Model-based Reasoning

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Introduction

- Description of the Field
- Motivations for development
- Relevance of the Field
- Objectives
- Overview
- Models → Background

- Recommended Text:
  "Qualitative Reasoning"
  Ben Kuipers, MIT Press 1994
  £40 if you are really interested!

Model-based Reasoning

- Qualitative Reasoning
  - Symbollic, using no numbers
  - Structural though incomplete
  - Synonyms: Naive physics, Qualitative modelling, Qualitative simulation, Commonsense reasoning, Deep knowledge.
- Developments
  - Use of any models in the domain reasoning process
  - Numerical, Interval, Semi-quantitative, Fuzzy, Qualitative, Rule-based, Procedural

Systems

- Natural Systems
  - Physical: Fluid behaviour, Chemical reactions
  - Biological: Drug uptake, Cardiac performance, Renal operation, Photosynthesis
  - Ecological
- Artificial Systems
  - Physical: Electrical circuits, Mechanical systems, Chemical plant
  - Economic: Housing markets, Organisations

Motivations

- Problems with RBS
  - Reasoning from First Principles
  - Dangers with “nearest approximation”
- Modellers requirements
- Second Generation Expert Systems
  - Use deep knowledge
  - Provide explanations of reasoning process
- Commonsense reasoning
  - Capture how humans reason
  - Enable use of appropriate causality
- Model reuse
  - Improved ease of ES maintenance

Is MBR relevant? (1)

- Domains of Application
  - Modelling of ecological systems
  - Diagnosis of industrial plant
  - Training of process operators
  - Control of process plant
- Industrial Investment
  - Number of large collaborative projects involving industry (e.g. Unilever, Siemens, BG) and academia
- Eye to the future
  - Industrial rollout
  - Focus on the essence of ‘Modelling’
- Development methods
  - KADS - Expert Systems development
  - ARTIST, PRIDE - Model-based Diagnosis

Is MBR relevant (2)

- Communication infrastructure
  - European - Monet
  - National - R&R (UK), MQD (France)
- Commercialisation
  - Tiger - Diagnosis of Gas Turbines
  - FLAME (Autosteve) - FMEA and Diagnosis of car electrics

Objectives

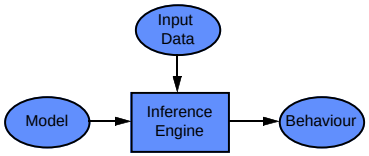
- Understand basis of QR and MBR
- Awareness of modelling perspectives
- Understanding of QR ontologies
- Detailed knowledge of constraint approaches - development and application
- Awareness of domains of application
- Awareness of issues in model construction
- (Understanding of spatial models)

Overview

- Background and Basics
  - Ontologies, Quantity spaces, Qualitative arithmetic, Operations, Causality.
- Major methods of QR
  - Devices, Processes and Constraints
  - Focus on constraint based and developments
- Reasoning Domains
  - Explanation, Diagnosis, Training, Prediction, Spatial reasoning, Kinematics
- Modelling Methodologies
  - Teleological, Behavioural, Multimodelling, Multiple models

What is a Model?

- Assume knowledge
  - You've all come across them.
- Physical
  - E.g. Doorlock mechanism
- Mathematical
  - Declarative Structure
    - Representation
      - Executable but distinct from inference mechanism.



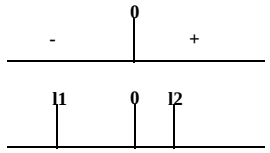
    - Prediction:
      - What value will it have?
    - Explanation
      - Why did it happen that way?
      - Facilitates understanding of system

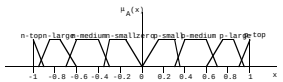
Basic Principles of QR

- Terminology and Concepts
  - new(ish) field: proliferation of terms
  - underlying concepts basis for all QR
- Symbollically represents the important (qualitative) distinctions in a system
  - increasing, steady, decreasing
  - high, medium, low
- Scales of Measurement
  - nominal, ordinal, interval, ratio
- Qualitative versus Quantitative?

