta)$ is at least $P(I \mid \Delta) \times P(O \mid \Delta)$.

Basic properties (cont.)

Property 3 (sketch)

Explanations of inputs and outputs (as given in ProbLog) directly provide consistency-based diagnoses, and therefore conflict-based diagnoses.

Hence, no probabilistic reasoning is necessary.

Example 2

```
0.1::ab(C).
0.5::in1(C,true) ; 0.5::in1(C,false).
0.5::in2(C,true) ; 0.5::in2(C,false).
0.5::out(C, true) ; 0.5::out(C,false) :- ab(C).

out(o1, true)  :- \+ ab(o1), (in1(o1, true) ; in2(o1,true)).
out(o1, false) :- \+ ab(o1), in1(o1,false), in2(o1, false).
```

Consider $\Omega = \{\texttt{in1(o1, false)}, \texttt{in2(o1, false)}, \texttt{out(o1, true)}\}$
$\Delta = \{\texttt{\textbackslash+ ab(o1)}\}$ is not consistency-based, thus it cannot be conflict-based.
In contrast, $\Delta' = \{\texttt{ab(o1)}\}$ is consistency-based and thus conflict-based.

Incomplete observations

Here, logical consistency does **not** imply a conflict-based diagnosis.

Example 3

Consider the OR-gate example with $\Omega = \{\texttt{in(o1, false)}, \texttt{out(o1, true)}\}$.
$\Delta = \{\texttt{\textbackslash+ ab(o1)}\}$ **is** consistency-based. However, Δ **is not** conflict-based.

$$P(I \mid \Delta) = 0.5$$
$$P(O \mid \Delta) = 0.75$$
$$P(I, O \mid \Delta) = 0.25$$

Hence, $\mathrm{conf}_{\Delta}(\Omega) \simeq 0.18$.

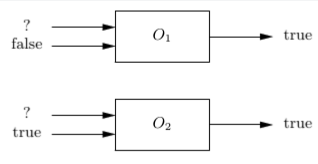
Incomplete observations

Again, explanations can be used to identify malfunctioning components

Property 4 (sketch)

If, assuming some component is abnormal reduces the conflict (then it is not the case that the observed outputs follow from the observed input)
$\Rightarrow$ there is some explanation for the observed inputs and negated observed outputs in which the component is assumed to be normal.

Example 4



- If $\Delta = \{\backslash\texttt{+ ab(o1)}, \backslash\texttt{+ ab(o2)}\}$, then $\mathrm{conf}_{\Delta}(\Omega) \simeq 0.05$.
- By Prop. 4, we do not need to examine O_2, as its output is completely determined by its input (I_2). $\Delta' = \{\backslash\texttt{+ ab(o1)}, \texttt{ab(o2)}\}$ lead to $\mathrm{conf}_{\Delta'} = 0.18$
- This is not the case for O_1. Indeed, $\Delta'' = \{\texttt{ab(o1)}, \backslash\texttt{+ ab(o2)}\}$, $\mathrm{conf}_{\Delta''} = -0.12$

Conclusions & Future work

Conclusions:

- Preliminary exploration of conflict-based diagnosis in PLP
- Abductive machinery of PLPs seems very useful to computing conflict-based diagnoses

Future work:

- Further studying the partial observations
- Generalizing the framework, e.g. probabilistic behavior of systems
- Consider conflict-based diagnosis with time