Cognitive Systems

Foundations of Information Processing in Natural and Artificial Systems

Lecture 9

Mental Representations

Universität Bremen

Mental Representations: Overview

- 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 methods of psychology behavior research

Knowledge Representation Theory (Palmer, 1978)

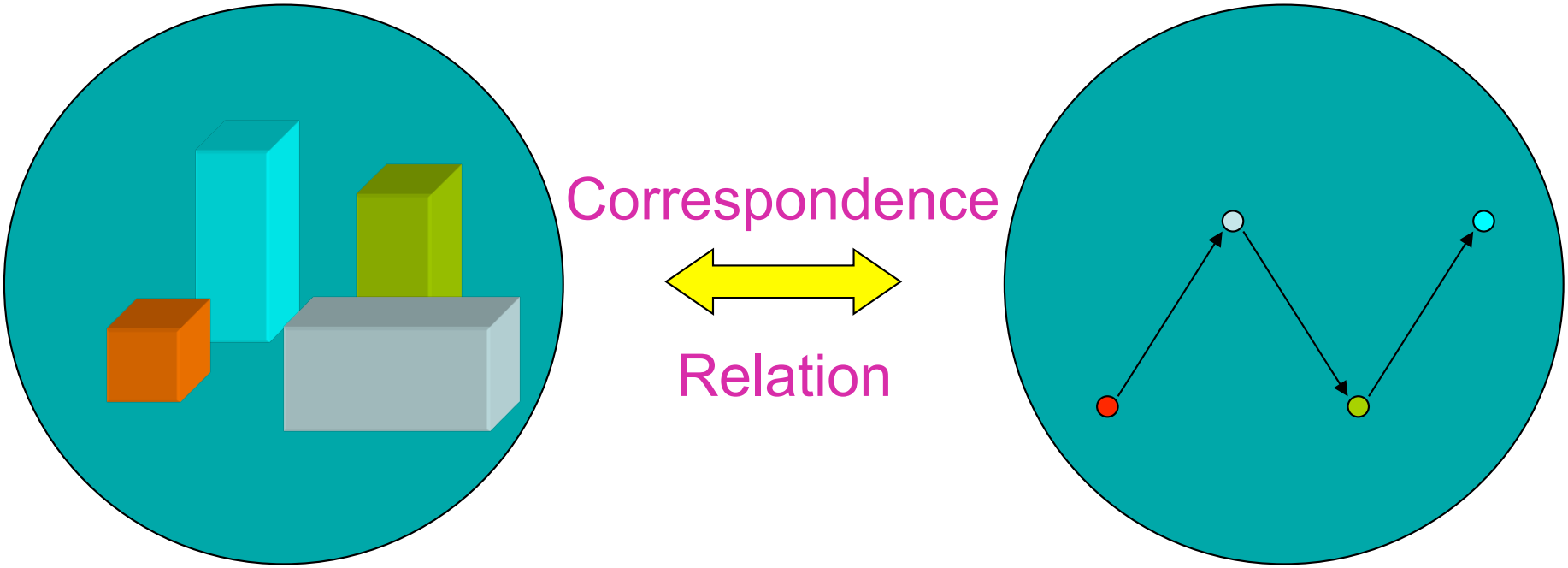
- Meta-Theory of representations to describe properties of representations

- 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 (Palmer, 1978)

Represented World

Representing World



[Palmer, 1978]

Knowledge Representation Theory (Palmer, 1978):
Representation system

Five components of a representation system:

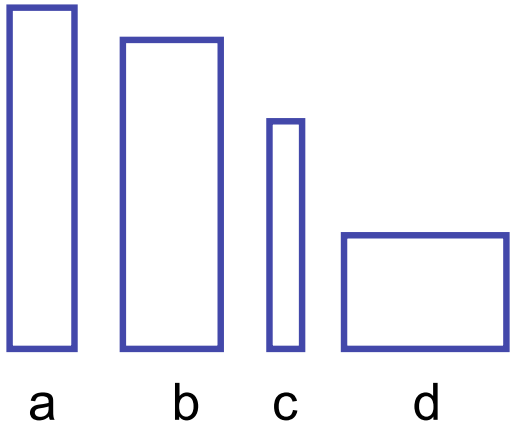
1) the represented world W_1,
2) the representing world W_2,
3) what aspects of the represented world are being modeled?
4) what aspects of the representing world are doing the modeling?
5) what are the correspondences between the two worlds?

