The Goal of Language Understanding

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Chapters 2 through 7 are in separate files. Later chapters make occasional references to earlier chapters, but they can be read independently.

1. Problems and Challenges

Early hopes for artificial intelligence have not been realized.

The task of understanding language as well as people do has proved to be far more difficult than anyone had thought.

Research in all areas of cognitive science has uncovered more complexities in language than current theories can explain.

A three-year-old child is better able to understand and generate language than any current computer system.

Questions:

- Have we been using the right theories, tools, and techniques?
- Why haven't these tools worked as well as we had hoped?
- What other methods might be more promising?
- What can research in neuroscience and psycholinguistics tell us?
- Can it suggest better ways of designing intelligent systems?

Early Days of Artificial Intelligence

1960: Hao Wang's theorem prover took 7 minutes to prove all 378 FOL theorems of *Principia Mathematica* on an IBM 704 – far faster than the two brilliant logicians, Whitehead and Russell.

1960: Emile Delavenay, in a book on machine translation:

"While a great deal remains to be done, it can be stated without hesitation that the essential has already been accomplished."

1965: Irving John Good, in speculations on the future of AI:

"It is more probable than not that, within the twentieth century, an ultraintelligent machine will be built and that it will be the last invention that man need make."

1968: Marvin Minsky, the technical adviser for the movie *2001*:

"The HAL 9000 is a *conservative estimate* of the level of artificial intelligence in 2001."

The Ultimate Understanding Engine

Sentences uttered by a child named Laura before the age of 3. *

Here's a seat. It must be mine if it's a little one.

I went to the aquarium and saw the fish.

I want this doll because she's big.

*When I was a little girl, I could go "geek geek" like that,
but now I can go "This is a chair."*

Laura used a larger subset of logic than Montague formalized.

No computer system today has Laura's ability to learn, speak, and understand language.

* John Limber, The genesis of complex sentences. In T. Moore (Ed.), *Cognitive development and the acquisition of language*. New York: Academic Press, 1973.
http://pubpages.unh.edu/~jel/JLimber/Genesis_complex_sentences.pdf

Why Has Progress Been So Slow?

Theorem provers in 1960 were much faster than humans.

Today's computers are a million times bigger and faster.

If deduction were the critical bottleneck, the predictions by Delavenay, Good, and Minsky would have come true years ago.

What is the bottleneck? Is it the amount of knowledge required?

Claims by Lenat and Feigenbaum (1987):

1. "Slowly hand-code a large, broad knowledge base."

2. "When enough knowledge is present, it will be faster to acquire more through reading, assimilating data bases, etc."

3. "To go beyond the frontier of human knowledge, the system will have to rely on learning by discovery, carrying out research and development projects to expand its KB."

Cyc Project

The largest system based on formal logic and ontology:

- **Cyc project founded by Doug Lenat in 1984.**
- **Starting goal: Implement the background knowledge of a typical high-school graduate.**
- **Ultimate goal: Learn new knowledge by reading textbooks.**

After the first 25 years,

- **100 million dollars and 1000 person-years of work,**
- **600,000 concepts,**
- **Defined by 5,000,000 axioms,**
- **Organized in 6,000 microtheories.**

Some good applications, but more needs to be done:

- **Cyc cannot yet learn by reading a textbook.**
- **Cyc cannot understand language as well as a child.**

Bird Nest Problem

Robots can perform many tasks with great precision.

But they don't have the flexibility to handle unexpected shapes,

They can't wash dishes the way people do — with an open-ended variety of shapes and sizes.

And they can't build a nest in an irregular tree with irregular twigs, straw, and moss.

If a human guides a robot through a complex task with complex material, the robot can repeat the same task in the same way.

But it doesn't have the flexibility of a bird, a beaver, or a human.

Intelligence and Tools

The ability to make tools is a critical sign of intelligence:

- All animals, including humans, are born with a set of built-in tools.

- Birds can't wash dishes for the same reason that humans can't wash dishes with a sewing machine: they have the wrong tools.

- Humans make and use the most elaborate tools, but biologists keep discovering more species that make and use tools.

The role of instinct:

- Birds have an instinct to build nests, beavers have an instinct to build dams, and humans have an instinct to speak a language.

- But the details of the nests, dams, and languages depend on the animals' built-in tools, the environment, learning from parents, and creativity.

Language is a kind of mental tool: *

- The power and flexibility of language results from its integration with every aspect of perception, action, cognition, and learning.

* Stout, Toth, Schick, & Chaminade (2008) Neural correlates of early stone age toolmaking: technology, language and cognition in human evolution.

