Knowledge-based Systems for Industrial Applications

1 The Topic
2 Tasks
3 Modeling
4 Diagnosis

Goal:
• Practical Requirements
• Theories of Model-based Diagnosis
• Basis for Implementation
• Application Examples
• Script: Chap. 10.4
Task:
- Determine based on the given observations:
- What is happening in the system?
## 1 The Topic

## 2 Tasks

## 3 Modeling

## 4 Diagnosis

### 4.1 Consistency-based Diagnosis

**Goal:**
- Generation of Diagnosis Hypotheses
- Formal (logical) Theory
- With and without Fault Models
- Implementation
- Applications
- Script: Chap. 10.4.(1)
Iterative Diagnosis - formally

Formally:

- $\text{MODEL} \cup \text{OBS} \models \bot$
- $\models$
- $\text{MODEL'} \cup \text{OBS} \not\models \bot$
Why Do We Need a Model?

The essential question:
Do the observations indicate a violation of the goals?

- \( \text{OBS} \cup \text{GOALS} \uparrow \)
- Why isn’t it sufficient to check this?

- Some goals may not be directly observable
- E.g. RPM of a motor is OK, but
  - too much energy/fuel consumed or
  - limits on emissions exceeded
- Faults may be masked (w.r.t. to primary goals)
  - in particular for controlled systems
- Model links observations and goals

Hence:
- \( \text{MODEL} \cup \text{OBS} \cup \text{GOALS} \uparrow \)
Current Application Project: Air Handling Unit

- EMWiNS project; Univ. College Cork
- Goal: reduction of energy cost
Localization of Faults (per Minute)

- Air mixing box
- Heating/cooling coils
- Sensors
Well-designed-system Assumption

Correctly designed system:
• \( \text{MODEL}_{\text{OK}} \models \text{GOALS} \)

Hence:
• \( \text{MODEL}_{\text{OK}} \cup \text{OBS} \models ? \perp \)
Provided: Automatic Model Composition (Chapter 3)

- **Model Revision**
- **Library**
- **Conceptual Model**
- **Model Composer**

- **Inconsistency**
  - inconsistent
- **Behavior Model**
- **Predictor**
- **Diagnosis**
  - consistent
- **Observations/Goals**
Provided: Behavior Prediction (Chapter 3, esp. 3.2 (later))

Model Revision

Library

Conceptual Model

Model Composer

Behavior Model

Predictor

Inconsistency inconsistent

Diagnosis consistent

Observations/Goals
Next: Consistency Check

- Inconsistent
- Consistent

Inconsistency

Diagnosis

Consistent

Observations/Goals

Predictor

Model Revision

Library

Conceptual Model

Model Composer

Behavior Model
Discrepancies
How to Detect Inconsistencies?

- Inconsistencies: empty set of possible values for a variable
- Contradictory restrictions on values

\[
\begin{align*}
\text{MODEL } \cup \text{OBS } \cup \text{GOALS} & \models \text{Restr}_1(\text{var}_0) \\
\text{MODEL } \cup \text{OBS } \cup \text{GOALS} & \models \text{Restr}_2(\text{var}_0) \\
\text{Restr}_1(\text{var}_0) \wedge \text{Restr}_2(\text{var}_0) & \models \bot
\end{align*}
\]
How to Detect Inconsistencies? - Example ABS Hydraulics

- Inconsistencies: empty set of possible values for a variable
- Contradictory restrictions on values

In the diagram:
- The hydraulic unit and brake pedal connections are shown.
- There are options for under-braked and over-braked conditions, with specific configurations for the front left and rear right wheels.
Inconsistencies: empty set of possible values for a variable
Contradictory restrictions on values

How to Detect Inconsistencies? - Example ABS Hydraulics

Constraint CID₁:

\([\Delta p_{WBC}] = [0] \text{ at } t₀ \land
[\Delta p_{WBC}] = [-] \text{ after } t₀ \Rightarrow
\partial[\Delta p_{WBC}] = [-] \text{ after } t₀\)
**Theorem**

$f(t)$ continuously differentiable function

$f(t_0) = 0$ and $f(t) > 0$ for $t \in (t_0, t_e) \Rightarrow$

$\exists \ t_1$ such that $t_0 < t_1 < t_e$ and

$\frac{df(t)}{dt} > 0$ for $t \in (t_0, t_1)$

**Constraint CID$_1$**

$[f(t_0)] = [0]$ and $[f(t)] = [+]$ for $t \in (t_0, t_e) \Rightarrow$

$\exists \ t_1$ such that $t_0 < t_1 < t_e$ and

$\partial f(t) = [+]$ for $t \in (t_0, t_1)$
Problems in Discrepancy Detection

• Observations
  - Imprecise sensors/human perception
  - Noise (unmodeled external influences)
  - E.g. Impact of pavement on braking

• Imprecise goals
  - E.g. fuel consumption not tolerable

• Limited knowledge
  - Imprecise parameters
  - Limited knowledge about interdependencies
  - E.g. pressure $\rightarrow$ de-acceleration
Coping with Imprecision in Discrepancy Detection

- “ Exact” prediction
- Imprecision reflected in discrepancy detection
- E.g. relative deviation:
  \[ \text{var}=\text{val}_1 \land \text{var}=\text{val}_2 \land |\text{val}_1 - \text{val}_2| > \Delta \ast \text{val}_1 \Rightarrow \bot \]
- E.g. absolute deviation:
  \[ \text{var}=\text{val}_1 \land \text{var}=\text{val}_2 \land |\text{val}_1 - \text{val}_2| > \Delta \Rightarrow \bot \]
- E.g. different orders of magnitude:
  \[ \text{var}=\text{val}_1 \land \text{var}=\text{val}_2 \land \neg (\text{val}_1 \approx \text{val}_2) \Rightarrow \bot \]

- Imprecision reflected in the model
- E.g. different qualitative values:
  \[ \text{var}=\text{qval}_1 \land \text{var}=\text{qval}_2 \land \text{qval}_1 \neq \text{qval}_2 \Rightarrow \bot \]
- E.g. disjoint intervals:
  \[ \text{var}=\text{int}_1 \land \text{var}=\text{int}_2 \land \text{int}_1 \cap \text{int}_2 = \emptyset \Rightarrow \bot \]