Knowledge Representation Theory (Palmer, 1978):
Two Worlds and their Relations

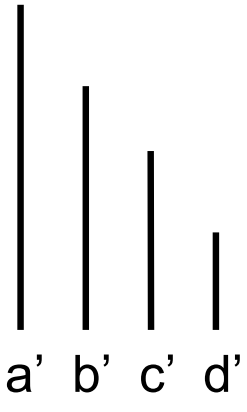
- Represented World: A world *about which* we want to make statements / assertions
- Representing World: A world *in which* we make statements / assertions / inferences
- In cognitive science, it is very important to distinguish the two worlds (e.g. terminologically); it easily can happen that the representing 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):

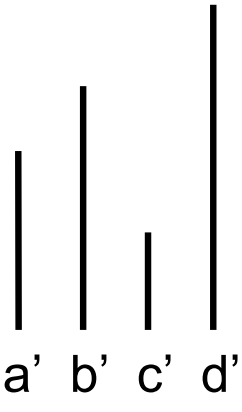
Examples of Spatial Representation



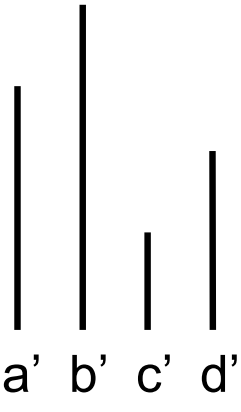
A Represented world



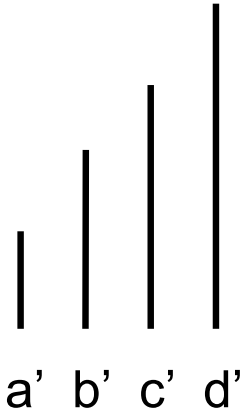
B Taller than
=> Longer than



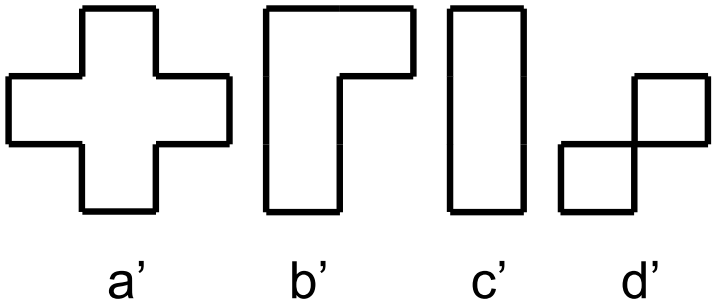
C Wider than
=> Longer than



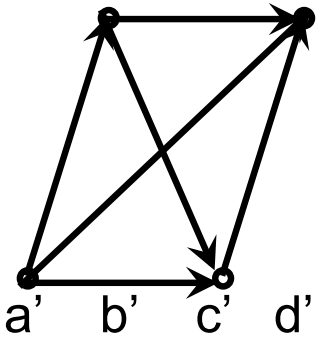
D Larger than
=> Longer than



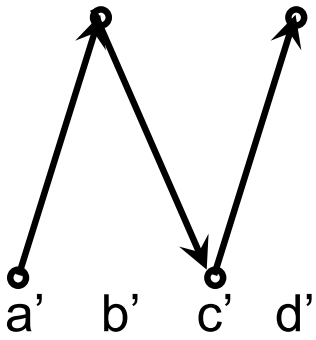
E Taller than
=> Shorter than



F Taller than
=> Larger than



G Taller than
=> Points to



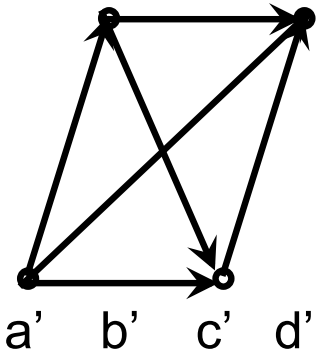
H Taller than
=> Chains to

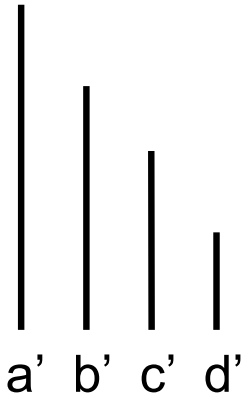
Knowledge Representation Theory (Palmer, 1978):
Intrinsic vs. extrinsic representation

