Intelligent Decision Support Systems

(Part XII – MODEL-DRIVEN TECHNIQUES IN DECISION SUPPORT: QUALITATIVE REASONING MODELS)

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PART 12 – MODEL-DRIVEN TECHNIQUES IN DECISION SUPPORT

Qualitative Reasoning Models

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Model-Driven Techniques

Qualitative Reasoning Models
Qualitative Reasoning Models

- Qualitative Reasoning Models
  - QR modelling
  - Causal Loop Diagrams (CLDs)
Qualitative Reasoning Principles

- The world is plenty of very complex information
- Humans knowledge about the world is limited, and hence, incomplete
- Notwithstanding, humans are able to manage that *complexity* and *reason with incomplete information*, and make deductions about it
- *Qualitative reasoning* basic approach is to provide some techniques being able to *represent* and *reason with incomplete knowledge about physical devices or mechanisms*.
- QR field was originated from the *qualitative physics* subfield, which aid to reason about physical domains and the temporal evolution of these systems, in a different way than the classic numerical and quantitative one, mostly based in Ordinary Differential Equations (ODEs).
Qualitative approach to Modelling

MODEL

REALITY

Physical World

ORDINARY DIFFERENTIAL EQUATIONS (ODEs)

QUALITATIVE MODEL

BEHAVIOUR

ACTUAL BEHAVIOUR

QUANTITATIVE BEHAVIOUR: CONTINUOUS FUNCTIONS

QUALITATIVE BEHAVIOUR

QUANTITATIVE ABSTRACTION

QUALITATIVE ABSTRACTION

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Block-Spring Artifact Example

$k$: the spring constant, $k > 0$

$F$: the force acting on the block, according to Newton’s law, $F = m \times a$

$F'$: the spring force, according to Hooke’s ideal spring law, $F' = -k \times x$

$x(t_0) = 0$

$v(t_0) = v_0, \ v_0 > 0$
Qualitative Reasoning Flowchart (1)

- Qualitative Model Building
  - Formulation of the Qualitative model
    - Scenario Analysis
    - Model fragments composition
    - Ontology fragments use
  - Representation of the Qualitative model
    - Qualitative variables
    - Qualitative relationships

- Qualitative Model Simulation
  - Qualitative states
  - Qualitative behaviours
  - Qualitative behavioural predictions
    - Behaviour tree
    - Envisionment / State-Transition Network
### Qualitative Reasoning Flowchart (2)

#### Qualitative Model Formulation

- **Qualitative Variables**
  - Quantity Space: \(<0, \text{MAX}, +x>\)
  - \([x]_0 = [x], [x]=+ \text{ if } x > 0, [x]=- \text{ if } x < 0, [x]=0 \text{ if } x = 0\)
  - \(x \in [a,b]\)
  - \(\text{QV}(v(t)) = <\text{qmag}, \text{qdir}>, \text{qmag} \in \text{QSpace}(v(t)), \text{qdir} \in \{\text{inc, dec, std}\}\)

#### Qualitative Model Representation

#### Qualitative Simulation

- **Qualitative States**
  - \(S_i = \langle X_1, X_2, \ldots, X_N \rangle\)

- **Time**
  - \(t_0 < t_1 < (t_1, t_2) < \ldots < t_f\)

- **Qualitative Behaviours**
  - \(\langle (S_0, t_0), (S_1, t_1), (S_4, (t_3, t_2)), \ldots \rangle\)

#### Qualitative Relationships / Constraints

- **Confluences**
  - \([x] + [y] = [z]\)

- **Influences**
  - Indirect: \(P^+(y, x), P^-(y, x)\)
  - Direct: \(l^+(y, x_i), l^-(y, x_i)\)

- **Monotonic functions**
  - \(M^+(x, y), y = f(x) \text{ and } f \in M^+\)

#### Qualitative Simulation Environments

- ENVISION program (de Kleer & Brown, 1984)
- GIZMO (Forbus, 1984), QPE (Forbus, 1990)
- MINIMA (Williams, 1988)
- QSIM algorithm (Kuipers, 1986)

#### Behavioural Predictions

<table>
<thead>
<tr>
<th>Behaviour Tree</th>
</tr>
</thead>
<tbody>
<tr>
<td>(S_0 - o - S_1 - S_4 - \ldots )</td>
</tr>
<tr>
<td>(\mid - S_2 - o - S_5 )</td>
</tr>
<tr>
<td>(\mid - S_3 \mid - S_6 )</td>
</tr>
</tbody>
</table>

#### An ENVISION

- \(S_0 \rightarrow S_1 \rightarrow S_2 \rightarrow S_3 \rightarrow S_4 \rightarrow S_5 \rightarrow S_6 \)
U-tube System Example

Tank A

A-MAX

amtA
pressA

flowAB

Tank B

B-MAX

amtB
pressB

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U-tube System Model
U-tube System Qualitative Transition Graph
Causal Loop Diagrams (CLDs)

- A simplified understanding of a complex problem
- A common language to convey the understanding
- A way of explaining *cause* and *effect* relationships
- Explanation of underlying feedback systems
- Helps us understanding the overall system behavior
- They are Directed Graphs:
  - Nodes: variables
  - Edges: causal relationships
Positive Relationship

- Positive causation
  - An increase/decrease in the origin variable causes a change on the destination variable in the *same direction*, given that all the other variables remain constant:
    - the larger the population, the more births
    - the more money in the bank, the more in interest
Negative Relationship

- Negative causation
  - An increase/decrease in the origin variable causes a change on the destination variable in the opposite direction, given that all the other variables remain constant:
    - The more predators, the less preys
    - The less predators, the more preys

Negative causal relation

- Air Pollution
- Public Health
The Structure of Causality

Variables change:

”in the same direction”

”in the opposite direction”
Closed Cycles in a CLD

Reinforcing Feedback loop

Photosynthesis \rightarrow R \rightarrow \text{Growth} \rightarrow + \rightarrow \text{Nutrient uptake} \rightarrow + \rightarrow \text{Nutrients available} \rightarrow - \rightarrow \text{Nutrient uptake}

Balancing Feedback loop

B \rightarrow \text{Nutrient uptake} \rightarrow + \rightarrow \text{Nutrients available} \rightarrow + \rightarrow \text{Nutrient uptake} \rightarrow B
Atmospheric system

- Earth's temperature
- Sunshine
- Evaporation
- Clouds
- Rain
- Amount of water on earth

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Natural system
Social system

- Dyslexia
- Ability to read
- Amount of frustration in school
- Amount of attention paid in school
- Readiness to read
- Degree of troublemaking in school
- Amount of pressure from teachers and parents to perform academically

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Economic system
Combined system
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