Cognitive Evaluation of Spatial Formalisms: Intuitive Granularities of Overlap Relations

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ABSTRACT

The authors present four human behavioral experiments to address the question of intuitive granularities in fundamental spatial relations as they can be found in formal spatial calculi. These calculi focus on invariant characteristics under certain (especially topological) transformations. Of particular interest to this article is the concept of two spatially extended entities overlapping each other. The overlap concept has been extensively treated in Galton’s mode of overlap calculus (Galton, 1998). In the first two experiments, the authors used a category construction task to calibrate this calculus against behavioral data and found that participants adopted a very coarse view on the concept of overlap and distinguished only between three general relations: proper part, overlap, and non-overlap. In the following two experiments, the authors changed the instructions to explicitly address the possibility that humans could be swayed to adopt a more detailed level of granularity, that is, the authors encouraged them to create as many meaningful groups as possible. The results show that the three relations identified in the first two experiments (overlap, non-overlap, and proper part) are very robust and a natural level of granularity across all four experiments. However, the results also reveal that contextual factors gain more influence at finer levels of granularity.

Keywords: Calculi, Granularity, Human Behavioral Experiment, Intuitive Granularities, Modes of Overlap

1. INTRODUCTION

Understanding human information processing is the central concern of the interdisciplinary research field of cognitive informatics (Wang, 2007a; Wang et al., 2010). Key topics in this research area are the investigation and modeling of abstraction and inference processes, which both have been identified as “preeminent traits of the human brain” (Wang, 2007b; Wang, 2012), as well as of processes underlying spatiality, time, and motion (Wang, 2009; Dawson & Boechler, 2007; Dong, 2007). In our work, we are concerned with the cognitive abstraction and inference operations underlying spatial competences, thinking, and language.

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Specifically, our efforts address the question to which degree formal models of spatial representation and reasoning suggested in AI and the spatial sciences are adequate to capture and describe human conceptualizations and commonsense reasoning. Our general approach is based on behavioral experiments (using a crowdsourcing approach) with the goal of evaluating and improving these formalisms.

Research on granularities has a long tradition in cognitive computing and cognitive informatics (Hobbs, 1985; Wang et al., 2010). Tasks that require to flexibly change between different levels of granularity are omnipresent in the cognitive organization of spatial knowledge and central to numerous computational models and applications (Hobbs, 1985; Kuipers, 2000; Richter & Klippel, 2005). An important research endeavor in this context is the identification of intuitive levels of granularity in human conceptualizations and commonsense understanding of spatial relations (Pothos et al., 2011). The understanding of this key part of human spatial cognition plays a crucial role in the design of intuitive user interfaces and of intelligent spatial reasoning and assistance systems.

As pointed out in Dawson and Boechler (2007), and Dong (2007), human understanding of certain kinds of spatial relations, for example, topological and direction relations, does not seem to follow the quantitative notion of metric space. This realization resulted in many models, so-called spatial calculi, which attempt to formalize relations for different aspects of space by introducing a finite and typically small number of elementary relationships (see, for instance, (Cohn & Renz, 2008) for an overview of this research field referred to as qualitative spatial reasoning).

Competing levels of granularity can be found in several spatial calculi, such as the prominent topological Region Connection Calculus (RCC) (Randell, Cui, & Cohn, 1992) and Intersection Model (IM) (Egenhofer & Franzosa, 1991) calculus families. The same holds true for formalisms dealing with direction or orientation information where we can observe a recent trend towards approaches in which levels of granularity are adaptable (see (Renz & Mitra, 2004; Moratz & Wallgrün, 2012)). In addition to capturing human intuition and categorization behavior, these approaches aim at improving the computational efficiency of processing spatial and temporal information by providing an adequate level of granularity sufficient to solve a particular task or for performing a task in a hierarchical manner by going from coarse levels to finer levels of detail. Overall, granularity is a key element of computationally processing information and/or communicating it to a human user where involving too much detail would violate principles of cognitive ergonomics as discussed, for example, in Clark’s 007 Principle: “In general, evolved creatures will neither store nor process information in costly ways when they can use the structure of the environment and their operations upon it as a convenient stand-in for the information-processing operations concerned. That is, know only as much as you need to know to get the job done.” (Clark, 1989, p. 64).

While the importance of spatial calculi is widely acknowledged in both spatial and cognitive sciences (e.g., (Kuhn, 2007; Lakoff & Johnson, 1980)), there is comparatively little behavioral assessment of the question whether the distinctions made in the suggested formalisms, hereafter referred to as qualitative equivalence classes (QEC), actually are suitable to capture humans’ intuitive processing of spatial information (see (Klippel, Li, Yang, Hardisty, & Xu, 2013; Mark, 1999) for overviews). In our research, we aim at remedying this situation by comparing the QEC-implied categories of fundamental spatial concepts with the cognitive behavioral data collected in free classification experiments in order to prove, disprove, or calibrate the cognitive adequacy of a formal model. In this article, we are addressing the question of contextual influences and intuitive granularities for the fundamental spatial concept of overlap (between two spatially extended entities). Overlap relations have been formalized by Galton (1998) in his modes of overlap calculus. In order to efficiently evaluate overlap relations, we are employing crowdsourcing
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