Conceptual Neighborhood Blindness – On the Cognitive Adequacy of Gradual Topological Changes

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Abstract. In this paper we examine whether the formalization of changes in the spatial relations of two moving regions provides an adequate characterization of the conceptualization of perceived motion events of those regions. The changes we consider are topological transformations that result in gradual topological changes. Using a series of experiments, we investigate the conceptualization and perception of conceptual neighborhoods and the role of conceptual neighborhoods in characterizing motion events. Our experiments employ a grouping paradigm and a custom made tool for presenting animated icons. The experiments are coupled with follow-up tasks to elaborate on the relation between conceptualizations—as revealed by the groupings—and different modalities of externalization such as language and graphics. The results of the experiments are relevant to the more general topic of *change blindness*, an important phenomenon in psychology.

1 Introduction

Detecting changes in our spatial environments is an important cognitive ability in our everyday life, for example, in overtaking a car or in detecting the change of high and low tide during a tideland hike. However, psychological experiments have shown that we are often oblivious to changes even if they are pertinent and *important not to ignore* (for an overview see [17, 19]). While most of these previous studies target visual stimuli, in this paper we are interested in conceptual processes and whether similar change blindness exists in this domain as well. We further focus our research on geographic concepts and on the discrepancy between formal characterizations of spatiotemporal phenomena and their cognitive conceptualization.

In this line of research, *conceptual neighborhoods* [6] have become a central concept in qualitative spatial reasoning. The underlying assumption is that conceptual neighborhoods possess cognitive and computational advantages [7]. While this seems to be the case for static spatial relations, conceptual neighborhoods inherently have

the ability to characterize dynamic processes too [5]. The assumption that "qualitative equals cognitive" is often made (in fact, several cognitive phenomena can indeed be explained best rather qualitatively than quantitatively). However, we often obtain contradictory results from behavioral studies, especially when visual communication is involved [10]. For example, the RCC-8 calculus [16] demonstrates cognitive adequacy while the RCC-5 calculus fails in this respect [11]. An in-depth analysis of the cognitive conceptual processes that underly gradual conceptual changes is therefore necessary. The remainder of this paper is structured as follows. First, we will briefly discuss some results found in the literature on the cognitive adequacy of topological relations. We then discuss briefly motion/change events and subsequently provide the rationale for our studies and detail the methodological setup.

2 Topology and the Cognition of Spatial Relations

In their studies on topological relations and their adequacy to represent cognitive and linguistic concepts, Egenhofer and Mark [13] conclude that *topology matters and metrics refines*. They applied different methods to test whether the 9-intersection model [4] is valid with respect to cognitive and linguistic categories. In a grouping task [14] participants had to sort graphic representations of topological relations into categories. In an agreement task [13, 14] participants judged the suitability of a linguistic description of a graphic representation with the same topological characteristics but varied metric properties. A third alternative explored by these authors was to present participants with a linguistic description of a spatial relation and ask for a graphic representation thereof, i.e., a sketch map. All these studies, with different advantages and disadvantages, seem to confirm the initial statement that the 9-intersection model, as a means of formalizing topological relationships, is able to characterize the core of human conceptual processes that categorize spatial relationships. Further studies of the cognitive adequacy of topological relationships have drawn a somewhat different picture. For example, the RCC calculi [16] have been analyzed in a study by Knauff and co-workers [11]. Their results show that participants adhere to the topological relations specified by the RCC-8 calculus but not by the RCC-5 calculus (at a coarser level of granularity). In fact, they claim that the RCC-5 calculus and the modification of the 9-intersection to 5-topological relations (which does not exactly correspond to the RCC-5) are cognitively irrelevant (see Figure 1).

One problem that becomes obvious by looking at the stimulus material used in experiments by Knauff and co-workers [11] is an overemphasis of the boundaries of the regions involved. Although other factors—such as the orientation of the regions and their shape—are randomized, the study by Knauff uses regions whose existence is completely reliant on their boundaries. The regions consist of two circles of two different colors drawn on a gray background. Thus, this experimental design grants boundaries their own ontological status upfront, and the conclusion that the RCC-8 shows cognitive adequacy while the RCC-5 does not is open to criticism. The research addressed in this paper aims to shed more light on the conceptualization of geographic regions. Consequently, the boundary approach seems to be inadequate since an inherent characteristic of geographic entities is that their boundaries are vague [1].