Learning: Deep, Active, and Cognitive

Geoffrey Hinton, a leader in the development of artificial neural nets, showed that multiple levels of nets are better. *

- **Nets at the early levels learn low-level features.**

- **Later levels learn combinations of the lower-level features.**

- **The multilevel version that he called *deep learning* can learn complex patterns more quickly and accurately than a single, larger net.**

Other researchers claim that *active learning* is better. **

- **Different aspects of a pattern are signficant for different purposes.**

- **Animals constantly shift their attention from one aspect to another.**

- **Active learning should use feedback from other cognitive processes.**

But there is more to learning than pattern recognition.

- **For all animals, learning supports and depends on every aspect of perception, action, and cognition.**

* http://www.cs.toronto.edu/~hinton/
** http://burrsettles.com/pub/settles.activelearning.pdf

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Visualization and Formalization

Paul Halmos, mathematician:

"Mathematics — this may surprise or shock some — is never deductive in its creation. The mathematician at work makes vague guesses, visualizes broad generalizations, and jumps to unwarranted conclusions. He arranges and rearranges his ideas, and becomes convinced of their truth long before he can write down a logical proof... the deductive stage, writing the results down, and writing its rigorous proof are relatively trivial once the real insight arrives; it is more the draftsman's work not the architect's." *

Albert Einstein, physicist:

"The words or the language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The psychical entities which seem to serve as elements in thought are certain signs and more or less clear images which can be *voluntarily* reproduced and combined... The above-mentioned elements are, in my case, of visual and some of muscular type. Conventional words or other signs have to be sought for laboriously only in a secondary stage, when the mentioned associative play is sufficiently established and can be reproduced at will." **

* Halmos (1968). ** Quoted by Hadamard (1945).

Semantics Without Visualization

Richard Montague (1970):

"I reject the contention that an important theoretical difference exists between formal and natural languages."

Hans Kamp (2001):

"The basic concepts of linguistics — and especially those of semantics — have to be thought through anew... Many more distinctions have to be drawn than are dreamt of in current semantic theory."

Barbara Partee (2005):

"The present formalizations of model-theoretic semantics are undoubtedly still rather primitive compared to what is needed to capture many important semantic properties of natural languages... There are other approaches to semantics that are concerned with other aspects of natural language, perhaps even cognitively *deeper* in some sense, but which we presently lack the tools to adequately formalize."

Kamp was a student of Montague's who developed Discourse Representation Theory. Both Kamp and Partee have promoted formal semantics for years.

Language, Logic, and Perception

For everyone from Laura to Einstein, perception, action, and mental models are more fundamental than language or logic.

Meanings expressed in language are based on perception.

Thinking and reasoning are based on mental models that use the same mechanisms as perception and action.

