Towards a cognitive conceptual framework of movement

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This paper reviews cognitive theories of spatio-temporal phenomena and integrates concepts from computer science, geography and psychology literature. We propose a conceptual framework for space-time integration from a cognitive viewpoint to enhance pattern recognition of moving point data in a cognitively plausible way.

Large amounts of movement data are generated daily through technological devices, such as mobile phones, GPS and navigational aids. The exploration of moving point datasets to identify movement patterns has recently become a research focus in GIScience (Dykes and Mountain 2003). Several visual analytics tools have been developed, such as CommonGIS (Andrienko 1999) or GeoVista Studio (Gahegan 2001) to visually explore large moving point datasets. Visual analytics tools combine computational methods with the outstanding human capabilities for pattern recognition, imagination, association and analytical reasoning (Andrienko et al. 2003).
However, large amounts of movement data make pattern extraction extremely difficult for humans. Cognitively plausible tools are needed to enhance pattern recognition and knowledge retrieval. A conceptual framework to understand how humans understand spatio-temporal processes, in particular movement is necessary to improve the design of visual analytics tools.

Time-geographic research has been done over the last decades to understand human travel behavior, activity patterns, migration and mobility behavior (Hägerstrand 1970, Axhausen and Gärling 1992, Kwan 2004, Doherty et al. 2002). Analysis and visualization of movement has been applied to geographic information systems and visual geoanalytics tools (Andrienko and Andrienko, 2007). Geographic information systems are an effective environment to study space-time behavior and spatio-temporal processes (Kwan 2004).

Geographic information science has addressed the integration of spatio-temporal phenomena into databases (Langran, 1992). Effort has been made to incorporate cognitive principles into geographic database representation, such as the pyramid framework (Mennis and Peuquet 2000). This approach facilitates knowledge acquisition through a modifiable geographic database, because it combines database representation with human geographic cognition (Mennis, Peuquet 2000). However, Peuquet (2004) notes that “very little has been done so far to extend a more natural, cognitive world view into a usable (i.e. implementable) framework for space-time database representation”. Therefore, the connection between theory and practice is still missing (Peuquet 2004).
Geovisualization research also emphasizes the need to “employ a human-centered approach” (Dykes et. al 2005) and a “development of theory and practice to support

universal access and usability" (Dykes et al. 2005). Fuhrmann et al. (2005) state that an extended cognitive theory could guide system design to improve geovisualization tools.

Several disciplines, such as psychology and geography have studied the perception and cognition of space and time. Spatial cognition research is concerned with structures and processes of spatial knowledge and reasoning (Barkowsky et al. 2007). Much research has been done on spatial knowledge acquisition, navigation, and internal representations of space (Barkowsky et al. 2007). Piaget (1969) notes that the acquisition of space and time occurs in parallel. Still, most of spatial cognition research has not focused on the integration of time as an additional factor for geographic phenomena. Cognitive concepts of movement, where time and space are integrated hardly exist. Route knowledge, as one step of spatial knowledge acquisition integrates space and time and is termed "procedural knowledge" (Golledge 1988). Most research integrating cognitive theories on movement are limited to decision-making of travel estimation and wayfinding (Raubal et al. 2004, Doherty et al. 2002).

A recent approach to integrate time in geographic phenomena is the identification of events (Worboys 2005, Klippel et al. 2007). While Klippel et al. (2007) argue that the development of an explicit representation of geographic events is a current research objective, cognitive foundations of geographic event conceptualization have not been addressed sufficiently. Zacks and Tversky (2001) have done research on events from a cognitive or perceptual perspective (Zacks and Tversky 2001). The integration into movement or spatio-temporal phenomena, however, is still lacking.

Previous work does not address a proper integration of space and time from a cognitive perspective, in particular the perception of movement. Our proposed framework aims at understanding movement from a cognitive perspective by integrating space-time concepts and approaches from related but non-integrated separate fields. Therefore relevant work from computer science, psychology and geography grounds the proposed framework. A conceptual framework including the perception and cognition of movement behavior is useful to improve the design of visual analytics tools for pattern extraction. We outline additional research questions that need to be addressed in future work to extend the framework, for example, the implications of context for visual analysis of moving objects. If movement is perceived differently for different moving point objects, then cognitively and perceptually adequate visual analytics tools need to be adapted accordingly.

The proposed framework considers a series of empirical studies to gain further insights into the cognitive and perceptual aspects of understanding movement behavior with visual analytics displays. McCarly and Kramer (2007) suggest that eye movements are a window to perception and cognition. Eye movement research has been successfully employed to study usability issues in human computer interaction (Poole and Ball 2004) as well as for studying perceptual issues in visual geoanalytics displays (Fabrikant and Goldsberry 2005). It therefore seems to be a valuable method to better understand how different moving entities, for example, animals, humans, or eye movements, can be perceived for inference and decision making with visual analytics displays.

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