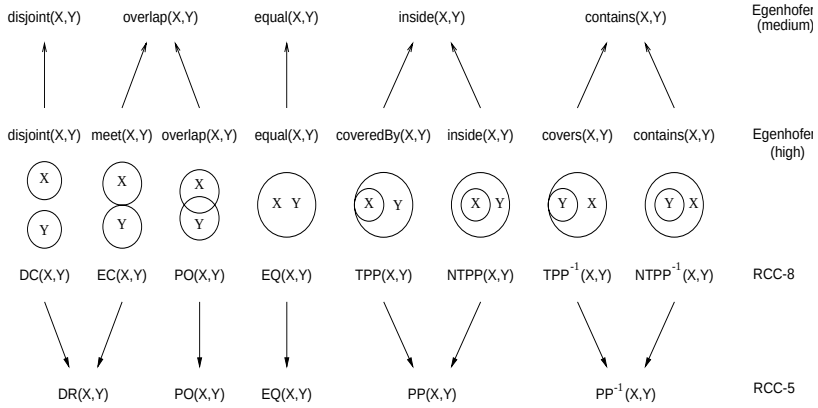

Fig. 1. Comparing different granularities in Egenhofer's approaches and the two RCC calculi (see [11]).

Ridemann [18] analyzed the correspondence of operators used in current GIS packages, their formal specification, and the mismatch between the linguistic label attached to these operators and the conceptualization of a human user. Her results from a simple agreement task (only 'yes' or 'no' answer were possible) showed that matches between topological terms and the 9-intersection model do exist. However, most of these matches are not yet used in the analyzed GIS products. On the other hand, it seems questionable that most human users understand the topological concept "covers" correctly, but more research is required.

To varying degrees these studies show that topological relations, primarily the 8 basic relations that are either specified by Egenhofer's 9-intersection model or in the RCC-8 calculus, are suitable to characterize cognitive conceptual knowledge.

3 Motion/Change Events

While we have focused so far on the cognitive adequacy of static spatial relations formalized by topological relations, a question that has not been sufficiently addressed in this community is the one of motion/change events that are characterized by topological relations and more specifically gradual changes.

Dynamic aspects of geographic-scale phenomena form a growing topic in spatial and information sciences. As the technology advances, for example, in monitoring qualitative spatiotemporal change using sensor networks [21], the need for a fundamental understanding of the conceptualization of dynamic processes by cognitive agents arises. Relating the formal characterization of events with the conceptualizations of events by cognitive agents is necessary to automate the identification and characterization of conceptual structures that discretize continuous dynamic processes into conceptual units. Our research addresses these issues and develops methods of transducing data, such as recorded by sensor networks, into conceptual knowledge. While research on the characterization of cognitive events has a long history within several sciences (for an overview

see [23, 2]), we still lack a good understanding of the conceptualization of geographic events. Indeed, an objective of current research in geographic information science is the explicit representation of spatial events [9, 20], but the cognitive foundations of geographic event conceptualization have not been addressed sufficiently. We aim to elicit the core of conceptual structures of geographic events. The research we propose here, however, does not intend to identify event boundaries from scratch, as, for example, reported in research on the perception on the structure of events [24]. In contrast, our research presupposes the existence of event classes as identified by topological and geometric transformations that characterize the behavior of geographic regions, e.g., RCC calculi [16], the 9-intersection model [4], or topological changes monitored in geosensor networks [21]. For static relations, for example, formal characterization that involves 8 topological relations—the 9-intersection model or the RCC-8—have demonstrated cognitive adequacy (see previous Section). Whether this holds for dynamic relations, too, is an open question.

4 Geographic Event Conceptualization

The RCC-8 relations and Egenhofer's 8 topological relations derived from his 9-intersection model describe the same set of topological relations [3], especially when they are used to describe two-dimensional circles as in our experiments. The conceptual neighborhood graph (see Figure 2[1]) is adopted from work by Egenhofer and Al-Taha [5] while the labels are the classical RCC descriptions of topological relations. This procedure seems to be cognitively plausible and avoids irritations that might arise by using linguistic labels like *overlap* or *covers*, denoting regions that in fact share the same space but they do not actually overlap or cover each other [2].

The adapted conceptual neighborhood graphs for RCC-5 and the reduced Egenhofer relations differ slightly as they merge different topological relations together. While the RCC-5 calculus combines DC and EC, Egenhofer's model combines EC and PO. Both coarser models combine TPP and NTPP as well as TPP^{-1} and NTPP^{-1}.

