Notes for Meeting 8
Qualitative Modeling and Simulation

Review of Symbolic Reasoning

We have examined methods for deductive, abductive, and analogical reasoning that share a concern with:

- symbolic representations

- pattern matching or unification

- relational knowledge structures

- multi-step inference over these structures

Work on expert systems (e.g., Feigenbaum, 1980) relied on the same assumptions but emphasized the role of domain-specific knowledge.

Shallow Reasoning

The expert systems movement was very successful, with many knowledge-based systems used in industry and elsewhere.

But the domain-specific knowledge on which they relied typically:

- supported only shallow explanations

- was based on empirical associations

- did not refer to structure or function

These characteristics limited their usefulness (e.g., one could not use the same knowledge for design and diagnosis).

This led some researchers to develop "deeper" approaches to knowledge-based reasoning.

A Motivating Example

Consider a simple physical scenario that includes a pot that sits on an electric heating coil and that contains a block of ice.

Suppose we turn on the heating coil. What happens to the ice over time?

- Did you use differential equations to reach your conclusions?

- What form of knowledge did you use to predict system behavior?

- What reasoning method did you use to make those predictions?

People can reason qualitatively about complex situations using MENTAL MODELS of those situations.

What is a Mental Model?

We have all seen physical models. Examples include model airplanes, dolls, globes and orreries, and even models of DNA structure.

Mental models are cognitive versions of physical models that are:

- symbol structures in which the elements designate external entities or events, and in which relations among those elements designate relations among the entities or events.

- abstractions of the external entities or events in that that they ignore any details irrelevant to the task at hand.

- support reasoning about the elements or about relations among them, and thus let one answer questions.

There is little question that humans reason with mental models, but we are still getting computers to support this ability.

The Qualitative Reasoning Movement

The qualitative reasoning movement developed ways to represent and use mental models to reason about physical systems.

The basic approach incorporated a number of structures and mechanisms:

- A qualitative model that includes a set of entities or variables and causal relations among them, some that change values.

- Qualitative states that the modeled system may occupy over time.

- Envisionments that comprise sequences of qualitative states that designate possible trajectories over time.

- An interpreter that simulates the qualitative model to produce possible envisionments for the system.

Most techniques reasoned over qualitative differential equations in a manner similar to chaining over rules.

Uses of Qualitative Reasoning

One can use mental models and qualitative reasoning in different ways:

- Simulation of physical situations (e.g., cooling a house)

- Monitoring of complex artifacts (e.g., power plants)

- Diagnosing malfunctioning devices (e.g., an automobile)

- Designing physical artifacts (e.g., a power system)

- Explaining physical systems to students (e.g., thermodynamics)

These problems involve different forms of qualitative reasoning, but they can operate over the same representations.

Approaches to Qualitative Reasoning

Struss (1997) describes three different approaches to mental models and qualitative reasoning:

- Component-oriented methods (e.g., Envision) that have components, conduits, and terminals;

- Process-oriented methods (e.g., QPT) that assume entities, variables, and processes that influence them; and

- Constraint-oriented methods (e.g., QSIM) that include a set of functions for variables and qualitative constraints on them.

Although these approaches differ in their ontologies, they use very similar mechanisms to support qualitative reasoning.

A Sample Qualitative Process

Struss gives an example of a qualitative process from Forbus' (1984) qualitative process theory:

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Process heat-flow

  Individuals
    source is-a object, has-quantity(source, heat)
    dest is-a object, has-quantity(dest, heat)
    path is-a heat-path, heatconnection(path, source, dest)
  Preconditions
    heat-aligned(path)
  Quantity-conditions
    A[temperature(source) > A[temperature(dest)]
  Relations
    Let flow-rate be a quantity
    A[flow-rate] > 0
    flow-rate prop+ [temperature(source) - temperature(dest)]
  Influences
    I- [heat(source), A(flow-rate)]
    I+ [heat(dest), A(flow-rate)]
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A set of such processes constitutes a qualitative process model of a physical situation.

Criteria for Qualitative Reasoning

Struss (1997) lists three distinct criteria for evaluating AI systems that carry out qualitative reasoning:

- Effectiveness: The system must solve the reasoning problem.

- Efficiency: The system must handle the problem in reasonble time.

- Naturalness: Humans should find it easy to interact with the system.

The final criterion does not require that it operate in the same way as humans, but it must share some of their concepts.

These criteria are more generally applicable to cognitive systems that claim to support high-level cognition.

Challenges for Qualitative Reasoning

Research in mental models and qualitative reasoning has encountered a number of challenges:

- Handling order of magnitude reasoning

- Constraining exponential growth of envisionments

- Using relevant portions of large knowledge bases

- Acquiring models form experience and instruction

The community continues to make progress on these problems, but its activity has decreased over the past decade.

Assignments for Meeting 9
Analogical Reasoning

Read the articles:

- Gigerenzer, G. (2008). Why heuristics work. Perspectives on Psychological Science, 3, 20-29. [required]

- Wikipedia entry on decision theory. [required]

- Tutorial on decision theory. [required]

- Work on the third exercise (due 11:59 PM on 2/21/2011).