The Cognitive Conceptual Approach as a Leitmotif for Map Design

A. Klippel[1], P. U. Lee[2], S. Fabrikant[3], D.R. Montello[3], J. Bateman[4]

Abstract

Abstract. This paper explores the possibility of organizing map design around *conceptual spatial representations* (CSRs). CSR refers to a mental representation that is instantiated in interaction with a spatial environment, a spatial representational medium, and/or while solving spatial problems. For this approach we coin the term *cognitive conceptual*. We detail the basic assumptions in a contrastive manner, i.e., by juxtaposing it against a stylized cartographic approach, and indicate future directions for this research.

Introduction

Imagine the following situation: Dan and Alex are on the phone, and Dan gives Alex directions how to get to his place. Alex has not been at Dan's before and does not know the geography too well. To get a better idea of Dan's description, he starts to draw a sketch map based on Dan's verbal instructions.

The conceptual spatial representations (CSRs) (Klippel & Tappe, 2001; see also Jackendoff, 1997) that Alex instantiates are based on general cognitive principles and his partial knowledge, e.g., what it means to 'turn right' or to 'cross a bridge'. To graphically externalize these concepts on a sheet of paper, he has to find compromises compatible with the characteristics of the representational medium. This requires choosing exactly one out of a number of different possible instantiations, even though his knowledge is too incomplete to pick the correct one.

In general, the design of a map requires a cognitive agent; thus conceptualization processes are unavoidably involved. In the case of a cartographer, a given data set is interactively and iteratively rendered more precise, according to his or her conceptualization of the spatial data, until the map is finalized. It is this conceptualization and expertise that are reflected in the map.

On the other hand, the cognitive sciences investigate mental conceptions of space, what we might call the more naive view on space. Research on graphically communicating with these underspecified concepts is qualitatively different from the approach of cartography.

To make this point clear, we discuss the two approaches in full awareness that neither exists in a pure form. Nevertheless, by contrasting them we aim to provide a better understanding of cognitive science research on (carto)graphic representations as a basis for a *cognitive conceptual approach* to map design.

The Cognitive Conceptual Approach to Map Design

We differentiate between two general approaches to map making; one can be termed the *cognitive conceptual approach* (CCA) and the other, more generally used, the *data-driven approach* (DDA). The DDA starts with rich representations of spatial environments and derives representations that are more schematic by systematic abstraction, for example, by cartographic generalization. In contrast, the CCA is characterized by taking conceptual spatial representations (CSRs) as a starting point, and produces richer (more detailed, more precise) representations by concretizing, combining, and contextualizing them, for example, in a representational medium.

Cartographic map design starts with collecting data on spatial environments in a defined manner—either by surveying or by deriving information from secondary sources, such as aerial photographs and thematic sources (e.g., Robinson et al., 1995). Consequently, spatially accurate—in the sense of complete, rich, and correct—representations and surveys constitute the starting point for deriving less accurate depictions; the converse is rarely possible. This DDA approach is intertwined with the research area of cartographic generalization, which is, roughly speaking, the thematic and graphic simplification of cartographic representations (e.g., Dent, 1996). Figure 1 illustrates different abstractions of spatial information in a simplified manner and how they fit into either CCA or DDA approaches (for detailed models of map design and cartographic communication see, e.g., Gottsegen, Montello, and Goodchild, 1999; Muercke, Muehrcke, and Kimmerling, 2001).

The starting point for the DDA is a rich spatial environment. One conceivable step of abstraction is an aerial photograph taken in orthogonal fashion. Here, we are already at the stage of an external, planar, and bounded representational medium with the same representational characteristics and constraints as maps, but

[1] Cooperative Research Centre for Spatial Information, Department of Geomatics, University of Melbourne, aklippel@unimelb.edu.au
[2] SJSU / NASA Ames Research Center, Mail Stop 262-4, Moffett Field, CA 94035 USA, plee@mail.arc.nasa.gov
[3] Department of Geography, UCSB, California, USA, [sara, montello]@geog.ucsb.edu
[4] Department of Linguistics, Universitaet Bremen, Germany, bateman@uni-bremen.de

