1 The Topic

2 Tasks

Goal:
• Overview of different tasks
• Systematic and formal characterization
• as a requirement for theory and implementation
• Script: Chap. 10.2
Basis for Problem Solving: Knowledge about the Technologies

(Re-)Design

Recycling

Maintenance

Manufacturing

Control

- Function
- Components
- Processes
- Materials

- Production-processes
- Disturbances
- Faults
- ...
Basis for Problem Solving: **Models**

- Representation of **knowledge** about a complex domain
- **systematic**
- **structured**
- **formal**
- for **inference** of statements about the **behavior** of systems in this domain

**Not** a (behavior) model:
- Database with product parameters
- Sets of experimental data
- Equation (without equation solver)

Modeling:
- Design
- Manufacturing
- Control
- Maintenance
- Recycling
Model as a Substitute of a System

- Representation of **knowledge** about a complex domain
  - **systematic**
  - **structured**
  - **formal**
  - for **inference** of statements about the **behavior** of systems in this domain

Model as a **substitute** of the real systems:
- certain aspects **not** directly **observable**,
- **critical** situations,
- real system **not** (yet) **available**

Model as an **approximation** of real system behavior
### Notation

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\models$</td>
<td>entails</td>
</tr>
<tr>
<td>$\not\models$</td>
<td>does not entail</td>
</tr>
<tr>
<td>$\bot$</td>
<td>inconsistency, “false”</td>
</tr>
<tr>
<td>$\models \bot$</td>
<td>is consistent</td>
</tr>
<tr>
<td>$\models \bot$</td>
<td>is inconsistent</td>
</tr>
<tr>
<td>$\models \not\bot$</td>
<td>check for consistency</td>
</tr>
</tbody>
</table>
Task:
- Concept of a realizable system
- whose behavior fulfills a specification of goals
The Design Task

Task:
- Concept of a realizable system
- whose behavior fulfills a specification of goals
Task:
- search for a model
- that is consistent with the specification of goals
The Design Task - Formally

Formally:

- \( \text{MODEL} \models \text{GOALS} \)
- Weaker: \( \text{MODEL} \cup \text{GOALS} \not\models \bot \)
Iterative Design

Task:
- Incremental modification of design hypotheses
- Precondition: good initial hypothesis
Iterative Design - Formally

Formally:

- $\text{MODEL} \cup \text{GOALS} \not\models \bot$
- $\rightarrow \text{MODEL'} \cup \text{GOALS} \not\models \bot$
Space of Design Alternatives – Different Design Tasks

- parametric design:
  - alternative parameters
- configuration:
  - alternative component types
- Innovative design:
  - alternative structures
  - new component types
Task:
- Determine of the effects of (classes of) component faults
- under different operating conditions
The FMEA Task

Task:
- Determine of the effects of (classes of) component faults
- under different operating conditions
Model-based FMEA

Task:
• Predict the behavior
• of a model of the faulty system
The FMEA Task - Formally

Formally:

• $\text{MODEL}_{\text{fault}} \cup \text{OPERATING\_CONDITIONS} \not\models ?$

• $\text{MODEL}_{\text{fault}} \cup \text{OPERATING\_CONDITIONS} \not\models ? \text{ EFFECT}$
Manufacturing, Assembly - Tasks

- Essential: Not the behavior of the final product,
- but the behavior of the manufacturing line
- Manufacturing process subject to:
  - design, monitoring, control, maintenance
Provide evidence:
• with (few/cheap) tests,
• That the manufactured system operates correctly
• i.e. has no relevant component faults
Prove evidence:
- with (few/cheap) tests,
- That the manufactured system operates correctly
- i.e. has no relevant component faults
Test Generation - Formally

Formally:

• MODEL₀ ∪ INP ⊨ OBS₀
• MODEL₁ ∪ INP ⊨ OBS₁
• OBS₀ ∪ OBS₁ ⊨ ⊥
For the given observations:
- Does the system work consistently with the goal specification?
For the observations given:

