Casimir: Comprehensive Computational Modeling of Mental Spatial Knowledge Processing

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The ability to reason about space and spatial relations is crucial for a wide range of human activities. Due to this importance, spatial reasoning has been the subject of much psychological research over the last decades. One main finding is that spatial cognition processes employ special types of mental representations, namely *spatial mental models* and *mental images*. These representations are built from knowledge residing in long-term memory as well as from information that, at a given moment, is available from the environment via perception. Furthermore, mental models/images have been found to possess an array of analogical properties, i.e., some relations in the representing mental world are analogous to relations in the represented external world.

That being said, the analogical properties, in principle, provide the means to establish an advantageous bond between (1) computational cognitive modeling with the aim of gaining further insights into human spatial cognition; (2) designing artificial cognitive systems with enhanced spatial abilities that incorporate general principles of such computational models; and (3) computer-based applications that exploit the models to provide adequate spatial task assistance to the human reasoner. Yet, no computational cognitive model of spatial cognition currently exists that would be suited for such task: On the one hand, existing cognitive architectures aimed at modeling human cognition in general fail to take into account the special representations used in spatial reasoning. On the other hand, models that use analogical representations only address certain aspects of spatial cognition and not the whole range of spatial knowledge processing humans are capable of. Thus, a more general model of spatial cognition that employs analogical representations as observed in humans seems to be lacking. To close this gap, we currently develop *Casimir* (*c*ognitive *a*rchitecture, *s*pecification, and *i*mplementation of *m*ental *i*mage-based *r*easoning) as one such model in the project R1-[ImageSpace] of the SFB/TR8 Spatial Cognition.

Casimir comprises various modules, e.g., regarding long-term and working memories, or externalization. The modules realize distinct cognitive systems involved in spatial reasoning; they communicate via a common blackboard architecture, and consistent spatial cognition emerges from their interplay.

In long-term memory, the persistent (spatial) knowledge of the model is stored as a graph similar to a semantic network. Every node in the graph represents some information which is linked to other nodes (i.e., information) associated with it. Knowledge retrieval is realized by spreading activation as every node has some activation which declines over time, partly spreads to nodes linked to it, and determines whether this node is retrieved. Nodes with activation above a certain threshold enter working memory. A retrieval process results in some subnet, termed *spatial knowledge fragment*. In working memory, this fragment which is still propositional is transformed into an analogical representation, such as a spatial mental model or mental image. The actual representation type depends on the spatial task to be solved. In accord with basic psychological research we assume that the construction of mental images is cognitively more costly than the construction of mental models. Consequently, mental images are only created if the current task demands additional visual detail (e.g., form information) that only mental images but not mental models can provide. Whereas mental models and knowledge fragments reside in working memory proper (i.e., are held in non-specific representation formats), mental images due to their similarity to visual perception are held in a dedicated spatio-analogical substructure of working memory.

Due to the limited capacity of human working memory, humans frequently externalize spatial information into diagrams to reduce memory load. The externalization module realizes this aspect by mapping analogical working memory representations onto diagrams and vice versa.

Casmir’s implementation currently consists of a number of core modules and modules for long-term memory and externalization. Present work includes implementing working memory and integrating all modules.