Lecture 10
Mental Representation
Mental Representations: Overview

- Basics of representation
- Categorisations
- Palmer - Fundamental Aspects of Cognitive Representation
  - Knowledge Representation Theory
- Analogical Representations
  - Misrepresentations
- Mental Models
Mental Representations: Overview

- Basics of representation
- Categorisations
- Palmer - Fundamental Aspects of Cognitive Representation
  - Knowledge Representation Theory
- Analogical Representations
  - Misrepresentations
- Mental Models
Basics of representation
(Charles Sanders Peirce)

- Representation
  - (1) is realized by a representation bearer
  - (2) it has content or represents one or more objects
  - (3) its representation relations are grounded in some way
  - (4) it can be interpreted by some interpreter

Mind/brain computer metaphor

- What kind of computer? => what kind of representation?
  - conventional von Neumann (symbolic, rule-based, local) => data structured
  - connectionist (parallel, distributed) => activation states of nodes or sets of nodes
    - + implicit knowledge in connections

Properties of cognitive capacities

- Pretheoretical properties
  - (1) each capacity is intentional (*aboutness*)
  - (2) all capacities can be pragmatically evaluated (degrees of success)
  - (3) most capacities - productive

- Posit mental representations that can represent
  - specific objects
  - different kinds of objects (concrete objects, sets, properties, events, states of world)
  - both correct and incorrect
  - with constituent structure (productivity clause)
  - with compositional semantics (productivity)

- Last two used against connectionism (Fodor and Pylyshyn, 1988)

Grounding of mental representations

- **Functional role semantics** (procedural semantics) - Wittgenstein, Sellars, Harman, Field - the meaning of a mental representation is its role in the cognitive life of the agent (*use* theory of meaning)
  - allows for actual and counterfactual reasoning (what use a symbol would have had if states had differed)

- **Informational semantics** - symbol-world relationship is described in information-theoretic terms (source, signal, receiver); existence of thought depends on the capacity of systems to transform (perceptual) information into meaning

- **Structural isomorphism** - mental representation as a model of the thing it represents (Palmer)

- **Causal historical** (Devitt, Sterelny) - a token in the language of thought applies to an object if there is a causal chain connecting representation bearer with object

- **Biological function** (Millikan, 1984) - akin to animal communication signals, mental representations are “intentional icons”; content depends on natural associations between such icons and biological functions of the interpreter device (bee dance+nectar location associations)
Mental Representations: Overview

- Basics of representation
- Categorisations
  - Palmer - Fundamental Aspects of Cognitive Representation
    - Knowledge Representation Theory
  - Analogical Representations
    - Misrepresentations
- Mental Models
Categorizations I
(Thagard, P., 1995)

- 6 main kinds, each with associated computational processes
  - sentences or well-formed formulas of a logical system
  - rules (like in production systems)
  - concept representations (i.e. frames)
  - schemata
  - scripts, analogies, images
  - connectionist

Logic (and well-formed sentences)

- well-formed => syntactic way of making inferences, independent of (semantic) content
- syllogism (Greek - *inference, conclusion*), deductive reasoning (Aristotle)
  - All men are mortal. (proposition, asserted true, major premise)
  - Socrates is a man. (proposition, asserted true, minor premise)
  - => Therefore, Socrates is mortal. (conclusion)
- great in inference power, as representation little psychological plausibility
Rules (and production systems)

- was meant to represent the way people do logical reasoning
- IF <condition> THEN <action>
- rules - match to condition and actions - not universally true (difference from logic)
- example: Getting a train ticket from a train ticket machine
- good representational power (however, one needs to add in all conditions and actions explicitly)
Concepts

- related to categories - groupings of concrete and abstract objects
- elements of propositional thought (but not only)
- a few main theories
  - classical view - concepts defined by a conjunction of singly necessary and jointly sufficient attributes (problems: non-necessary information included, typicality judgements, different categorisations)
  - prototype theory - most common attributes of a category (Rosch and Mervis, 1975)
  - exemplar theory - not a prototype, but multiple exemplars (Medin and Shoben, 1988)
  - theory theory - concepts are part of understanding of the world, developmental view, relations to other concepts important (Murphy and Medin, 1985)
- closer to the level at which people reason (explicitly); higher psychological plausibility
Frames (Minsky, 1975) and schemata

