Qualitative Physics: Past, Present, and Future

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1 Overview

Qualitative physics is a subfield of Qualitative Reasoning that focuses on representing and reasoning about the physical world.

People Forbus, deKleer, Brian Williams, Pandu Nayak, Yumi Iwasaki, Boi Faltings, Falkenhainer, Pat Hayes, Bruce Kuipers, Reid Simmons, Dan Weld.

Terms Sign algebras, Quantity Space, landmark values, Order of Magnitudes, device ontology, process ontology, envisionment.

Systems Newton - deKleer. Frob - Forbus, QSIM - Kuipers, FOG - Raiman, O[M] - Mavrovouniotis and Stephanopolous, 87.

2 Why Qualitative Physics?

Why not just do physics?

- Modeling Problem: How to get all the equations describing a physical system, if they even exist? And even if you do have them, you have to deal with the complexity of solving them.
- Resolution problem: An alternative to finding a solution to the set of equations is to do a simulation. But in order to do this, you need accurate set of values for the input parameters. Also, doing a complete simulation is also computationally expensive.
- Narrowness Problem: The solution to the set of equations, or the output of the simulation give us just a single answer; often in order to interpret the output we really want to characterize the possibilities that might occur.

Nice Quote:

> A robot pouring coffee should be cognizant of the possibility of overflow, and not spend its time calculating just how big the resulting puddle might be.

Key to Qualitative Physics: find ways to represent continuous properties of the world by discrete systems of symbols. Relevance principle: the distinctions made by a quantization must be relevant to the kind of reasoning performed.

Good quantizations allow more abstract descriptions of state, which in turn make possible more concise descriptions of behavior.

3 The Past

Early attempts at doing textbook physics and math problems:

- STUDENT - Bobrow, 1968
- CARPS - Charniak, 1968
- MECHO - Bundy, 1979
- ISSAC - Novak, 1976

Typically found they had insufficient information to completely solve problems. Needed common-sense knowledge, knowledge about the world.

First system to use qualitative physics to solve the problem: NEWTON - DeKleer. Solved problems that were single point mass sliding on surface. Created an envisionment, an explicit representation of all possible behaviors. Could answer some simple questions using just this. Next performed algebraic manipulation to solve more complex questions.

Nice quote #2 (deKleer)

> An intelligent problem solver has to be able to answer stupid questions and preferably with less work than it takes to answer subtle questions.

Next big event, Pat Hayes "Naive Physics Manifesto", Hayes, 1985/1978. Histories; events should be represented as spatially bounded, but temporally extended, pieces of space-time. Designed to solve several problems with situation calculus.

Third, Frob - Forbus, 1980, reasoned about motion through free space. Two dimension world with balls bouncing (precursor to Pong?) Answered "where will ball end up?", "will two balls collide?"

4 Present

4.1 Qualitative Dynamics

How physical systems to change over time.

4.1.1 Representations for numbers

Signs (deKleer, Williams) Reduce number to its sign (-1, 0, 1). Also signs of derivatives used to indicate whether a quantity is increasing, constant or decreasing (Forbus, deKleer, Williams). In QP theory (Qualitative Process Theory, Forbus), sign of derivative of Q denoted DS[Q].

- Advantage: simplicity (typical example from KR is sign multiplication)
- Disadvantage: can only compare to a single reference value.

Inequalities Quantity Space (Forbus): a set of inequalities to describe a quantity.

The values a quantity is compared to is termed landmark values (Kuipers, 1986).

Temporally generic landmark value is one that refers to a class of temporal behaviors, not just a single behavior. For example, the boiling point of water (at a certain pressure).

Temporally specific landmark - Kuipers, QSIM, one of the few systems that does use these types. example, cholesterol level today vs. cholesterol level last week.

Orders of Magnitude

- FOG - Raiman, 86. Introduces three new relationships:
  - $A \ll B$: A is negligible compared to B
  - $A \cong B$: A is very close to B
  - $A \sim B$: A is the same magnitude as B
- O[M] - Mavrovouniotis and Stephanopolous, 87. Assigns labels to ranges of ratios.

  $$A \sim< B \text{ when } \frac{|A|}{|B|} < (1 = e)$$

  read "A is slightly smaller than B".
- Davis- 1987, a formalism also based on infitesimals. Constructs a qualitative calculus for both numbers and durations of intervals.

4.1.2 Equations

Notion of equations is qualitative physics is also typically weaker.

arithmetic operations. typically have addition, subtraction, mult. But, effects may not be unambiguous. For example, what is sign$(A + B)$? Confluences, (deKleer and Brown), equations involving sign values.

monotonic functions: represent monotonic increasing and monotonic decreasing relationships between variables.