The symbols and syntax of mathematics and logic are abstractions from the symbols and patterns in natural languages.
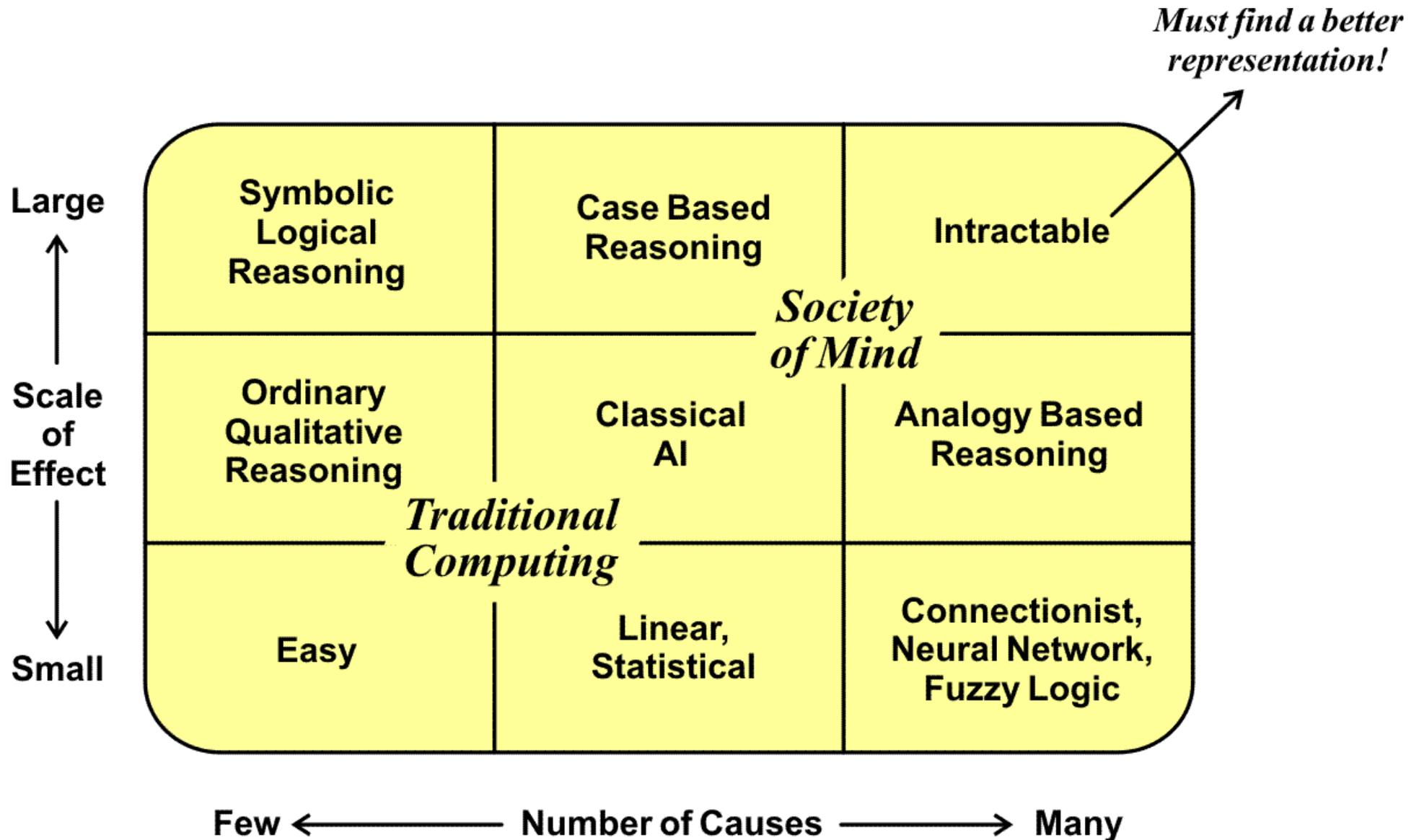
Computer systems can manipulate those symbols much faster and more accurately than any human.

But computers are much less efficient in perception and action.

That limitation makes them unable to process language in the same way that people do.

How could computers support human-like methods?

Minsky's Challenge

Must find a better representation!

	Few ← Number of Causes → Many		
Large	Symbolic Logical Reasoning	Case Based Reasoning	Intractable
Scale of Effect	Ordinary Qualitative Reasoning	Classical AI	Analogy Based Reasoning
Small	Easy	Linear, Statistical	Connectionist, Neural Network, Fuzzy Logic

Society of Mind

Traditional Computing

Adapted from a diagram by Minsky, Singh, & Sloman (2004).

Meeting the Challenge

As Minsky's diagram shows, AI methods cannot process large numbers of causes and complex effects as efficiently as humans.

Statistical methods and neural networks can relate many causes (input variables), but only small-scale effects (simple outputs).

Logic can reason about complex effects (multiple interrelated phenomena), but only with simplified causes (few axioms).

In his *Society of Mind* and *Emotion Engine*, Minsky proposed systems of heterogeneous, interacting agents:

- How could those agents improve computational efficiency?
- Can psycholinguistics and neuroscience guide the design of agents?
- What kind of logic, reasoning, and semantics would they support?
- Would they use symbolic, statistical, or image-like representations?
- Or would they use a combination of many kinds of representations?

2. Psycholinguistics and Neuroscience

Language is a late development in evolutionary time.

Systems of perception and action were highly developed long before some early hominin began to talk.

People and higher mammals use the mechanisms of perception and action as the basis for mental models and reasoning.

Language understanding and generation use those mechanisms.

Logic and mathematics are based on abstractions from language that use the same systems of perception and action.

Language can express logic, but it does not depend on logic.

Language is situated, embodied, distributed, and dynamic.

3. Semantics of Natural Languages

Human language is based on the way people think about everything they see, hear, feel, and do.

And thinking is intimately integrated with perception and action.

The semantics and pragmatics of a language are

- **Situated in time and space,**

- **Distributed in the brains of every speaker of the language,**

- **Dynamically generated and interpreted in terms of a constantly developing and changing context,**

- **Embodied and supported by the sensory and motor organs.**

These points summarize current views by psycholinguists.