- knowledge structures posited to represent knowledge of ordinary aspects of the world (e.g. what is a room? a classroom? a kitchen?)
- contain fixed structural information
- posited for both human knowledge and AI knowledge
- frames will provide default values to knowledge about the world when knowledge from observation is missing (bias)
  - example: fluorescent lights memory of classroom;
  - biases in witness testimony
- schemata - psychological constructs, primitive forms of generic knowledge (related to frames)
Scripts

- scripts - subclass of schemata (Schank and Abelson, 1977), similar to frames
- represent sequences of actions which can be made generic (closer to representing procedural knowledge)
  - example: order in a restaurant
Analogy

- similarity between two different domains, in which same relations hold
- can be used as inference, hypothesizing, learning and discovery tool
- case-based reasoning - assuming each new situation will be categorised by analogy to a known case, and acted upon accordingly
- done by a mapping process which aims to align the structures of two representations (Gentner’s structure-mapping theory, 1983)
  - involves adaptation and re-representation of one or both analogues
- psychologically plausible
Categorizations II

- dual-coding theory (Paivio, 1986)
  - two basics modes of representation
    - imagistic
    - propositional

- Eysenck, M. W., and M. T. Keane.
  - imagistic - modality-specific, nondiscrete, implicit, loose combination rules
  - propositional - amodal, discrete, explicit, strong combination rules

Mental Representations: Overview

- Basics of representation
- Categorisations
- Palmer - Fundamental Aspects of Cognitive Representation
  - Knowledge Representation Theory
- Analogical Representations
  - Misrepresentations
- Mental Models
Fundamental Aspects of Cognitive Representation (Palmer, 1978)

- Knowledge Representation Theory

- Goal: To understand the nature of (internal and external) representations of the world

- Concise theory of cognitive representations that
  - can be tested by empirical methods of psychology
  - can be used for the construction of artificial representation systems
Knowledge Representation Theory (Palmer, 1978)

- Meta theory of representations to describe properties of representations

- To understand *mental* representations, it is useful to examine properties of *external* representations
  - moving from simple to complex to clarify basic issues
Knowledge Representation Theory

- Represented world
- Representing World

Correspondence
Relation

[Palmer, 1978]
Knowledge Representation Theory (Palmer, 1978): Representation system

Five components of a representation system:

1) the represented world $W_1$,

2) the representing world $W_2$,

3) what aspects of the represented world are being modeled?

4) what aspects of the representing world are doing the modeling?

5) what are the correspondences between the two worlds?
Knowledge Representation Theory (Palmer, 1978): Two Worlds and their Relations

- Represented World: A world *about which* we want to make statements / assertions

- Representing World: A world *in which* we make statements / assertions / inferences

- In cognitive science, it is very important to distinguish the two worlds (e.g. terminologically); otherwise it easily can happen that the representing world is identified with the ‘true world’.

- A representation always is a representation *of something*.

- Can we make sure that the result of an operation in the representing world represents something in the represented world?
Knowledge Representation Theory (Palmer, 1978): Examples of Spatial Representation

A. Represented world
B. Taller than => Longer than
C. Wider than => Longer than
D. Larger than => Longer than
E. Taller than => Shorter than
F. Taller than => Larger than
G. Taller than => Points to
H. Taller than => Chains to
Intrinsic vs. extrinsic representation

- A representing world that necessarily maintains a property of the represented world represents this property \textit{intrinsically}, otherwise it represents this property \textit{extrinsically}.

- Example:

representation of transitivity of the relation “taller than”
Intrinsic vs. extrinsic representation

Language: Extrinsic representation

- There is no language-inherent constraint that prevents conflicting propositions like:
  - a is taller than b
    - and
  - b is taller than a
Knowledge Representation Theory (Palmer, 1978): Cognitive Representation

![Diagram showing relationships between mental model, real world, mental world, and cognitive theory.]