The research questions that interest us are whether the formal specification of gradual topological changes corresponds to the cognitive conceptualization thereof. Specifically, questions that need to be addressed from a cognitive perspective are:

- Do we find the same effect as reported in [11], that participants always rely on 8 topological relations when they have to characterize the changing spatial relationships between two regions? Is this effect still found when the stimuli used lack the explicit representation of region boundaries and the gradual changes are realized by different alpha values that distinguish the regions.
- Is it sufficient to take only topological characteristics of gradual changes into account?

[1] Please note that although the regions in this figure are depicted basically by their boundaries, in our studies the regions are realized by gray areas with different alpha values.

[2] The authors are not aware of any study that examines in detail the semantics of *cover*. But the definitions found in WordNet (wordnet.princeton.edu) suggest that *cover* involves two distinct objects in a specific and distinct spatial order.

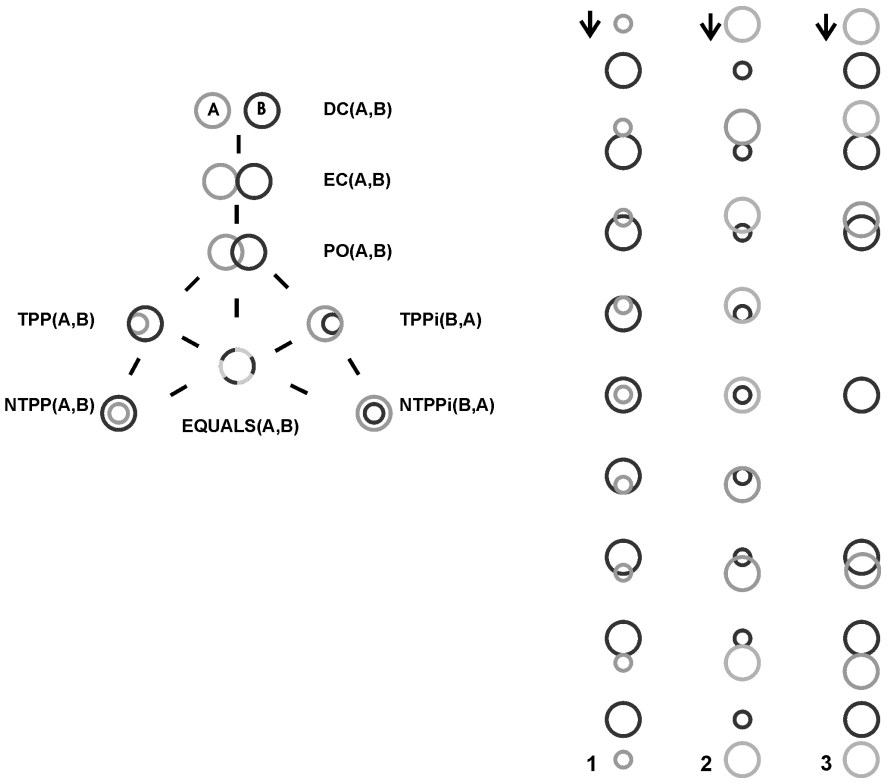

Fig. 2. Modified conceptual neighborhood graph for topological relations (left part) [5]. Gradual changes in topological relations caused by translation (right part), 3 basic scenarios: 1. A is smaller than B and A is moved over B; 2. A is larger than B and A is moved over B; 3. A and B have the same size, shape, and orientation and one of them is mover over the other.

– Does the identity of regions influence the conceptualization, which leads to the distinction between TPP and TPPi in the conceptual neighborhood graph (see Figure 2)?
– What other factors influence the conceptualization of gradual topological change? For example, the proportion of the regions involved and the availability of a referent, i.e. one region's movement is related to the fixed position of the other.

5 Design

To realize our event experiment, we are using a purpose built software tool that allows for grouping animated icons representing different event characteristics displayed on a computer screen. In contrast to other card sorting/grouping tools [8, 11] it is especially designed to use animated icons.

The animated icons show simple geometric figures and topological transformations representing the behavior of two regions. The transformations change topological relations of the regions gradually, a concept we discussed as conceptual neighborhoods [6]. We start with the gradual changes in topological relationships as identified by Egenhofer and Al-Taha [5]. Our first focus lies on *translation*. Egenhofer and Al-Taha identify 3 scenarios for these gradual changes (see Figure 2):

1. A is smaller than B and A is moved over B (or B over A).
2. A is larger than B and A is moved over B (or B over A).
3. A and B have the same size, shape, and orientation and one of them is moved over the other.