- Is the model *consistent* with the goal specification?
Monitoring - Formally

Formally:
- $\text{MODEL} \cup \text{OBS} \cup \text{GOALS} \models ? \bot$

If system design is correct:
- $\text{MODEL} \models \text{GOALS}$
- then
- $\text{MODEL} \cup \text{OBS} \models ? \bot$
- suffices
Task:
• Determine based on the given observations:
• What is happening in the system?
The Diagnosis Task

Task:
- Determine based on the given observations:
- What is happening in the system?
Model-based Diagnosis

Task:
- Determine the models
- that are consistent with the observations
The Diagnosis Task - Formally

Formally:
• \( \text{MODEL} \cup \text{OBS} \not\models \bot \)
Iterative Diagnosis

Task:
- Incremental modification of fault hypotheses
- Initial hypothesis: system as designed (all components OK)
Iterative Diagnosis - Formally

Formally:

- \( \text{MODEL} \cup \text{OBS} \not\models \bot \)
- \( \text{MODEL}' \cup \text{OBS} \not\models \bot \)
Testing for Diagnosis - Task

**Task:**
- Determine with (few/cheap) tests,
- **which fault** occurred.
Formally:

- \( \text{MODEL}_{F_1} \cup \text{INP} \models \text{OBS}_1 \)
- \( \text{MODEL}_{F_2} \cup \text{INP} \models \text{OBS}_2 \)
- \( \text{OBS}_1 \cup \text{OBS}_2 \models \bot \)
Task:
- Re-establishment of goal functionality
- as far as possible
Therapy Task

Task:
- Re-establishment of goal functionality
- as far as possible
Iterative Model-based Therapy Proposal

Task:

- Modification of the model by actions
- until it is (or will be) consistent with the goals
Therapy Proposal - Formally

Formally:
- \( \text{MODEL} \cup \text{GOALS} \models \bot \)
- \( \models \text{MODEL} \cup \text{ACTIONS} \cup \text{GOALS} \models \bot \)
Therapy Needs Time!

**Formally:**
- \( \text{MODEL} \cup \text{GOALS} \not\models \bot \)
- \( \text{MODEL} \cup \text{ACTIONS} \cup \text{GOALS} \not\models \bot \)

- Time point \( t_1 \)
- Time point \( t_2 > t_1 \)
Different Therapy Tasks

- **Repair (in the narrow sense):**
  - Replacement of faulty components
- **Reconfiguration:**
  - exploit structural redundancy (Nets)
  - exploit analytical redundancy (new point of work)
- “Process therapy”:
  - structural changes
Diagnosis, Therapy, ...

MODEL

Model Revision

Therapy Actions

GOALS

OBS

MODEL

Model Revision

Disturbances

MODEL
Consistency-based Problem Solving: **Situation Assessment**

- **Inconsistency** → **inconsistent** → **Model**
- **Solution** → **consistent** → **Predictor**
- **Predictor** → **Observations**
Consistency-based Problem Solving: Therapy Proposal

Inconsistency

Model

Predictor

Goal

Therapy

inconsistent

consistent

inconsistent
Elements of Model-based Problem Solvers: Predictor

- Model-based prediction
- and consistency check

- “Criteria”:
  - Observations
  - Goals

Diagram:
- Inconsistency
- Model
- Predictor
- Solution
- Criterion

Inconsistent
Consistent
Elements of Model-based Problem Solvers: Model Revision

- Revision of inconsistent models

- Model Revision
  - Inconsistency: inconsistent
  - Solution: consistent
  - Model
  - Predictor
  - Criterion
Model Revision

Revisions:
- Component faults
- External disturbances
- Unexpected objects
- ...

→ Revision at a conceptual level!

Model Revision

Inconsistency
- inconsistent

Solution
- consistent

Library

Model

Criterion
Model Revision - at a Conceptual Level!

Model Revision

Conceptual Model

Model Composer

Inconsistency

Predictor

Solution

Criterion

Inconsistent

Consistent

Conceptual

Mathematical
Requirements on Modeling

- conceptual modeling
- executable behavior models
- qualitative models
- (automatic) model composition
- behavior prediction
- multiple modeling

Inconsistency

Conceptual Model

Model Composer

Behavior Model

Criterion

Solution

Predictor

Consistent

Consistent

Consistent

Consistent

Consistent

Consistent