- Mental model represents Real world and describes Cognitive theory.
- Mental world represents Mental model and describes Cognitive theory.
- Real world represents Mental model and Mental world.
- Cognitive theory describes Mental model and Mental world.
Mental Representations: Overview

- Basics of representation
- Categorisations
- Palmer - Fundamental Aspects of Cognitive Representation
  - Knowledge Representation Theory
- Analogical Representations
  - Misrepresentations
- Mental Models
Analogical Representations: Aaron Sloman (1971)

*Interactions between philosophy and artificial intelligence: The role of intuition and non-logical reasoning in intelligence*

- Philosophical issues can be enriched considerably through artificial intelligence
- Influential work triggering many discussions about representation types
- Intuitive Reasoning
Analogical Representations (Aaron Sloman, 1971):

Intuitive Reasoning

- Non-logic-based reasoning = illogical reasoning ???
- Non-linguistic representations
- Analogical representations, e.g. maps or scaled models
## Terminological clarification: “Analogical” and “Analog”

<table>
<thead>
<tr>
<th>Analog-ical</th>
<th>vs.</th>
<th>Frege-an</th>
</tr>
</thead>
<tbody>
<tr>
<td>(structure-preserving)</td>
<td></td>
<td>not structure-preserving</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Analog</th>
<th>vs.</th>
<th>Digital</th>
</tr>
</thead>
<tbody>
<tr>
<td>(continuous)</td>
<td></td>
<td>discrete</td>
</tr>
</tbody>
</table>
Analogical Representations (Aaron Sloman, 1971):

Ways of thinking & representing

- How are animals able to cope with their spatio-temporal environment?
  - They require a suitable conceptual and perceptual apparatus
  - They need to consider changes

- Different types of representations
  - in the world
  - for thinking
  - in the computer

- Are diagrams essential for a proof or are they merely psychological padding?
What are Formal Languages?

- Predicate logic?
- Programming languages?
- The “language” of maps?
- … of sketches?

*Logically valid inferences are a special case of something more general*
Analogical Representations (Aaron Sloman, 1971): Visual inferences (I)

- motion inference?
Analogical Representations (Aaron Sloman, 1971): Visual inferences (II)

- motion inference result
Analogical Representations (Aaron Sloman, 1971):
Valid inferences
Analogical Representations (Aaron Sloman, 1971): Analogical vs. Fregean (I)

- How can we decide which type of representation system to use in a given situation?
  - Which types of representations could be most useful?
  - Specific problem-dependent vs. general problem-independent strategies

- Images, maps, scaled models are largely **analogue**;

- Predicate calculus (invented by Gottlob Frege), programming languages, natural languages are largely (but not exclusively) **Fregean**.
Analogical Representations (Aaron Sloman, 1971): Analogical vs. Fregean (II)

- In an *analogical* system, properties of and relations between parts of the representing configuration *represent* properties of and relations between parts of a complex represented configuration.

- The structure of the representation reflects the structure of the represented world.
Analogical Representations (Aaron Sloman, 1971): Correspondence relations may be complex

- Context-dependent interpretation may be required:
  - “above” in the representation may mean “above”, “farther”, “closer”, “farther and
Analogical Representations (Aaron Sloman, 1971):

Fregean Representations (in contrast)

- Only one kind of relation between parts of a relation:
  - relation between “function-signs” and “argument-signs”

Example:

*The brother of the wife of Tom*

Two function-signs:  “the brother of ( )”
                      “wife of ( )”

Two argument-signs:  “Tom”
                      “wife of Tom”

→ *the brother of (the wife of (Tom))*
Analogical Representations (Aaron Sloman, 1971): Fregean Representations

- No correspondence between representing and represented configuration required

- Possibly correspondence with structures of procedures, by which the object is identified (structure of a route through a complex data structure)

- Predicate calculus is exclusively Fregean (compositionality of connectives like not, and, etc.)
Analogical Representations (Aaron Sloman, 1971): Natural Languages and Programming Languages

- Partially analogical
  - linear sequence of program segments corresponds largely to temporal process sequence
  - similar with (most) narratives

- Advantage of Fregean system: structure of the medium does not constrain the multitude of structures that can be represented or described

- Very general formation, representation, and inference rules can be applied to Fregean languages for very different domains
Analogical Representations (Aaron Sloman, 1971):
Restrictions for Analogical Representations

- Difficult or impossible to design a single two-dimensional analogical system for the representation of political, mechanical, musical, and chemical structures and processes

- Trade-off: Generality vs. Efficiency
  - Fregean systems are general
  - Analogical representations can be more efficient
Sloman’s “Afterthoughts” (1975)

- Terminological Explanation:
  - Fregean vs. symbolic (too general),
  - verbal (too special)

- Common misrepresentations (8)
Misrepresentations (1)

● “Analogical representations are continuous, Fregean representations discrete.”