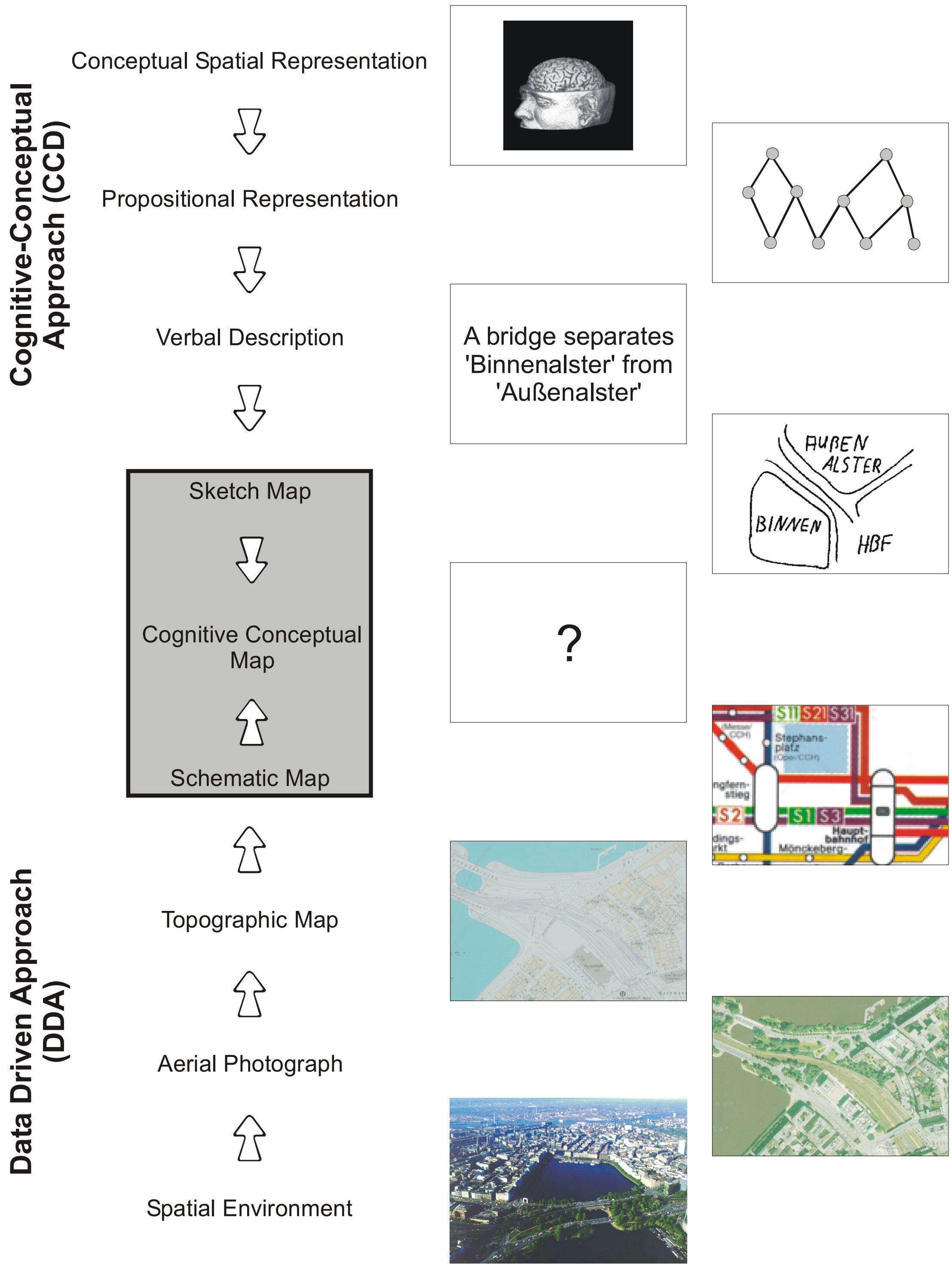

Figure 1. The levels of abstraction underlying top-down and bottom-up approaches to map making (cf. Freksa, 1999; MacEachren, 1994; Bryant et al., 1995; Wastl, 2000). The gray area denotes map-like representations in close relation to principles of cognitive organization (maps: Deutsche Grundkarte & Luftbildkarte St. Georg, Freie und Hansestadt Hamburg, Amt für Geoinformation und Vermessung; brain image: http://neuroimage.usc.edu/ 02.02.2003; aerial photograph: www.hamburg.de, 12.08.2002).

