Computational Modeling of Mental and External Reasoning with Sketches

Sven Bertel, Thomas Barkowsky, Peter König, Holger Schultheis, Christian Freksa

{bertel, barkowsky}@sfbtr8.uni-bremen.de, mail@peterkoenig.info,
{schulth, freksa}@sfbtr8.uni-bremen.de

Many spatial reasoning tasks involve external diagrams and mental images. Successful problem solving is often furthered by the close functional coupling of spatial reasoning with diagrams and images. For human problem solving of geographic tasks, we present the computational model NEVILLE which proposes a visual model of how mental images and external sketches interact. Behavioral adequacy for a selected set of phenomena such as limited working memory capacity and mental rotation of objects are among the goals realized.

Spatial Problem Solving with Sketches and Mental Images

Mental images are constructed from knowledge fragments retrieved from long-term memory and the interpretation associated with these fragments becomes part of the image (cf. Logie, 2001). As a consequence, structurally reinterpreting an image in mind is often hard. However, when the image gets externalized (i.e., when its content gets re-represented in terms of a sketch or diagram) its content can be easily reinterpreted (Verstijnen et al., 1998). Internal and external representations complement one another as representational and procedural limitations of one form are oftentimes compensated for by the other. For example, external representations are durable and stable, internal representations are volatile and flexible.

In the case of spatial problem solving (e.g., in reasoning about geographic knowledge), sketches serve as external representations. Mental images form their internal counter-parts and they are constructed in working memory from spatial knowledge fragments (Barkowsky, 2002).

When people solve a geographic problem, much interaction takes place between the drawing and their mental image. Some modifications—like the rotation of a single element—can easily be applied to a mental image but are impossible on a sketch without erasing the object or cutting out paper. On the other hand and unlike in the case of mental images, there hardly exist practical restrictions on capacity for drawings.

Spatial Problem Solving with NEVILLE

NEVILLE (Bertel et al., 2006; König, 2005) is an experimental computational model of the interplay between internal and external representations in human problem solving. Its field of application is reasoning about geographic questions using mental images and external sketches. The model contains a sketchpad for external representations, visualization components for both the pictorial and the propositional parts that constitute a mental image, and an interface to a long-term memory module. NEVILLE focuses on a subset of involved processes and phenomena. Its main assumptions are: the capacity of working memory is limited, mental representations are tied to interpretations, mental images are constructed on demand to serve an intended purpose (such as solving a problem), mental images are volatile; their elements fade over time when not refreshed by maintenance processes, comparable basic processes operate on mental representations that result from visual perception and on mental images

The main processes modeled in NEVILLE include the construction of mental images from memory, the externalization of mental images ("drawing a sketch"), the perception of external diagrams, the inspection of mental images and external diagrams by operations that shift focus and change zoom, the transformation of object representations in mental imagery (translation, scaling, rotation, mirroring), and the chunking of objects.

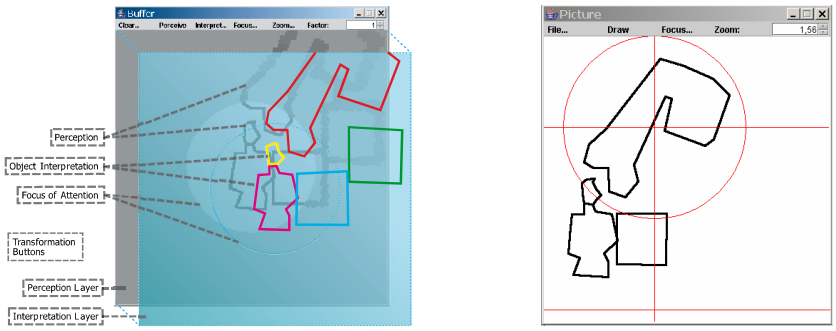

Fig. 1: Visualization of image buffer content and window of attention (left) and external picture with visual focus (right).

System Details

NEVILLE is implemented in JAVA. It demonstrates the interaction between drawings and mental images by providing a virtual sketchbook and proposing an interactive visualization of the imagery phenomena involved. NEVILLE consists of three structures that have been proposed in the cognitive science literature: *Picture* (the external sketch), *Buffer* (as a medium to hold the modeled mental images), and *Memory* (an XML interface to stored objects and spatial relations of an arbitrary long-term memory model). The user takes the part of directing the problem solving process (central control), including triggering the externalization, retrieval from memory, object transformation, and attention shifts. The system emulates mental processes like

shifting focus, zooming, mental rotation, and chunking. It visualizes the involved processes and adapts the representational contents.

By taking into account these cognitively motivated components and processes and by seeking behavioral adequacy for the test cases, the model aims at gaining further insights towards refinement of its architecture to successively improve structural and procedural adequacy. No data structure for the mental image is proposed in the model – the visualization on the computer screen serves as 'mental image'. With this modular approach, NEVILLE can be used as a visualization component with more extensive cognitive architectures (such as CASIMIR, Schultheis et al., 2005) in explorations of combined mental-diagrammatic reasoning.

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References

Barkowsky, T. (2002). Mental representation and processing of geographic knowledge – A computational approach. Berlin: Springer.

Bertel, S., Barkowsky, T., König, P., Schultheis, H., & Freksa, C. (2006). Sketching mental images and reasoning with sketches: NEVILLE – a computational model of mental & external spatial problem solving. In D. Fum, F. del Missier, & A. Stocco (Eds.), Proceedings of the 7th International Conference on Cognitive Modeling, Trieste (ICCM 2006), pp. 349–350. Edizioni Goliardiche, Trieste.

König, P. (2005). Von der Idee zum Bild und zurück. Diploma thesis, FB3 – Informatics, Universität Bremen.

Logie, H. R.: (2001). Working memory: a mental space for design and discovery. In S. J. Gero, B. Tversky, & T. Purcell (Eds), *Visual and Spatial Reasoning in Design II*. University of Sydney: KCDC.

Schultheis, H., Bertel, S., Barkowsky, T., Freksa, C., & Seifert, I. (2005). Casimir: Comprehensive computational modeling of mental spatial knowledge processing. In *Poster Proceedings COSIT'05*. Ellicottville, New York.

Verstijnen, M. I., Leeuwen, v. C., Goldschmidt, G., Hamel, R., & Hennessey, M. J. (1998). Creative discovery in imagery and perception: Combining is relatively easy, restructuring takes a sketch. *Acta Psychologica*, *99*:177-200