A representing world that necessarily maintains a property of the represented world represents this property *intrinsically*, otherwise it represents this property *extrinsically.*

Example:

Taller than
=> Points to





Taller than
=> Longer than

extrinsic *intrinsic*

representation of transitivity
of the relation “taller than”

Knowledge Representation Theory (Palmer, 1978):

Intrinsic vs. extrinsic representation

- Language: Extrinsic representation

  – There is no inherent constraint that inhibits propositions like:

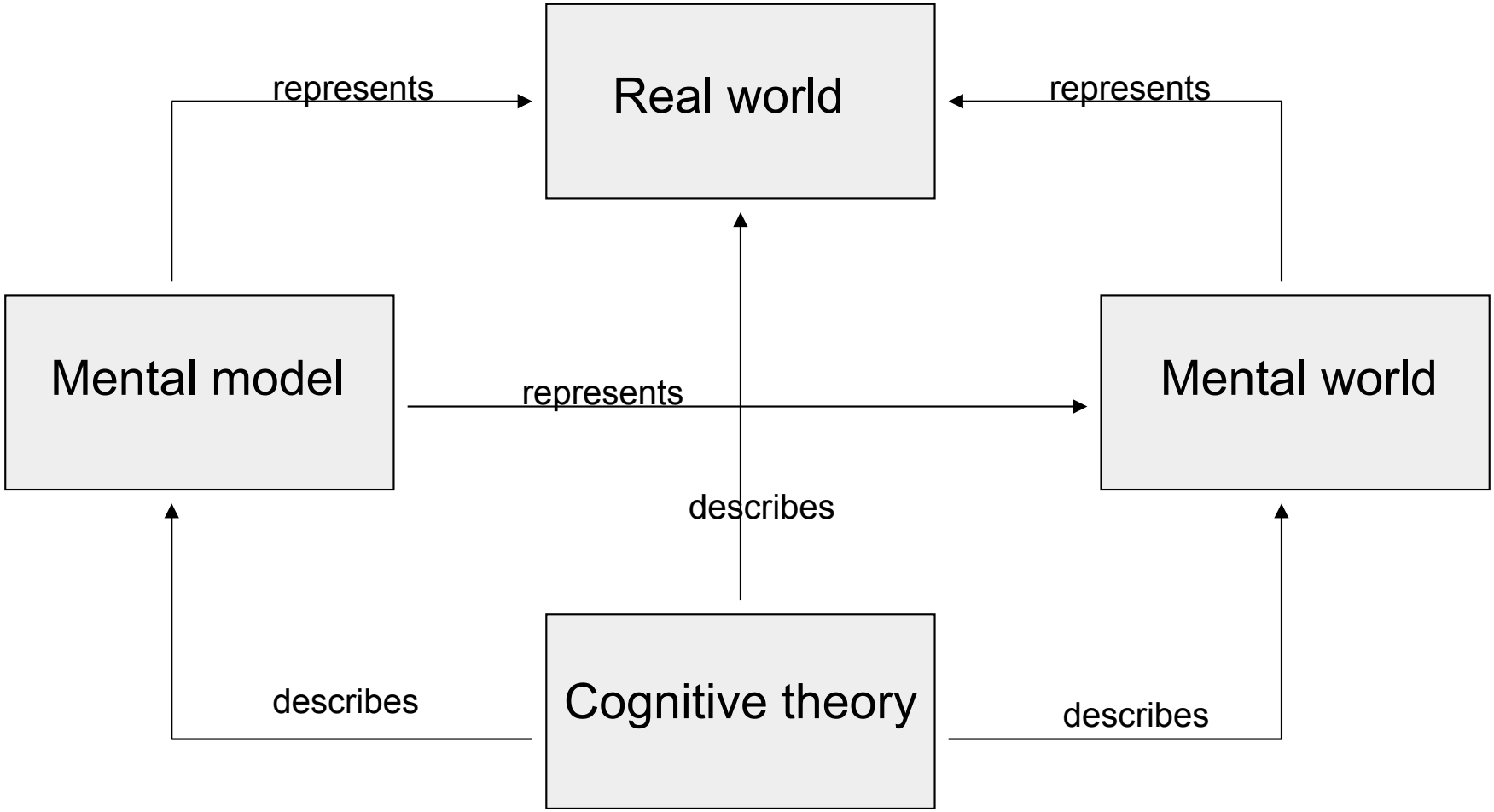
  – a is taller than b

  and

  – b is taller than a

Knowledge Representation Theory (Palmer, 1978):