without the corresponding symbolism. From this representation, topographic maps can be derived. Topographic maps fulfill measurable criteria concerning the accuracy of spatial information and the completeness of the data; they are standardized to a high degree (e.g., Grünreich, 1990; ATKIS; SDTS). Starting with large-scale maps, small-scale maps are derived by means of generalization (e.g., Brassel & Weibel, 1988; Buttenfield & McMaster, 1991). Various approaches have been undertaken to automate this process, but full automatization may never be achieved (e.g., Beard, 1991; Meng, 2003). Spatial information changes in the process of generalization—it becomes sparser. According to the purpose of the map (and sometimes because of the greater amount of information that has to fit less map space), some aspects are emphasized while others are de-emphasized; this is part of the conceptualization process of the cartographer. With less space available, symbolization plays a greater role, for example, objects formerly depicted by their ground plan are represented by symbols. The means to handle this transition are the classical cartographic generalization rules: elimination, aggregation, collapse, typification, exaggeration, selection, classification, simplification, conflict resolution (displacement), refinement, and symbolization (e.g., Dent, 1996).

Beyond the scope of the cartographic tenet (i.e., to give the map-reader a precise image of the environment (Dorling & Fairbairn, 1997)), maps are termed *diagrammatic, special purpose*, *task-specific*, or *schematic* (e.g., Freksa, 1999; Muehrcke, Muehrcke, and Kimmerling, 2001). A schematic representation focuses only on a relevant set of spatial aspects (e.g., Barkowsky & Freksa, 1997) and provides design freedom that allows for the representation of highly focused, context-adapted information. Work on diagrammatical representations and schematic maps, where concepts of design are applied (for example, in European subway maps that use only straight lines), gives rise to a different view of map making. MacEachren states: "As we move toward the graphic end of the continuum, […], there is an increasing number of abstraction decisions left to the analyst/map designer." (MacEachren 1994, p. 39). It follows that the relation between topographic and schematic maps can be characterized as a one-to-many relation; from the same topographic map—or the underlying data set—an inexhaustible set of schematic maps can be derived (see Fig. 2).

In the DDA perspective on map making—here focusing primarily on topographic information—a cartographer (or a graphic designer) starts with the richest source of information and reduces and focuses this information further and further according to his or her conceptualization processes of the cartographer (or graphic designer). This approach leads to a systematic reduction in accuracy, in possible inferences, and in the number of depicted entities. On the other hand, we gain design freedom, for example, to apply design concepts, to focus on specific aspects, and most of the time to increase readability. The design concepts may or may not reflect principles of mental knowledge representation, for example, the straightening of curved street segments as reported by Evans (1980).

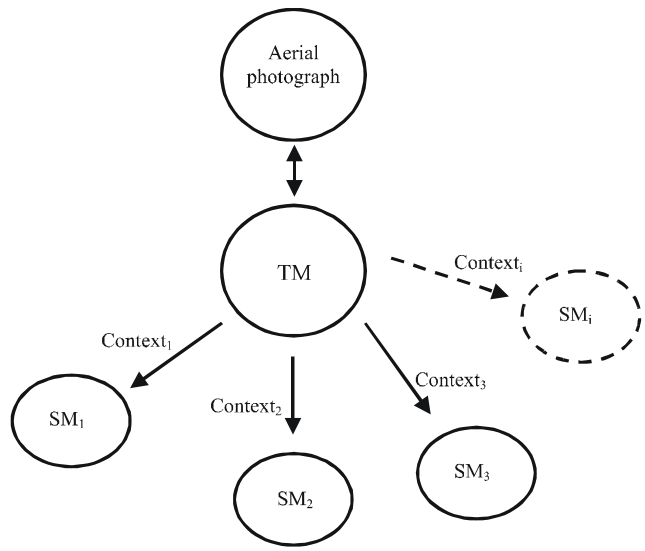

Figure 2. The relation (one to many) between a topographic map (TM) and schematic maps (SM).