Qualitative Reasoning

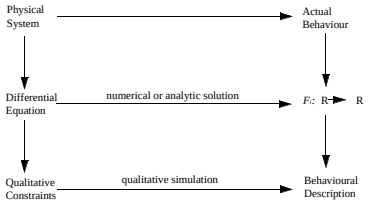
- Components of a Qualitative Model
  - Ontology (a way of looking at the world)
  - Variables (things that change)
  - Quantity space (values variables take)
  - Relations (what variables do to each other)
- Quantity Spaces





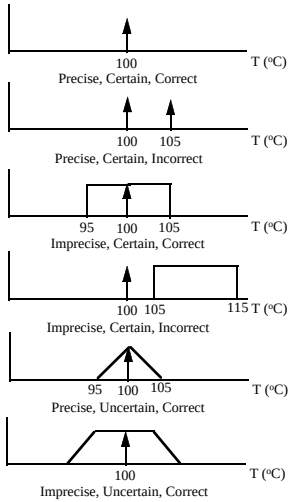
Qualitative Relations

- Behavioural Abstraction



- Incompleteness
  - Not the same as “Uncertainty”
    - but is related to “Precision”
  - Known model structure (assumed)
  - Imprecise knowledge of system functional relations
- Operators
  - ADD, MULT, DERIV

Precision and Uncertainty



Arithmetic Operations

- Sign Algebra

MULT

⊗	+	0	–
+	+	0	–
0	0	0	0
–	–	0	+

DIV

⊘	+	0	–
+	+	X	–
0	0	X	0
–	–	X	+

Aritmetic Operations (2)

ADD

⊕	+	0	–
+	+	+	?
0	+	0	–
–	?	–	–

SUB

⊖	+	0	–
+	?	+	+
0	–	0	+
–	–	–	?

Arithmetic Operations (3)

A = B - C

where B & C both have value [+], A will be undefined

- Disambiguation
  - may be possible from other information
  - A = [+] if B > C
  - A = [0] if B = C
  - A = [-] if B < C
- Functional Relations
  - Y = **M+**(X)
  - Y = **M-**(X)

Qualitative Vectors

- Convenient representation of state and behaviour
- Consists of Magnitude and first *n* derivatives of a variable:

  x -> d^0 (zeroth derivative)

  x' -> d^1 (first derivative)

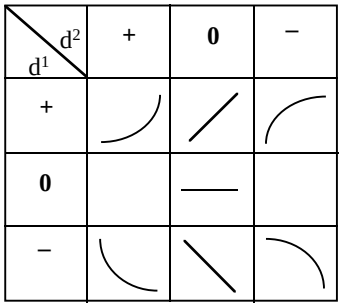
  x" -> d^2 (second derivative)

  . . .

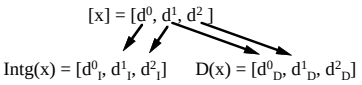
  [x] = (d^0, d^1, d^2 . . .)

- Usually need at least two elements in a vector (three is better because curve shapes can be seen).

Qualitative Vectors (2)



Qualitative Calculus



For Integration:

$d^0_I = d^0 + d^1 = d^1_I + d^2_I$

(by Taylor's Theorem)

For Differentiation:

d^2_D: depends on what is known of the original function (or system in which it appears)

Model Types

- Static (Equilibrium)
  - algebraic equations only
    [A] = [B] + [C]
    [X] = M+([Y])
    M = U * V
- Dynamic
  - contains derivatives,
  - requires integration
    x' = k.x
    $y = \int x dt$
  - may also have algebraic parts

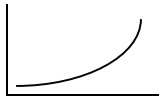
- **NB: Dynamic is not the same as time varying!!!**

Behaviour Types

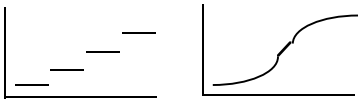
- Results of Simulation/Inference are known as **ENVISIONMENTS**
- TOTAL ENVISIONMENT
  - All possible behaviours for all possible inputs
- COMPLETE ENVISIONMENT
  - All possible behaviours for a specific input
- ATTAINABLE ENVISIONMENT
  - All behaviours from a specified initial value and input ~ with a fixed quantity space
- PARTIAL ENVISIONMENT
  - All behaviours from a specified initial value and input ~ with landmark generation

Model Types (2)

- Continuous
  - no gaps in quantity space
  - no jumps allowed
  - focus of QR (mainly)



- Discontinuous/Discrete
  - finite number of gaps in quantity space
  - jumps can occur



Behaviour Types (2)

- Envisionments are represented as a graph or a tree
- BEHAVIOUR
  - Single path through an envisionment graph or behaviour tree
- HISTORY
  - Behaviour of a single variable removed from its envisioned context.

Ontology

- A way of representing what there is in the world (closed)
- Two (main) perspectives:
  - Functional: focuses on purpose (design)
  - Behavioural: focuses on operation
- Three Behavioural Ontologies:
  - Devices (Components): pipes, tanks valves
  - Processes: heating, reacting, decomposing
  - Constraints: relations between variables