Notes for Meeting 7
Analogical Reasoning

Review of Abductive Inference

Some AI work on rule-based reasoning focuses on abductive inference:

- Given: A set of inference rules and a set of facts
- Find: Explanations of how the rules connect these facts
- Many approaches to this task reason backward from a query.

Abduction inference is important in many areas, including natural language, diagnosis, and plan understanding.

Although most work on abduction uses rules, this is not the only way to encode background knowledge.

A Motivating Example

The earliest AI results on analogy came from Evans' (1962) work on geometric analogy problems like those on IQ tests.

These are stated as analogical "proportions" of the form:

X is to Y as Z is to A, B, C, D, or E

These tasks require one to represent and reason about the shapes of component objects and their spatial relations.

Although these problems are abstract, they are not trivial and there are good reasons that IQ tests include them.

Some Other Examples

We encounter analogies frequently in many areas of life, including:

- plays and movies (e.g., West Side Story)
- instruction (e.g., teaching about electric circuits)
- game playing (e.g., a frontal assault in chess)
- computer programming (e.g., entry by a back door)
- science (e.g., Rutherford's model of the atom)

The ability to reason with analogies is important in many settings.

The Task of Analogical Reasoning

We can specify the generic task of analogical reasoning as:

- Given: A base description of a situation stated as a set of relational literals.
- Given: A target description of a situation stated as a set of relational literals.
- Find: One or more mappings between objects, predicates, and literals that occur in the two descriptions.

Such structural analogies involve mappings between rich, relational representations, as contrasted with "nearest neighbor" matching.

Why Are Analogies Useful?

Given an analogical mapping between base and target situations, one can:

- Use relations in the base to make inferences about the target to support:
  - Understanding the target situation in terms of the base
  - Explaining aspects of the target situation in terms of the base

In other words, we can view analogy as a form of abduction that operates over ground literals or facts rather than over rules.

An Example Analogical Mapping

Solar System		Atom
b1 = mass(sun)	<=>	t1 = mass(nucleus)
b2 = mass(planet)	<=>	t2 = mass(electron)
b3 = greater(b1, b2)	<=>	t3 = greater(t1, t3)
b4 = attract(sun, planet)	<=>	t4 = attract(nucleus, electron)
b5 = rev-around(sun, planet)	<=>	t5 = rev-around(nucleus, electron)
b6 = and(b4, b3)	***	t6 = and(t4, t3)
b7 = cause(b6, b5)	***	t7 = cause(t6, t5)
b8 = temperature(sun)		
b9 = temperature(planet)		
b10 = greater(b8, b9)		
b11 = yellow(sun)		

[*** marks inferred predictions]

Component Mechanisms of Analogy

Analogy reasoning involves five distinct computational components:

1. Storing relational structures in memory
2. Retrieving analogical candidates in response to a probe
3. Mapping retrieved candidates onto the probe
4. Evaluating alternative candidates
5. Making inferences about the probe based on the selected mapping

We can view the task of finding mappings as involving search through the space of candidates.

Early research sidestepped the retrieval problem and focused on other aspects of analogy.

The Structure-Mapping Engine

Falkenhainer, Forbus, and Gentner (1986) describe the Structure-Mapping Engine (SME).

This system embodies Gentner's theory of structure mapping by:

- encoding the base and target as sets of relational literals, including second-order relations;
- finding local matches between arguments and predicates of the same type, ranking them by scores;
- finding maximal global matches by combining local matches in consistent ways;
- using each mapping to generate inferences for the target from the base; and
- returning a list of global matches ranked by their scores.

The authors have found that SME's rankings are similar to those produced by adults, but not by children.

Other Research on Analogy

Much of the effort in this area has focused on analogical mapping and inference, but there has also been work on:

- indexing and retrieval of analogies (e.g., Gentner & Forbus, 1991)

- analogical planning (e.g., Veloso et al., 1995; Jones & Langley, 2005)

- physics problem solving (e.g., VanLehn & Jones, 1993)

- generation of designs (e.g., Goel, 1997)

There has also been research on more incremental methods for analogical mapping (e.g., Keane & Brayshaw, 1988).

Analogy, Abduction, and Deduction

How do analogical reasoning and abductive inference differ from deductive rule-based reasoning?

- Both involve partial matching rather than all-or-none matching, in that only some elements must match against given elements.

- Thus, they support a relational form of pattern completion.

- Despite the claims of some connectionists, symbolic representations and processing do not imply fragile behavior.

Both abductive and analogical inference are important topics that deserve more attention in both AI and cognitive psychology.

They also have implications for other facets of computer science, such database storage and retrieval.

Assignments for Meeting 8
Qualitative Reasoning and Simulation

Read the articles:

- Struss, P. (1997). Model-based and qualitative reasoning: An introduction. Annals of Mathematics and Artificial Intelligence, 19, 355-381. [required]

- Iwasaki, Y. (1997). Real world applications of qualitative reasoning: Introduction to the special issue. IEEE Expert: Intelligent Systems. [optional]

- Bring questions about the third exercise (due 11:59 PM on 2/28/2011).