● Counter-example:

   A list whose elements are ordered according to the order of what they represent.
“Analogue representations are 2-dimensional, Fregean representations are 1-dimensional.”

Counter-example:
- 1D analogue representations (e.g. list)
- 2D Fregean mathematical notation (integral or summation symbols, normal representation of fractions)
Misrepresentations (3)

- “Analogical representations are isomorphic with what they represent.”

- Counter-example:
  - 2D pictures need not be isomorphic with the 3D scenes they represent analogically
Misrepresentations (4)

- “Fregean representations are symbolic, analogical representations non-symbolic.”

- Counter-example:
  - “Symbolic” includes both maps and sentences of a language; the notion *symbolic* often is used in a sloppy way
Misrepresentations (5)

● “Sentences in a natural language are all Fregean.”

● Counter-example:
  ● Some English sentences function in a partially analogical way:

    She shot him and kissed him
    vs.
    She kissed him and shot him

*Tom, Dick and Harry stood in that order*
“Analogical representations are complete”
  - while Fregean representations may be incomplete: *Tom stood between Dick and Harry*
  - no information about other people

Counter-example:
  - A map or sketch map showing only some of the towns
“Fregean representations have a grammar, analogical representations do not.”

Counter-argument

- It is easy to define a grammar for lists and trees frequently used as analogical representations in computing.
Misrepresentations (8)

- “Although digital computers can use Fregean representations, only analog computers can handle analogical representations”

- Should be clear by now.
Mental Representations: Overview

- Basics of representation
- Categorisations
- Palmer - Fundamental Aspects of Cognitive Representation
  - Knowledge Representation Theory
- Analogical Representations
  - Misrepresentations
- Mental Models
Mental Models

● Human beings translate external events into internal models and reason by manipulating these symbolic representations.

Kenneth Craik 1943

● “Model”: a system which has a similar relation-structure to that of the processes it imitates

The spoon is to the left of the knife
The plate is to the right of the knife
The fork is in front of the spoon
The cup is in front of the knife

Where is the fork in relation to the cup?

The spoon is to the left of the knife
The plate is to the right of the knife
The fork is in front of the spoon
The cup is in front of the knife

- Where is the fork in relation to the cup?

  spoon   knife    plate
  fork    cup

Interpretation by inspection
Indeterminate Descriptions
(Byrne & Johnson-Laird, 1989)

The spoon is to the left of the knife
The plate is to the right of the spoon
The fork is in front of the plate
The cup is in front of the knife

• Where is the fork in relation to the cup?
Indeterminate Descriptions
(Byrne & Johnson-Laird, 1989)

The spoon is to the left of the knife
The plate is to the right of the spoon
The fork is in front of the plate
The cup is in front of the knife

● Where is the fork in relation to the cup?

  spoon   knife   plate      spoon   plate   knife
  cup     fork     fork     cup

● More difficult – takes longer

● Reasoning not based on formal rules of inference, but on processes
  that construct models and formulate conclusions from them.
Preferred Mental Models
(Knauff, Rauh, Schlieder, 1995)

- Certain mental models are generated more easily than others

- Example:
  - the reception immediately precedes the dinner
  - the dinner takes place during the final rehearsal

- The following relations are possible:
  - the reception overlaps with the rehearsal
  - the reception takes place during the rehearsal
  - the reception starts with the rehearsal
  - the reception precedes the rehearsal
Preferred Mental Models

- People are frequently happy when they found one (of several possible) solutions

- People are not good at pursuing several hypotheses simultaneously
Next week

- Mental Images, Rotation, Scanning, Attention