Condition 1 and 2 are conceptually similar. Their differentiation makes sense if we take into account two regions with their own (constant) identities. Additional variations we introduce are 1.) different sizes of the regions to test whether the proportion has an influence on the conceptualization, taking up the discussion of reference objects in cognitive science [12], i.e. whether the larger object or the locationally fixed object is the reference; and 2.) different directions from which one region moves toward another region or from which they move toward each other to counterbalance perceptual effects.

The 9 basic cases we distinguish are:

1. A is smaller than B and A is moved over B.
2. A is smaller than B and B is moved over A.
3. A is smaller than B and both move toward each other.
4. A is larger than B and A is moved over B.
5. A is larger than B and B is moved over A.
6. A is larger than B and both move toward each other.
7. A and B have the same size and A is moved over B.
8. A and B have the same size and B is moved over A.
9. A and B have the same size and both move toward each other.

Case 3 and 6 are not differentiated by Egenhofer and Al-Taha [5]. Likewise the cases 8 and 9 do not appear in their original characterization. We find these distinctions important as two geographic regions can potentially move at the same time, for example, different parts of an oil slick.

In our study, the participants see a screen that is divided into two parts (see Figure 3). On the left side of the grouping tool the animated icons are presented in random order. The right side of the grouping tool is empty at the beginning of the experiment. In this part, the participants have to create groups of animated icons that they rate as being similar. The interaction with the tool was kept simple and the placement of the animated icons is realized as drag and drop.

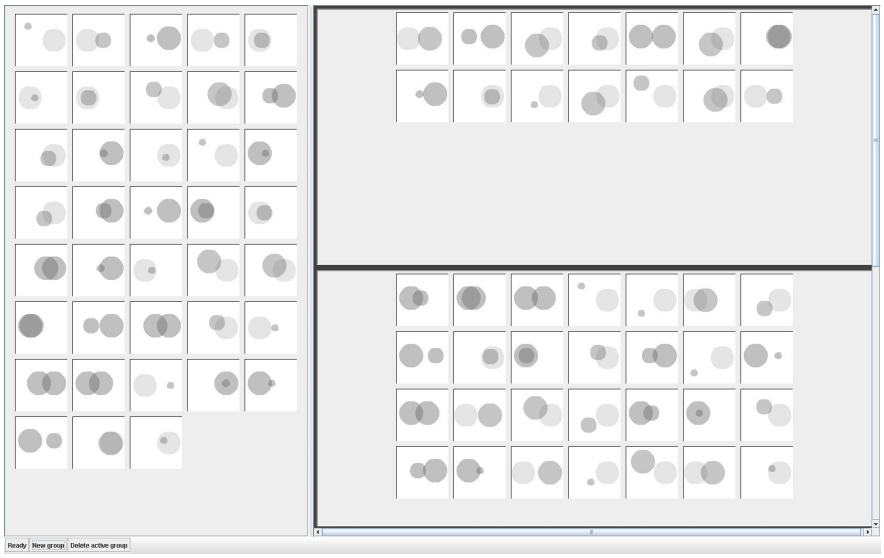

Fig. 3. Screen shot of the tool that realizes the grouping interface with (in the experiment) animated icons.

Five follow up tasks are required by the participants after they finished the main tasks, i.e. after they placed all available animated icons into groups:

1. Each group that a participant created should be labeled by a linguistic expression. This expression should not exceed three words.
2. The spatial changes in each group should be described in no more than 25 words.
3. The basic changes in spatial relations should be named explicitly.
4. For each group a symbol should be drawn that captures the spatial changes that occur in that group.
5. The participants are asked to create a hierarchical order (taxonomy) of the groups.

6 Discussion and Outlook

A first result of the analysis of the grouping task is displayed in Figure 4. This first, rough analysis already indicates that the grouping criteria applied by our participants are not the once formally distinguished. For example, a clear distinction is made whether

one object is moving or whether both objects move toward each other. Topologically these cases are not distinguished. A more detailed analysis is underway to provide deeper insights in the differences between formal and cognitive similarities.

