An Interdisciplinary Approach to the Representation of Route Knowledge

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0. Introduction

The development of theories concerning the representation of *large-scale* space is an important subtopic in the investigation of spatial concepts. This becomes apparent in specific tasks like the generation of route descriptions, where performance often depends on a person's *cognitive map* of or, more specifically, her *route knowledge* about a certain region. In this paper I want to present an interdisciplinary approach to the representation of *route knowledge* that integrates psychological investigations of cognitive mapping and linguistic theorizing (analyses of route descriptions; semantics of spatial expressions) in order to develop constraints for formal representations in AI models. It will be shown that it is both possible and necessary to distinguish between different representational structures (route maps vs. survey maps) and different representational processes (experience-based vs. planning-based route finding).

1. Psychological access to route knowledge

In cognitive and environmental psychology, some insights about the properties of cognitive maps have been gained during the past two decades. Above all, it has become clear that the notion 'cognitive map' must not be taken literally but has to be understood as a metaphor for the mental representations of large-scale space (cf. Tversky 1981, Kuipers 1982). This is obviously relevant for the explanation of distortions of cognitive maps (that is, distortions of cognitive distances, directions, and angles) found in numerous experiments (cf. Golledge 1986 for an overview): instead of assuming a distorted mental analogue of the outer world, one has to look for principles governing *organization* (e.g., partiality and hierarchical structuring) and *processing* (access to and retrieval of informaton; heuristics) of macrospatial knowledge which phenomenally lead to those distortions (cf., e.g., Tversky 1981), as well as for the different types or levels of that knowledge (cf. the sensomotoric, procedural, topological, and metric representations of Kuipers/Levitt 1988). In line with this multi-faceted view of cognitive maps, an exclusive interpretation of the notion 'cognitive map' in terms of mental imagery (cf. Levine et al. 1982) must be rejected. It has been shown that at least *primary* learning (based on experience) and *secondary* learning (based on real pictures or maps) of cognitive maps have to be differentiated (cf. Presson/Hazelrigg 1984). Similarly, the distinction between procedural *route maps* and more image-like *survey maps* (cf. Thorndyke/ Hayes-Roth 1982) runs counter to this restrictive interpretation.

Chase (1982) has shown that route competence must in fact be kept distinct from survey competence. In his experiments, taxi drivers were found to be no better in survey competence than others, while there were striking differences with respect to route competence. As to the organization of route knowledge, Moar/Carleton (1982) could show that routes get integrated into a route net from early on, with professional drivers exhibiting a greater degree of route integration than the so-called "normal population" (cf. Stern/Leiser 1988). Moreover, significant interindividual similarities could be found in the partitioning of routes (Allen 1981). Route segments therefore are not arbitrarily constructed but are the results of a general process. In this connection it is interesting that the categorization effect (cf. Maki 1981) appears within route segments (cf. Allen/Kirasic 1985): response patterns are systematic within but unsystematic across route segments.

2. Linguistic access to route knowledge

Empirical linguistic data – in this case route descriptions – are an important information source for the investigation of cognitive maps. If interpreted adequately, they might give hints about which structures are used by which processes during the performance of a task involving macrospatial knowledge (see 4.).

The semantics of natural language expressions – here: of spatial expressions – provides a further source of information in that semantic representations constitute the interface between conceptual route knowledge and spatial expressions (cf. the so-called *two-level semantics* of Bierwisch/Lang 1989), therefore posing some restrictions on conceptual representations (see 5.).

3. Computational models of cognitive maps

Meanwhile there exist numerous computational models adressing aspects of the representation and processing of cognitive maps. With the exception of the TOUR-model (cf. Kuipers/Levitt 1988) and the TRAVELLER-model (cf. Leiser/Zilbershatz 1989), however, no attempt has been made to represent route knowledge. Moreover, even in these models the organization of route nets (that is, the construction of route segments) either remains unclear or is determined by ad-hoc principles (see 6.).