Philosophers and logicians have debated other issues:

- **NL as a formal logic; a sharp dichotomy between NL and logic; a continuum between NL and logic.**

4. Ludwig Wittgenstein

Considered one of the greatest philosophers of the 20th century.

Wrote his first book under the influence of Frege and Russell.

That book had an enormous influence on analytic philosophy, formal ontology, and formal semantics of natural languages.

But Wittgenstein retired from philosophy to teach elementary school in an Austrian mountain village.

In 1929, Russell and others persuaded him to return to Cambridge University, where he taught philosophy.

During the 1930s, he began to rethink and criticize the foundations of his earlier book, including many ideas he had adopted from Frege and Russell.

5. Dynamics of Language and Reasoning

Natural languages adapt to the ever-changing phenomena of the world, the progress in science, and the social interactions of life.

No computer system is as flexible as a human being in learning and responding to the dynamic aspects of language.

Three strategies for natural language processing (NLP):

1. **Neat: Define formal grammars with model-theoretic semantics that treat NL as a version of logic. Wittgenstein pioneered this strategy in his first book and became the sharpest critic of its limitations.**

2. **Scruffy: Use heuristics to implement practical applications. Schank was the strongest proponent of this approach in the 1970s and '80s.**

3. **Mixed: Develop a framework that can use a mixture of neat and scruffy methods for specific applications.**

NLP requires a dynamic foundation that can efficiently relate and integrate a wide range of neat, scruffy, and mixed methods.

6. Analogy and Case-Based Reasoning

Based on the same kind of pattern matching as perception:

- Associative retrieval by matching patterns.
- Approximate pattern matching for analogies and metaphors.
- Precise pattern matching for logic and mathematics.

Analogies can support informal, case-based reasoning:

- Long-term memory can store large numbers of previous experiences.
- Any new case can be matched to similar cases in long-term memory.
- Close matches are ranked by a measure of semantic distance.

Formal reasoning is based on a disciplined use of analogy:

- Induction: Generalize multiple cases to create rules or axioms.
- Deduction: Match (unify) a new case with part of some rule or axiom.
- Abduction: Form a hypothesis based on aspects of similar cases.

7. Learning by Reading

Perfect understanding of natural language is an elusive goal:

- Even native speakers don't understand every text in their language.
- Without human bodies and feelings, computer models will always be imperfect approximations to human thought.

For technical subjects, computer models can be quite good:

- Subjects that are already formalized, such as mathematics and computer programs, are ideal for computer sytems.
- Physics is harder, because the applications require visualization.
- Poetry and jokes are the hardest to understand.

But NLP systems can learn background knowledge by reading:

- Start with a small, underspecified ontology of the subject.
- Use some lexical semantics, especially for the verbs.
- Read texts to improve the ontology and the lexical semantics.
- The primary role for human tutors is to detect and correct errors.

What is Language Understanding?

Understanding a text in some language does not require a translation to a language of thought or logical form.

Instead, it requires an interpreter, human or robot, to relate the text to his, her, or its context, knowledge, and goals:

- That process changes the interpreter's background knowledge.
- But the kind of change depends critically on the context, goals, and available knowledge.
- No two interpreters understand a text in exactly the same way.
- With different contexts, goals, or knowledge, the same interpreter may understand a text in different ways.

The evidence of understanding is an appropriate response to a text by an interpreter in a given situation.

If a robot responds appropriately to a command, does it understand? What if it explains how and why it responded?

Related Readings

Future directions for semantic systems,
   http://www.jfsowa.com/pubs/futures.pdf

From existential graphs to conceptual graphs,
   http://www.jfsowa.com/pubs/eg2cg.pdf

Role of Logic and Ontology in Language and Reasoning,
   http://www.jfsowa.com/pubs/rolelog.pdf

Fads and Fallacies About Logic,
   http://www.jfsowa.com/pubs/fflogic.pdf

Conceptual Graphs for Representing Conceptual Structures,
   http://www.jfsowa.com/pubs/cg4cs.pdf

Peirce's tutorial on existential graphs,
   http://www.jfsowa.com/pubs/egtut.pdf

ISO/IEC standard 24707 for Common Logic,
   http://standards.iso.org/ittf/PubliclyAvailableStandards/c039175_ISO_IEC_24707_2007(E).zip

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For more information about the VivoMind software:

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Harrison, Colin James (2000) *PureNet: A modeling program for neurocognitive linguistics*, http://scholarship.rice.edu/bitstream/handle/1911/19501/9969261.PDF

For other references, see the combined bibliography for this site:

http://www.jfsowa.com/bib.htm