In contrast to the DDA to map making, the CCA starts with conceptual spatial representations (CSRs) (see Figure 1). CSRs are accessible to us, for example, by analyzing natural language expressions, sketch maps, and by applying various other psychological methods (e.g., Knauff et al., 1997). One conceivable step towards externalizing and concretizing CSRs is their verbalization. One key feature of linguistic expressions, in contrast to pictorial representations, is that they are underspecified. This means that there is interpretable space between an expression such as 'turn right' in a verbal description and the depiction of an intersection at which one has to turn right. Linguistic expressions are underspecified in that their interpretation *per se* is contextually adaptable to a greater extent than the interpretation of pictorial representations. The semantic content of a term such as 'turn right' only captures the general concept of change of direction according to one’s egocentric frame of reference, as induced by the main body axes. The application of this concept to a specific spatial configuration leaves room for interpretation. In contrast, visualizing spatial information requires choosing one depiction, which is rendered specific in its externalization on a two-dimensional, spatio-temporally fixed representation medium (e.g., Habel, 1998, 2003). Approaching schematic representations this way also leads to a one-to-many relation, in that one abstract, underspecified spatial conceptualization allows for various graphical representations.

Verbalization and graphicalization are two forms of externalizing CSRs at first levels of preciseness (see Figure 1). The transition from spatial natural language expressions to sketch maps involves compliance to further constraints of the medium. As indicated by the gray area in which schematic maps, cognitive conceptual maps, and sketch maps are placed in Figure 1, these kinds of representations share properties and are external, planar, and bounded representations that reflect—to varying degrees—CSRs.

In the 1950s awareness swept through cartographic research that higher-level cognitive processes of map readers are significant to the map-user interaction (cf. Robinson, 1952: for an overview see Montello, 2002). Yet, even for schematic maps that are close to sketch maps, it is claimed and is indeed common practice (e.g., Cabello et al., 2001) that they are derived in a DDA fashion, although guided by cognitive concepts: "[…] schematic maps differ from sketch maps in that they are derived from topographic maps […]" (Freksa, Moratz, and Barkowsky, 2000, p. 105).

Existing approaches

One goal of our work is to advance the cognitive paradigm and apply conceptual spatial representations 'directly' to map design. To distinguish maps resulting from a cognitive conceptual approach, we will refer to them as *cognitive conceptual maps*. Although our approach originates in conceptual spatial representations, in practice a combination of both approaches (CCA and DDA) seems advisable for many applications.

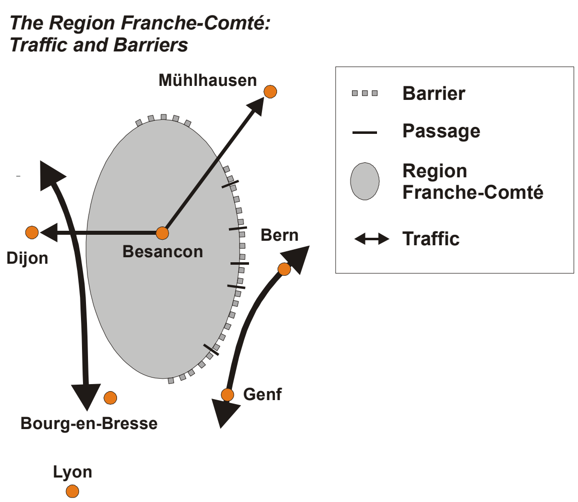

Figure 3. Example of a choreme map (Moine, 1994, modified).

Our work is in concert with several approaches that attempt to improve maps on the basis of conceptual spatial representations (e.g., Brunet, 1987; Tversky & Lee, 1998, 1999; Klippel & Richter, 2004; Fabrikant & Skupin, 2005).

Brunet (e.g., 1987), for example, proposed the theory of chorematic modeling. He identified spatial structures, systems, and subsystems, and manifested them in a limited number of spatial models that he characterized in a (choreme) table. Each model, an underspecified spatial construct, is assigned a graphic counterpart that is the basis for his approach to map design. He termed his maps "choreme maps" (see Fig. 3).