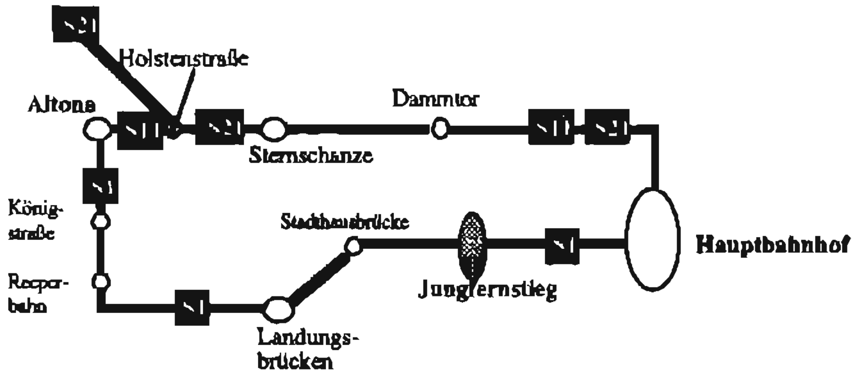

figure 1

4. Experience-based vs. planning-based route finding

Consider figure 1. For the route problem Jungferstieg->Holstenstraße, two route descriptions (call them r1 and r2) can be found in the empirical data of Schopp (1989). While r1 contains a rather short planning pause (7 secs), is less detailed, and describes a route *leading away* from the goal (via Hauptbahnhof), r2 contains a long planning pause (15 secs), is rather detailed, and leads towards the goal. Based on a discussion of these and other data I have proposed a distinction between experience-based and planning-based route finding procedures (see Carstensen 1991). While the former procedure – which assumedly underlies r1 – exploits route knowledge using an automatic, mostly unconscious, and rapid process (spreading activation in the route net), the latter – which accordingly is assumed to underlie r2 – can be expected to deliberately select between alternatives thereby exploiting survey knowledge (or the respective representations of secondary learning) whose metric aspects lead to the observable goal oriented performance.

5 Route categories and route nets

Taking serious the categorization effect, I take the route segments as route categories that are the outcome of a general categorization process which guarantees that similar or continuously varying perceptual inputs are grouped (continuation of movement or direction, iteration of landmarks) by abstraction of their common properties and that "breakages" in the flow of perception (turns, crossings etc.) are mirrored in the route net.

Now, as the semantics of spatial expressions at least require states, processes, and transitions between these (and not events, as I have shown in detail in Carstensen 1991, 1992), I propose to represent route categories as in figure 2 which depicts the following information: first, a transition from S_x (for example, 'BEING AT LOCATION X') to a process P (for example, 'MOVE'), a transition from P to S_y (for example, 'BEING AT LOCATION Y'), and a transition from S_x S_y; second, P as a chunk for the finer grained succession of the locative states and actions between S_x and S_y indicated by the thin circles and arrows; third, the correspondence between the associative structure of the sensomotoric views and actions and the conceptual structure.

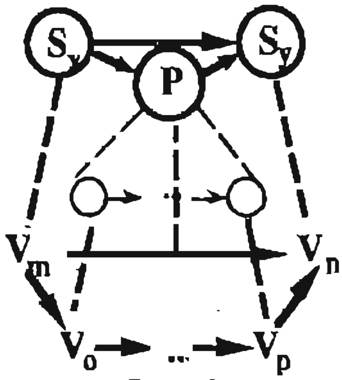

figure 2

Thus we have the following characteristics of a route net: the relationship between conceptual route categories and sensomotoric views and actions (similar to the TOUR-model), the integratedness of route (as in the TRAVELLER-model), and, in addition, conceptual criteria for the construction of route categories that are compatible with semantic representations.

6. Modelling experience-based route finding in route nets

As mentioned before, experience-based route finding is to be conceived of as an automatic spreading activation process in the route net. Two further principles determine the behaviour of this process: *bidirectionality* (the process starts simultaneously from source and goal) and sensitivity to the *frequency* of visiting a place (corresponding to a conceptual locative state or, traditionally, a node) (cf. Sadalla et al. 1980 for the relevance of this factor which is acknowledged but not used both by Kuipers/Levitt and Leiser/Zilbershatz). Performance of experience-based route finding is then determined by the following algorithm:

1) (a) carry out a breadth first search simultaneously from source and goal;
   (b) only activate connections that lead to nodes with a higher frequency value.

2) (a) terminate search if a common node has been reached;
   (b) concatenate the traversed nodes and connections and deliver the result as the found route.

Thus, experience-based route finding mirrors the typical behaviour of the "normal population" (the tendency to use the "basic network" of the most salient or most often traversed streets (cf. Chase 1982) and to accept obvious detours) and leads to the characteristic properties of r1 (rapidity, simplicity, the detour, and the selection of a (single) salient intermediate goal).

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