Cognitive Representation



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

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"

- Analog-ical vs. Frege-an
  (structure-preserving – not structure-preserving)

- Analog vs. Digital
  (continuous – discrete)

Analogical Representations (Aaron Sloman, 1971): Ways of thinking & representing

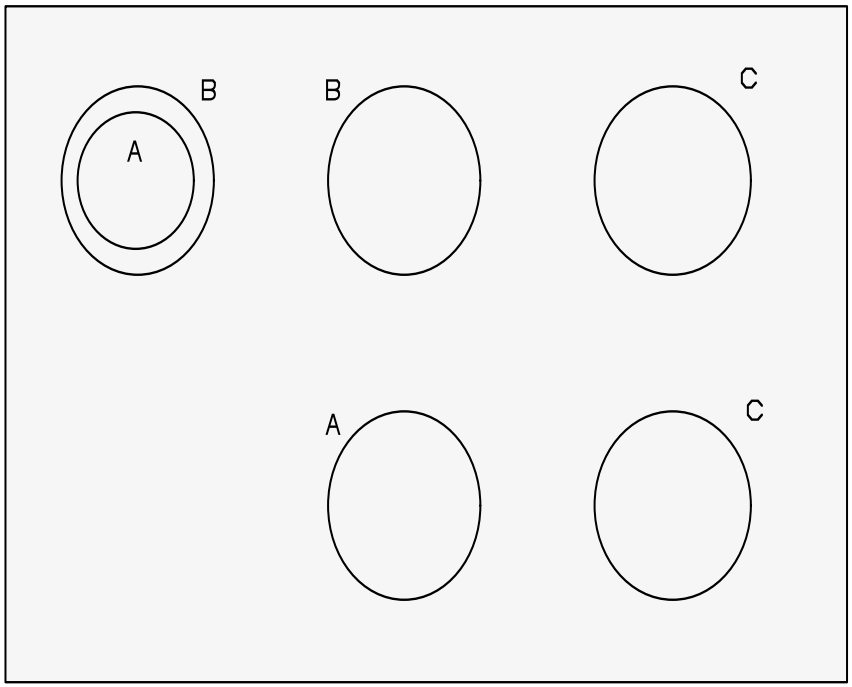
- How are Animals Able to Cope with their Spatio-Temporal Environment?
  - They require a suitable conceptual and perceptual apparatus
  - They need to consider changes
- Different types of representations
  - in the world
  - for thinking
  - in the computer
- Are diagrams essential for a proof or are 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):
Valid inferences



Analogical Representations (Aaron Sloman, 1971): Analogical vs. Fregean

- 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 *analogical*, predicate calculus (invented by Gottlob Frege), programming languages, natural languages are largely (but not exclusively) *Fregean*

