A Note Concerning
Qualitative Process Theory
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1. Introduction

Many kinds of changes occur in physical situations. Things move, collide, flow, bend, heat up, cool down, stretch, break, and boil. These and the other things that happen to cause changes in objects over time are intuitively characterized as processes. Much of formal physics consists of characterizations of processes by differential equations which describe how the parameters of objects change over time. But the notion of process is richer and more structured than this. We often reach conclusions about physical processes based on very little information. For example, we know that if we heat water in a sealed container the water can eventually boil, and if we continue to do so the container can explode. To understand common sense physical reasoning we must understand how to reason qualitatively about processes, their effects, and their limits. I have been developing a theory, called Qualitative Process theory, for this purpose[Forbus, 1981, 1982]. I expect this theory, when fully developed, to provide a representational framework for understanding human common sense physical reasoning. It should also be useful for constructing computer programs that reason about complex physical systems as well as common sense reasoning. Programs that explain, repair and operate complex systems such as nuclear power plants and steam machinery will need to draw the kinds of conclusions this theory sanctions.

Qualitative reasoning about quantities is a problem that has long plagued Artificial Intelligence and Cognitive Science. Many schemes have been tried, including simple symbolic vocabularies (TALL, VERY TALL, etc.), real numbers, intervals, fuzzy logic, and so forth. None are very satisfying. The reason is that none of the above schemes makes distinctions that are relevant to physical reasoning. Reasoning about processes provides a strong constraint on the choice of representation for quantities. Processes usually start and stop when orderings between quantities change. For example, when two objects with unequal temperatures are brought into contact there will be a heat flow from one to the other which will stop when the temperatures are equal. In Qualitative Process theory the value of quantities are represented by a partial ordering of other quantities determined by the domain physics. The representation appears both useful and natural.

QP theory is mainly concerned with the form of physical theories and only indirectly about their specific content. For example, heat flow processes which don't conserve energy and transfer "caloric fluid" can be written as well as the classical physical description. Newtonian, Aristotelian, and Impetus theories of motion can all be encoded. Thus QP theory provides a language for writing physical theories. In particular, the primitives are simple processes (such as flows, state changes, and motion), the means of combination are sequentiality and shared parameters, and the means of abstraction are naming these combinations, including encapsulating a piece of the process history (a kind of behavioral description, see [Hayes, 1979]) for the situation as a new process.

The basic Qualitative Process theory is not intended to capture the full range of qualitative reasoning about the physical world. Instead it is concerned with describing the weakest kind of information that still allows useful conclusions to be drawn. There are two reasons why this weak level of description is interesting. First, conclusions from weak information are often required to drive the search for conclusions from more detailed information (an illustration is [deKleer, 1975]). More importantly, I believe that the basic theory can be used to write what corresponds to people's common sense physical knowledge. To capture more sophisticated kinds of physical reasoning (for example, how an engineer makes estimates of circuit parameters or stresses on a bridge) extension theories containing more detailed representations of quantity, functions, and processes will be needed. Examples of extension theories could include order of magnitude estimates and numbers. By providing a shared basic theory, future studies of more sophisticated domains may yield a way to classify kinds of physical reasoning according to the extension theories they require.

2. An Example

There are several kinds of reasoning that can be performed using Qualitative Process theory, including reasoning about the limits of processes ("What might happen if this valve is left open?") and consequences of alternate situations ("How would the turning up the stove affect the heating of the kettle?") as well as explaining some problems involved in causal reasoning. Several examples of common sense phenomena have been examined in this context, including modelling a boiler, motion, materials (saying that you can push with a string but not pull with it), and an oscillator. An informal example will illustrate its flavor. Here is a simple problem involving physical systems that we solve easily:

Imagine looking at a large tank, partially filled with water. You can see two pipes leading into it, and you note that the level in the tank is dropping. Your goal is to figure out why this is happening.

In QP theory terms, "why this is happening" means finding a set of processes which are causing the changes in the situation. (In the complicated physical systems which comprise much of our technology, this is much harder than the simple example depicted here, because the relationship between what we can observe (through instruments) and the processes which serve as an explanation is much less direct). The reasoning goes as follows:

[1] No process affects level directly, but level is qualitatively proportional to Amount-of fluid.

[2] The only processes which affect Amount-of a contained fluid are boiling, evaporation, and fluid flow.

[3] No heat source is visible, so boiling can be ruled out.

[4] The time scale is short, so evaporation can be ruled out.

[5] By exclusion, fluid flow must be the source of the influence.

[6] Fluid flow requires a fluid path.

[7] Only two pipes are visible, so assume those are the only fluid connections to the tank.

[8] Only two fluid flows are possible, one through each pipe. Fluid flow can be measured; in this case both flows are into the tank.

[9] Therefore the influence of the fluid flows is positive.

[10] Therefore the level of the tank should be increasing, not decreasing.

[11] Either (1) Other processes affecting amount-of exist
(2) Evaporation or Boiling are occuring
(3) Measurements are wrong
(4) Other fluid paths exist

[12] Pragmatically, (4) is the most likely - e.g., a large leak in the tank.

Knowing what can be measured and the pragmatic information used in ruling out evaporation and in accepting the leak as the best prospect are not part of QP theory, but instead illustrate the interaction of the theory with other kinds of world knowledge. Note that the key to the deduction is the assumption of a finite vocabulary of processes that could cause the observed change. Hayes [Hayes, Liquids] suggests reasoning by elimination is a powerful technique in common sense reasoning; organizing physical knowledge around a vocabulary of processes provides further opportunity to do so.

3. Current State of the Theory

The current state of the theory is described in [Forbus, 1982]. Further theoretical developments are being carried out in the context of reasoning about simple fluid and mechanical systems. An implementation is underway.

4. References

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