4.1.3 Ontology

- Qualitative State Vectors Used by NEWTON, FROB. State vector consists of a) A quantization of the traditional state variables and b) a symbolic description of the type of activity. Advantages: natural, compact and easy to combine dynamic and kinematic representations. Disadvantage: lacks composibility.

- Device Ontology (deKleer, Brown, Williams) System is constructed from collection of devices. Behavior specified by internal laws, often decomposed into distinct states or operating regions. Advantages: fixed topology allows for efficient computation, composability, standard representation in traditional engineering methodology. Disadvantages: how to construct network model; not a problem in some domains, in others, less obvious. block example. device model unnatural for some cases.

- Process Ontology Qualitative Process Theory (QP) Forbus, 1981. Individuals field allows for quantification, instance of process for every combination of objects in a scenario that match the individual specifications. Preconditions and quantity conditions determine when process is active. Relations field describes what holds when process is active. Direct effects of a process are specified by influences field.

  Advantages: intuitively appealing - objects can come into existence and vanish. processes provide a simple notion of causality, allows explicit representation of modeling assumptions and conditions. Disadvantages: distinction between dependent and independent variables changes according to the type of analysis being performed. requires more inference to set up model. hasn't been formally explored as much as device.

Other issues: continuity - things change smoothly; in changing, a quantity must pass through all intermediate values.

causality - explicit-mechanism theories - ie, QP theory vs. implicit-mechanism.

Causal Ordering Proposal of Iwasaki & Simon

4.2 Qualitative Kinematics

qualitative spatial reasoning. but not navigation or manipulator-level planning.

Poverty conjecture: there is no purely qualitative kinematics. 1) proof by failure 2) no partial orders in 2D 3) people are bad at spatial reasoning.

4.3 Reasoning

4.3.1 Qualitative Simulation

Time is individuated by interesting events, not fixed time slices. Reduced precision introduces branching.

Envisionment (deKleer) - graph formed by the collection of all qualitative states of a system and transitions between them vs. History - specific behavior of object.

Logic of Occurrence (Forbus 1987) specifies how a history is related to an envisionment so that general behavioral constraints are enforced.

4.4 Open Problems

- Spatial Quantities
- Types of Numbers and Functions
- Large-Scale Organization of Qualitative Models
- Integration with Vision and robotics
- Complete Qualitative Physics

5 State of the Field

5.1 Yumi Iwasaki - 1996

In my opinion, model formulation in a broad sense of the word, including model abstraction, is the most exciting area of research in QR currently. By model formulation, I mean the question of how to formulate models – either from observation or from some repository of general knowledge of the domain. Some names that come to my mind are Forbus & Falkenhainer, Pandu Nayak, Iwasaki & Levy, Jeff Rickel (U. Texas), Ken Yip, Feng Zhao, Liliana Ironi. This question includes deciding on the set of phenomena to model, how to model each, the level of abstraction, what simplification, what approximation to make, etc.

There has been a steady stream of work, mainly out of U. Texas on semi-quantitative simulation. Mostly Ben Kuiper and company. Bert Kay is the name best known for this line of work among his students. Marcos Vescovi (formerly with KSL) and Adam Farquhar, also.

Reasoning about the behavior of complex, non-linear systems: Nishida, Feng Zhao, Ken Yip

Another direction I think is very exciting is qualitative reasoning in spatially distributed domains. Monica Lundell is active in the area.

applications

Use of QR for education: Forbus, Bert Bredeweg

Diagnosis: Peter Struss, Takashi Washio, Trave-Massuyes & Milnes

Design: Tomiyama (U. of Tokyo), Boi Faltings Tomiyama's team has done very interesting work on self-maintaining copiers. There was an article about this work in a recent AI magazine. It is the a shining example of a real-world, commercial application of QR.

6 Questions

Tell me about Qualitative Physics. What are some techniques used here?

Qualitative physics. What's the idea ? (after I explained) So what the the problems with this ? (he liked "granularity" as a problem. I knew he was involved in this, and that Pandu Nayak, a recently graduated PhD student, did some work on this.)

Knowledge Representation questions about qualitative physics, term hierarchies, problems with FOPC as a representation language.

Let's talk about qualitative physics.

What is Qualitative Physics ? Name some people working on it.

What are the problems with QP?

A refrigerator in a closed room is left open - a) what happens to the temperature of the room? (It drops for a short time, then goes up, due to the work done by the refrigerator) b) How would the qualitative physics people model this?

What are qualitative proportionalities [Q physics]