Modeling Mental Spatial Knowledge Processing as Integrating Paradigm for Spatial Reasoning

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Mental Spatial Knowledge Processing

Human reasoning about spatial environments or spatial configurations is often based on spatio-analogical mental representations (*mental images*). Due to restrictions in processing and storage capacity in human working memory, mental images are constructed dynamically as highly problem-adequate representations to infer a wanted spatial result.

In this contribution, I argue for the investigation of reasoning processes in mental images with respect to the integration of different aspects of spatial knowledge processing. From an AI perspective the properties of spatial knowledge processing in mental images point to a promising field of research in spatial and spatio-temporal reasoning.

Features of Spatial Knowledge Processing in Mental Images

The following core features of knowledge processing in mental images are of special interest for spatial and spatio-temporal reasoning.

Mental images integrate pieces of information. Mental images are constructed from pieces of information. Different spatial aspects (e.g., shapes, orientation information, topological relationships) are combined in a common representation. These pieces of information stem from long-term memory, from an actual visual perception, or from both sources.

Mental images process incomplete and coarse knowledge. Spatial knowledge used for the construction of the mental image in working memory is often incomplete, coarse, or of varying specificity. To compensate for incompleteness and to transform coarse spatial information into a specific image in the visual buffer, *default knowledge* has to be employed in the image construction process.

Mental images integrate pictorial and propositional information. Both pictorial (e.g., shape descriptions) and propositional (e.g., qualitative orientation relations) pieces of spatial information are integrated in the mental image. In the visual buffer, all kinds of spatial information are integrated in a unifying spatio-analogical representation.

Mental images have a variable resolution and scale. The mental representation medium for mental images (the *visual buffer*) is limited in size and in resolution. For this reason, mental images are constructed at a scale and a level of resolution that makes optimal use of the visual buffer. When more detailed or more coarse spatial information is needed, the image is zoomed accordingly.

Mental images are ontologically flexible. Prior to the integration of spatial entities in the image representation, the spatial type of the entities is often not determined (i.e., whether they are punctual, spatially extended, or linear). A spatial entity (e.g., a mountain range) may be processed as punctual object (e.g., when only the rough position in a continent is needed), as extended object (when its substructure is to be mentally represented), or as linear feature (when its property of separating two regions is in the focus of interest).

Processing spatial information in mental images is efficient. As mentioned above, human memory has severe capacity restrictions. The construction of mental images concentrates on spatial aspects relevant for a question at hand; an already constructed mental image is modified when additional or alternative pieces of spatial information have to be processed. Apart from having to cope with capacity restrictions, mental spatial reasoning processes often operate under time pressure. Mental images allow for computing fast (albeit suboptimal or non-exhaustive) solutions.

Mental images process both static and dynamic spatial information. Besides for reasoning about static configurations, mental images are also involved in processing dynamic spatial inferences. These dynamic inferences range from mental rotation of single objects to complex tasks in mental animation (i.e., complex dynamic processes are mentally inferred from static diagrams).

Approaches to Modeling Spatial Knowledge Processing in Mental Images

Several attempts to describe and utilize spatial knowledge processing in mental images have been made in cognitive psychology and in AI. Among them are implemented psychological models that demonstrate essential processing features of mental images (e.g., Kosslyn, 1980), functional psychological models that integrate extensive findings from neuroscience (e.g., Kosslyn, 1994), as well as pure AI adaptations that focus on the diagrammatic reasoning functionality rather than on cognitive modeling (e.g., Funt, 1980; Khenkhar, 1991; Glasgow & Papadias, 1992).

MIRAGE – Mental Images in Reasoning About Geographic Entities

As a cognitive modeling attempt from AI, the MIRAGE model (Barkowsky 2001; 2002) comprises many of the features of spatial knowledge processing listed above.

The model is based on the theses that (1) spatial knowledge is constructed on demand in working memory, that (2) this construction is based on underdetermined knowledge from long-term memory, that (3) that this knowledge from long-term memory comes in a fragmentary, hierarchically organized form, and that (4) the resulting representation in working memory is a mental image.

In the model, pieces of spatial knowledge from long-term memory (*spatial knowledge fragments*) are retrieved and successively integrated in a qualitative representation in activated long-term memory. To make this representation specific enough to evoke a mental image in the visual buffer, the representation is enriched by default assumptions (e.g. missing shape information for extended entities, missing qualitative spatial relations between entities involved). The resulting enriched representation is used for constructing the mental image proper in a visual buffer. This visual buffer representation is used to inspect the wanted spatial relation.

MIRAGE is intended as a first attempt to model the flexible way in which the human mind deals with spatial information that is fragmented, coarse, and incomplete.

Conclusions

Mental images are unifying representations in the human mind that integrate spatial knowledge of various types and from various sources. The construction of actual mental images in the visual buffer needs preprocessing in working memory to make the pieces of spatial information specific enough to construct the mental image proper.

From an AI point of view, modeling mental spatial knowledge processing in mental images is related to the field of diagrammatic reasoning: the use of a spatio-analogical representation medium for spatial knowledge processing immediately realizes spatial constraints through the structure of the medium.

Modeling spatial knowledge processing in mental images is interesting for two reasons: first, from a basic cognitive science research point of view, and second, under an application perspective.

Explaining Spatial Knowledge Processing in Mental Images. On the one hand, modeling spatial knowledge processing in mental images helps understand what is going on the mind when people reason spatially using mental images. On the other hand, this form of spatial reasoning seems to allow for deriving fundamental principles for the integration of different approaches of spatio-temporal reasoning.

Application Perspectives. An adequate computational model of mental processing of spatial knowledge offers interesting application perspectives. First, it should be interesting to employ such a model to overcome mental spatial reasoning limits that are due to capacity restrictions of the human mind. For example, in complex configuration tasks a system that externalizes mental reasoning processes may be helpful to keep track of comprehensive spatial reasoning processes. Second, a model of mental spatial knowledge processing can be integrated in interactive diagrammatic reasoning systems that cooperatively assist a human expert in carrying out spatial reasoning tasks (e.g., in urban planning). For example, the interactive system might solve standard problems according to a user's preferences, or it may interact with the human reasoning process to point to design alternatives or to avoid spatial inconsistencies.

References

Barkowsky, T. 2001. Mental processing of geographic knowledge. In D. R. Montello ed., *Spatial Information Theory - Foundations of Geographic Information Science* (pp. 371-386). Berlin: Springer.

Barkowsky, T. 2002. *Mental representation and processing of geographic knowledge - A computational approach*. Berlin: Springer.

Funt, B. 1980. Problem-solving with diagrammatic representations. *Artificial Intelligence, 13*, 201-230.

Glasgow, J., and Papadias, D. 1992. Computational imagery. *Cognitive Science, 16*, 355-394.

Khenkhar, M. 1991. Object-oriented representation of depictions on the basis of cell matrices. In O. Herzog and C.-R. Rollinger eds., *Text understanding in LILOG* (pp. 645-656). Berlin: Springer.

Kosslyn, S. M. 1980. *Image and mind*. Cambridge, MA: Harvard University Press.

Kosslyn, S. M. 1994. *Image and brain - The resolution of the imagery debate*. Cambridge, MA: MIT Press.