The follow up task that requires participants to reflect on the categories that they established and on the subprocesses (subevents) that take place in these categories, will allow us to shed light on the question of the appropriate model for characterizing gradual topological changes. We will be able to provide more insides into the question of what constitutes the best formal model to characterize cognitive conceptualization processes of motion events that involve change. An alternative would have been to apply more classical event boundary elicitation techniques such as segmentation of continuous information flows [24]. As we paid particular attention to not presuppose boundaries and realized the changes of topological relations by different alpha values to avoid perceptual effects, the boundary events might have been happening in too short a time window. Especially in the area of geographic event conceptualization, where most objects have rather vague boundaries, the introduction of highly salient, sharp boundaries like in the experiments by Knauff et al. [11] seems to be not appropriate.

The next steps offer various possibilities for deepening the knowledge about the conceptualization of geographic events. Besides the obvious extensions to test the remaining topological transformations that Egenhofer and Al-Taha discuss, such as scaling and rotation, we will focus on the combination of topological transformations and will combine them with transformations that single regions can undergo. The restriction we place on our research is the grounding of events in the domain of geographic phenomena. Our research objective, in general, addresses the question of how to process large amounts of geographic data to communicate it in a cognitive ergonomic way to a human user of an information system. We will, therefore, conduct targeted behavioral user studies to shed light on this question. Like the experiment discussed above, we will target approved formalism in Geographic Information Science and will validate their cognitive adequacy and make suggestions for improvements. The overall goal is an in-depth understanding of the relationship between the low-level data recordings and specifications of spatiotemporal information systems and the high-level conceptualization processes of a cognitive agent.

While these experiments aim to shed more light on basic conceptualization processes in interaction with moving objects that change their topological relationships, we will also relate our research to event experiments in the psychology community [22] and integrate into our research questions regarding the shape of trajectories and various other parameters that have shown to have an influence on the conceptualization of events (see, e.g. [15]). The restriction we pose on our studies is the relation to geographic events and the constraints they underly.

The topological relationships defined in the discussed approaches do not restrict the shape of the geographic regions. Current approaches in geographic information science, however, show a strong focus on new technological developments to record large amounts of data. Among the favorite approaches are geosensor networks. One future direction of our research therefore is the question of suitable formalism to monitor geographic events in geosensor networks and the changes that occur in the conceptualiza-

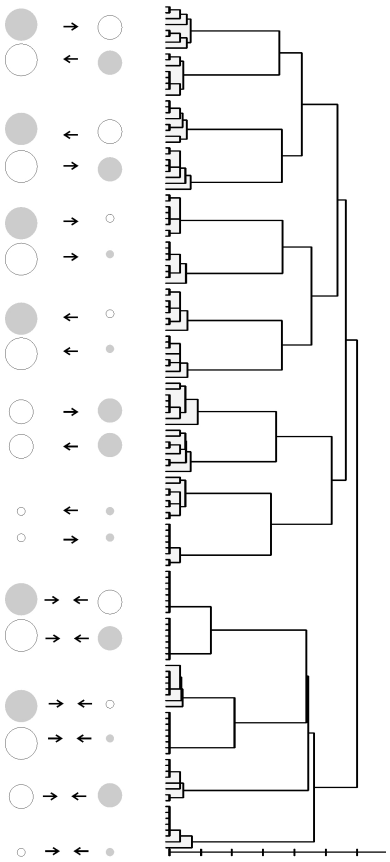

Fig. 4. Dendrogram for 144 animated icons. The icons on the left side represent groups of icons exemplarily.

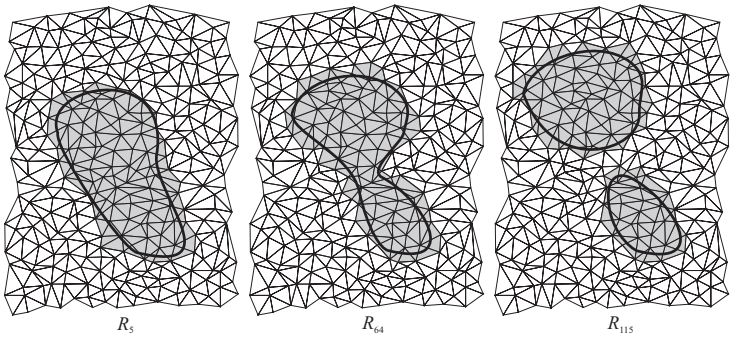

Fig. 5. Tracking the continuous evolution and gradual changes of regions in a geosensor network

tion processes of these events compared with those from the original characterizations of conceptual neighborhoods (see Figure 5).

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