Cognitive Modeling for Assisted Graphical Design

Sven Bertel
Cognitive Systems Group
Department of Mathematics and Informatics, Universität Bremen
P.O. Box 330 440, D-28334 Bremen
email: bertel@informatik.uni-bremen.de

Mental and external representations involved

Human reasoning about spatial environments, sketching and drawing in design, or solving of spatial configuration tasks often involves utilizing external graphical representations such as sketches, maps, or diagrams as well as mental spatio-analogical representations (e.g. in a visuo-spatial format, such as employed and constructed in mental imagery). Processes involved in the reasoning include those that operate more or less exclusively within the realm of external representations (e.g. in diagrammatic reasoning systems), those that operate on mental representations (such as in mental image inspection), and those that involve both mental and external representations (e.g. when reading an information item from a map and then using it in mental reasoning).

For the latter group of processes, two types of functions can be idealized, doubling in number by assuming internal and external perspectives: (1a) The external representations are constructed during the reasoning task and serve as externalizations to the mental reasoning processes. As such, they constitute a sort of graphical notes. (1b) The external representations provide information input to the construction of mental representations and to mental reasoning processes. (2a) The mental representations are constructed during reasoning on an external representation and they serve as temporary abstractions in extent, level of detail, or quality from the external. (2b) Mental reasoning on these abstractions can lead to modifying the external representations.

For most problems of practical relevance, however, processes of the four groups are closely intertwined. The prevailing assumption is that that external graphical representations created during such tasks are created to aid the functioning of memory and/or mental imagery. As for memory, graphical representations are seen as extensions to mental storage (e.g. cf. Larkin and Simon, 1987; Tversky, 1999), especially with concern to working memory.

As for mental imagery, external graphical representations are often seen to be part of a reflexive dialogue in which mental constructions are externalized, internalized again, externalized, etc., thus creating an “eternal loop”

(Gorayska and Mey, 1996). In this process, the constant re-representation of contents together with effects of graphical constraining are usually seen as a driving force in imagery-based graphical reasoning (e.g. Scaife and Rogers, 1996), as variants of structure favour different mechanisms of inference and lead to the introduction of new operators and operands. Purcell and Gero (1998) describe how – in design processes – it is this iteration that can lead from unstructured sketches to detailed design.

Assuming limitations to mental reasoning capacities is in line with an assistive human-computer paradigm in which an assistive system serves as a *prosthesis* to the mind (Stojanov and Stojanoski, 2001), that is, extending the mental capabilities naturally present without it. It lies on three postulates: (1) human mental faculties are restricted in that the mental resources they can draw on are limited, (2) the limitations to these resources lead to difficulties in solving some class of frequently encountered problems, and (3) where means exist to extend the limited resources, solutions come easier. The utilizing of external graphical representations as externalizations of mental reasoning processes can be regarded as such a means.

Particularly in more complex reasoning or design processes, however, a strong focus on externalizations can be misleading. Smithers (2001) argues that research on the role of such external graphical representations should center on synthesising *problems* whose solutions will then satisfy the original needs of a task. In design or configuration problems, a clearly specified problem statement does not need to exist from the beginning such that a solution could be constructed and refined step by step, i.e. iterating for subproblems in a loop of imagery, externalizations, and perception. Instead, characteristics of some formulation of the problem, of a solution, or possibly of both are revealed (cf. Suwa et al., 2000).

Naïve architectural sketches

The domain that I will focus on are sketches such as produced by future house owners to explore and express their ideas on the desired properties of the building. Typically, the information available will be underspecified and prototypical instantiations will be employed on various levels. During the development of a sketch the number of constraints involved increases in number, leading to modifications of previously selected bits of default knowledge. The produced sketch can be heterogenuous with respect to the level of detail exhibited in its parts: While one room in the house may be drawn quite accurately in intended proportions and may even show a draft of the future positions of furniture, another room may be left in some roughly rectangular shape for the time being.

Compared to design sketches or even to blueprints produced by a pro-

fessional architect, the sketches produced by the future owner may be less systematical with respect to the process of creation. For designers, Suwa and Tversky (1996) identified four classes of content of what they see, attend to, or think of – (1) the depicted elements and the perceptual features of those elements, (2) the spatial relations between the elements, (3) functional thoughts, and (4) knowledge. I expect these classes to vary significantly in terms of the respective differences between performance of a layperson and a professional.

Models involved

The basic motivation for my work is a modeling one and it centers on supporting naïve sketching in configuration processes such as in the scenario described above. An envisioned assistance tool to aid in the process of sketching will communicate with a user through an interactive electronic whiteboard, and he will be able to use it just as an elaborate version of paper and pencil. However, this tool will encorporate a computational modeling of mental imagery components and processes to adequately assess the effect that the presented external representations have on mental reasoning. Based on this modeling, proposals to the continuation of the design process can be made, with the goal of creating a mixed-initiative system (Burstein and McDermott, 1996).

Assistive functions provided could involve the handling of configurations with underspecified information, the management of intermediate result storage and retrieval, and proposals as how to problem- and solution-spaces of a configuration can be explored. As humans have problems reasoning beyond 2-dimensional spaces, applying the assistance towards integrating several two dimensional projections seems further promising.

One of the open problems, however, is how the different roles of external graphical representations in configuration or design problems – externalizations of mental processes vs. exploration of problem- and solution-spaces – can be differentiated in their respective requirements, and how the respective attempts to an assistance can be integrated into a coherent reasoning strategy.

References

Burstein, M.H. and McDermott, D.V. Issues in the development of human-computer mixed-initiative planning. In *Cognitive Technology: In Search of a Humane Interface*, B. Gorayska and J.L. Mey, eds, pp. 285–303. Elsevier Science, Amsterdam, 1996

Gorayska, B. and Mey, J.L. Of minds and men. In *Cognitive Technology: In Search of a Humane Interface*, B. Gorayska and J.L. Mey, eds, pp. 1–24. Elsevier Science, Amsterdam, 1996

Larkin, J.H. and Simon, H.A. Why a diagram is (sometimes) worth ten thousand words. In *Cognitive Science*, Vol. 11: pp. 65–100, 1987

Purcell, A.T. and Gero, J.S. Drawings and the design process. In *Design Studies*, Vol. 19: pp. 389–430, 1998

Scaife, M. and Rogers, Y. External cognition: How do graphical representations work? In *International Journal of Human-Computer Studies*, Vol. 45: pp. 185–213, 1996

Smithers, T. Is sketching an aid to memory or a kind of thinking? In *Visual and Spatial Reasoning in Design II*, J.S. Gero, B. Tversky and T. Purcell, eds, pp. 165–176. Key Centre of Design Computing and Cognition, University of Sydney, Australia, 2001

Stojanov, G. and Stojanoski, K. Computer interfaces: From communication to mid-prosthesis metaphor. In *CT 2001, LNAI 2117*, pp. 301–310. Springer-Verlag, Berlin, Heidelberg, 2001

Suwa, M and Tversky, B. What architects see in their design sketches: implications for design tools. In *Human Factors in Computing Systems: CHI'96*, pp. 191–192. ACM, New York, 1996

Suwa, M., Gero, J.S. and Purcell, T. Unexpected discoveries and s-invention of design requirements. In *Design Studies*, Vol. 21: pp. 539–567, 2000

Tversky, B. What does drawing reveal about thinking? In *Visual and Spatial Reasoning in Design (VR99)*, J.S. Gero and B. Tversky, eds, pp. 93–101. Key Centre of Design Computing and Cognition, University of Sydney, Sydney, Australia, 1999