Sketching Mental Images and Reasoning with Sketches: NEVILLE – a Computational Model of Mental & External Spatial Problem Solving*

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Abstract

Diagrams and mental imagery play pivotal roles for many spatial reasoning tasks, and the close functional coupling of spatial reasoning with diagrams and imagery is often crucial for successful problem solving. Problem solving by way of model (e.g., diagram) construction is a frequent strategy. This contribution presents the computational model NEVILLE which proposes a visual model of the interplay between mental images and external sketches in human problem solving for geographic tasks. NEVILLE aims at behavioral adequacy for a selected set of phenomena such as limited working memory capacity and mental rotation of objects. An exemplary problem and its solution are presented.

Sketching Images and Reasoning with Sketches

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, 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). Complementary functionality of imagery and visual reasoning routines in reinterpretability stands before a background of a close coupling of involved mental subsystems (Kosslyn & Sussman, 1995). 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.

The repeated re-representation in bipolar mental/external diagrammatic reasoning has been described as being pivotal to successful and, in particular, to creative problem solving (cf. Goldschmidt, 1991, for design problems). The use of external memory aids (e.g., of diagrams) helps creative thinking and problem solving by relieving memory load in mental manipulations (Logie, 2001). Also, diagram-based problem solving leads to the construction of specific solution models, a strategy which reduces problem complexity by sieving the problem space (cf. Bertel et al., in press).

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

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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.

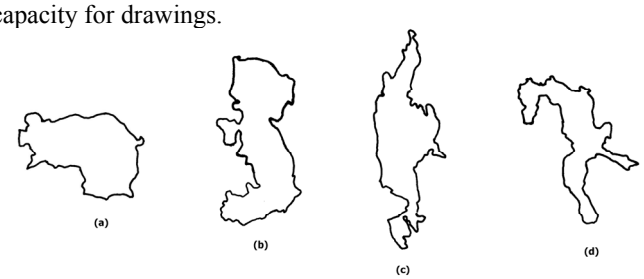

Fig. 1: Which figure shows the shape of the Baltic Sea? (Figures may be flipped or rotated.)

NEVILLE – Problem Solving by Construction

NEVILLE (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:

- 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.

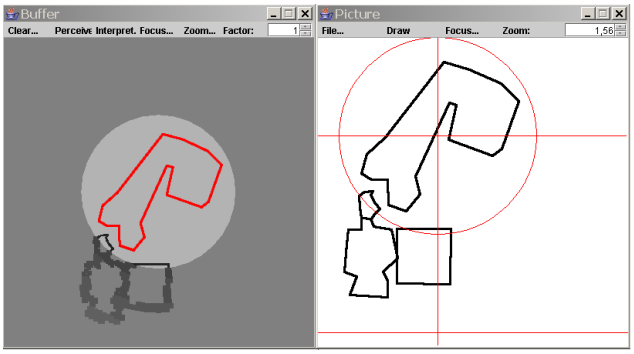

Fig. 2: Visualization of image buffer content and window of attention (left) and external picture with visual focus (right).

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.

(Re-) Shaping the Baltic Sea – an Example

The task is to identify the outline of the Baltic Sea among the shapes in Fig. 1. Solving the problem by drawing a map of the countries surrounding the Baltic Sea requires both internal and external representations (cf. Fig. 2). Imagine, for example, that at one point the user drew the Scandinavian Peninsula overly aligned with the north-south axis (cf. Fig. 3, top left). If this is later detected as being in conflict with an existing spatial knowledge fragment active in working memory the corresponding shape can be internalized by visual inspection and then rotated by a mental operation. Afterwards, it can again be externalized and the new shape replaces the previous one (Fig. 3, top right).

The mental image model has limited capacity; if more objects are required for the task, these can either be stored in the sketch and read off later or several objects can be grouped as one chunk.

Mental and visual foci (illustrated in Fig. 2), mental rotation procedures, and limited capacities give brief examples of the type of behavioral adequacy that NEVILLE aims at. NEVILLE's user performs the main part of the reasoning required for the task while the model forces him to consider the restrictions of the human cognitive system for each step. At the end of our reasoning example, the outline of the Baltic Sea is extracted from the diagram, mentally flipped and rotated, and compared to the (external) shapes in Fig. 1.

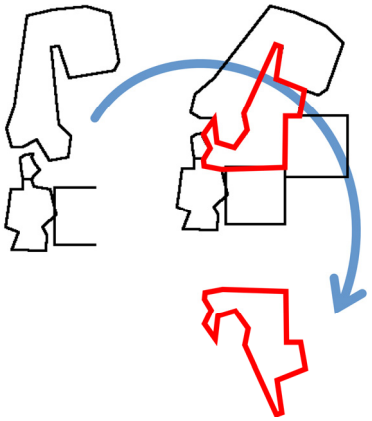

Fig. 3: Internalization of diagram (top left). Mental rotation and externalization produce a modified diagram (top right) from which a shape (bottom) is extracted. Shape comparison procedures can now recognize it as contour (d) in Fig. 1.

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