The other approaches mentioned above deal primarily with spatial information that is directly perceived during wayfinding and giving/receiving route directions. The common ground for all these approaches is the assumption that the same mental conceptualizations underlie different externalizations—graphically and verbally. The challenge for graphical representations is to find **the one** representation that corresponds to the CSR. Tversky and Lee (1998, 1999) proposed pictorial and verbal toolkits from which maps (and verbal route directions) can be constructed (see Fig. 4). Their approach has inspired the provision of sketch-map-like route maps over the Internet (Agrawala & Stolte, 2001).

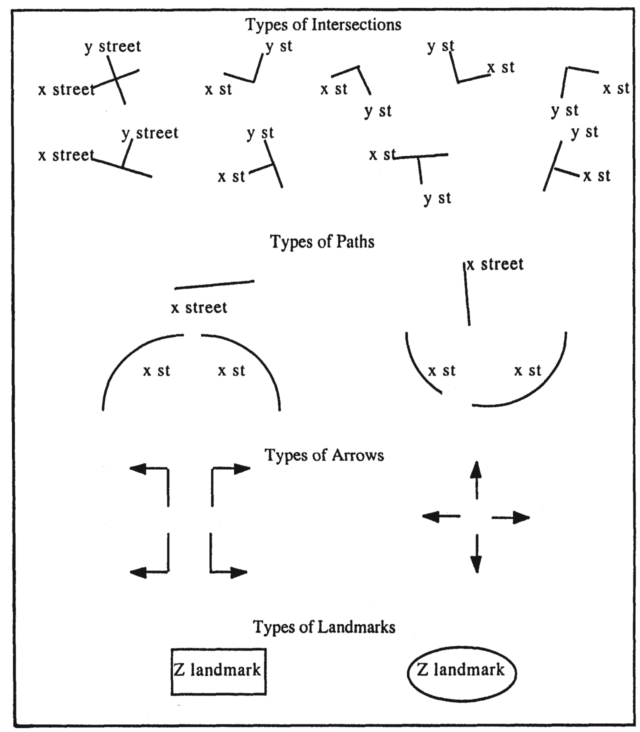

Figure 4. The pictorial toolkit for route directions by Tversky & Lee (1999).

As another basis for route maps, Klippel (2003) defined seven wayfinding choremes that are rendered more precise by integrating them into the structure of a decision point (see Fig. 5). The distinction between structure and function allows for a grammatical characterization of route knowledge on a conceptual level with the possibility of linking graphical and verbal externalization (Klippel et al., forthcoming 2005).

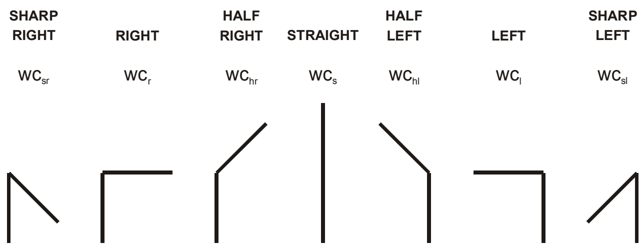

Figure 5. The basic set of wayfinding choremes (Klippel et al., forthcoming).

Conclusion

The cognitive conceptual approach to map design is orthogonal to the classical definitions of cognitive adequacy (Strube 1992), as it is neither the modeling of a cognitive process, nor does it exclusively aim to improve the interaction between user and representation. It starts with taking into account the extension of a cognitive system by an external representation medium (cf. Scaife & Rogers, 1996) and proposes to account for the conceptualization as an interaction between dependent knowledge structures, i.e., a cognitive conceptual representation. The approach is placed within the context of several research efforts that aim to define graphic representations for conceptual knowledge. The benefits of this enterprise lie in improving the interface of communication devices: the communication as such, as well as providing proper means for the automatic generation of graphic representations (for example, in ubiquitous computing environments).

Several questions await future investigation and are addressed in our research projects. From a cognitive-science perspective, the problem of appropriate and singularly identifiable CSRs and their relation to existing approaches such as conceptual spaces (Gaerdenfors, 2000) is pertinent. From the cartographic perspective, the graphical representation is in a medium that requires the instantiation of one out of several possible models. How the communication of conceptual knowledge graphically can be improved is a major concern. Determining the relation between graphical and verbal externalizations of CSR to allow for multimodal communication devices is an overarching research question.

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