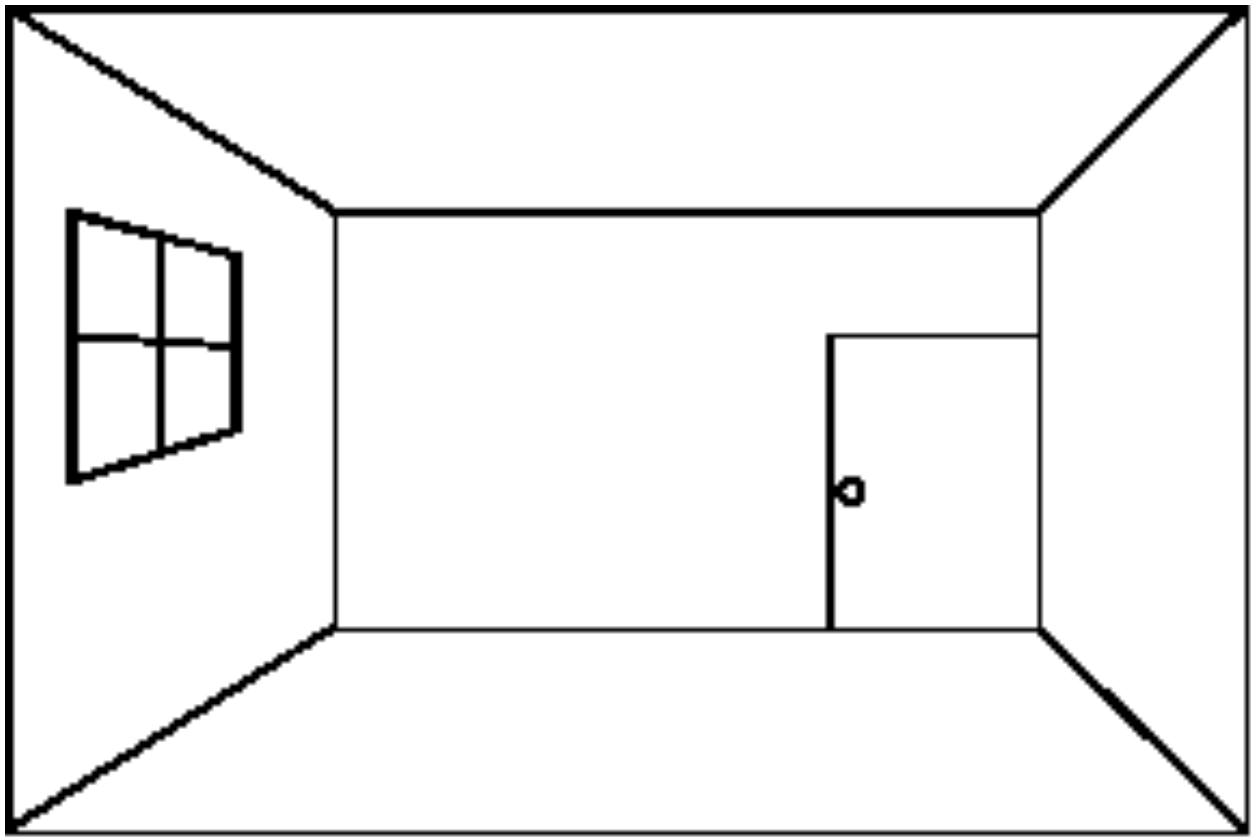
Analogical Representations (Aaron Sloman, 1971):

Analogical vs. Fregean

- 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 higher”, etc., in the real world; depending on local context

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 are more efficient

Pascale LE GALL, Agnès ARNOULD, Thomas BELLET 18.6.2009 10:15 OAS 3000

Graph transformations for topology-based geometric modeling

Topology-based geometric modeling distinguishes two aspects of objects : the topology giving their cellular structures made of vertices, edges, faces, etc. and their neighborhood relations) and the embedding precising their geometric shape. This is an efficient way to manage complex objects and define modeling operations. Topological data structures, usually called generalized maps, can be represented by labelled graphs whose labelled edges characterizing neignborhood relations satisfy some consistency constraints. As most topological operations can conveniently be defined by local transformations of the topological structure, we define them by using graph transformations rules.

We express syntactic properties on these rules ensuring both the dangling condition and preserving consistency constraints on topological structures.

As topological operations are often defined according to generic cellular structures, e.g. faces which can be specialized as a triangle, a square, a pentagon, ..., we introduce graph variables typed by the kind of concerned topological cells (vertices, edges, faces, etc.). We then define the substitution of these variables by using a pullback construction. We extend syntactic properties to these rules with variables ensuring the preservation of topological constraints. We close the talk by a presentation of our work in-progress concerning the introduction of variables denoting the dimension in order to define dimension independent operations and the simultaneous use of several variables to enrich our expressive power of our rule-based language, in particular, to define operations modifying geometric embedding of objects.

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.

Misrepresentations (2)

- “Analogical representations are 2-dimensional, Fregean representations are 1-dimensional.”

  Counter-example:

- 1D analogical 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*

Misrepresentations (6)

- "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

Misrepresentations (7)

- “Fregean representations have a grammar, analogical representations do not.”

- 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 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

Spatial reasoning in N-term series problems: Byrne & Johnson-Laird, 1989

- 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?

spoon knife plate
cup fork

spoon plate knife
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
  - mental rotation
  - mental scanning
  - attention