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Identifying Factors of Geographic Event Conceptualization

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Abstract. This paper examines whether the formal topological characterization of spatial relations between moving geographic regions provides an adequate basis for the human conceptualization of motion events for those regions. The paper focuses on gradual changes in topological relationships caused by continuous transformations of the regions (specifically, translations). Using a series of experiments, the conceptualization and perception of conceptual neighborhoods is investigated. In particular, the role of *conceptual neighborhoods* in characterizing motion events is scrutinized. The experiments employ a grouping paradigm and a custom-made tool for presenting animated icons. The analysis examines whether paths through a conceptual neighborhood graph sufficiently characterize the conceptualization of the movement of two regions. The results of the experiments show that changes in topological relations—as detailed by paths through a conceptual neighborhood graph—are not sufficient to characterize the cognitive conceptualization of moving regions. The similarity ratings show clear effects of perceptually and conceptually induced groupings such as *identity* (which region is moving), *reference* (whether a larger or a smaller region is moving), and *dynamics* (whether both regions are moving at the same time).

Keywords: Event Structure Perception, Topology, Spatio-Temporal Reasoning, Conceptual Neighborhoods

1 Introduction

Dynamic aspects of geographic-scale phenomena continue to form a fundamental topic in geographic information science (e.g., Hornsby and Egenhofer 2000a, MacEachren et al. 1999, Miller 2005, Peuquet and Duan 1995, Reitsma and Albrecht 2005, Worboys 2005b). As technology advances, yielding more sophisticated systems for monitoring dynamic aspects of our environments, the need for a basic understanding of the conceptualization of dynamic geographic phenomena by cognitive agents becomes more important (Worboys and Duckham 2006). The focus of this paper is on the occurrent aspects of such phenomena, that is, events in the geographic world such as wildfires, storms, and migrations. A formal model of the cognitive conceptualization of dynamic geographic phenomena would provide a basis for the identification of discrete conceptual units within continuous geographic events. Such a model has applications to diverse domains, such as computing with words, the generation of natural language output, and the design of cognitively adequate interfaces to geographic information systems (GIS).

Conceptual neighborhoods (Freksa 1992a) have become a central concept in qualitative spatial reasoning and in the formalization of static as well as dynamic aspects of spatial cognition. Conceptual neighborhoods possess cognitive and computational advantages (Freksa 1992b), bridging the gap between a formal characterization of spatial relations and their cognitive counterpart. The assumption that "qualitative equals cognitive" is apparently true of our understanding of static spatial relations, and several cognitive phenomena can indeed be explained best qualitatively rather than quantitatively (Hayes 1978). Conceptual neighborhoods inherently have the ability also to characterize dynamic processes (Egenhofer and Al-Taha 1992). Yet, we often obtain contradictory results from behavioral studies, especially when visual communication is involved (Hommel et al. 2000, Klippel et al. 2005). An in-depth analysis of the cognitive conceptual processes that underlie gradual conceptual changes is therefore necessary.

The remainder of this paper is structured as follows. First, the existing literature on the cognitive adequacy of topological relations is briefly introduced. Motion/change events are then discussed, providing the rationale for our studies, before detailing the methodology used in this research. Our results indicate that topological relations alone are not sufficient for characterizing human conceptualization of *moving* spatial objects—*regions* in our terminology. We provide evidence for the important role of factors such as the identity of regions; the general dynamics, i.e., whether one or both regions are moving; and the relative sizes of regions.

2 Background

The term "region" is used in this paper to refer to any areal spatial object (cf. "regions" in RCC). In this section the existing literature connected with the conceptualization of dynamic regions is reviewed from three perspectives.

First, the strong link between formal topological models of static spatial relations and the human conceptualization of those relations is examined (section 2.1). Second, the question of the conceptualization of dynamic motion and change events is discussed, highlighting a gap in the existing literature connected with the study of the conceptualization of dynamic spatial relations between moving geographic regions (section 2.2). Third, the approach adopted in this research is set out, building on existing formal models of geographic events and addressing to what extent these models correspond to human conceptualization of geographic events (section 2.3).

2.1 *Topology and the cognition of spatial relations*

In their studies of the adequacy of using topological relations to represent cognitive and linguistic concepts, Mark and Egenhofer (1994a) conclude that *topology matters and metric refines.* Mark and Egenhofer applied different methods to test whether the 9-intersection model (Egenhofer 1991) is valid with respect to cognitive and linguistic categories. In a grouping task participants had to sort graphical representations of topological relations into categories (Mark and Egenhofer 1994b). In an agreement task participants judged the suitability of a linguistic description of graphical representations with the same topological characteristics but different metric properties (Mark and Egenhofer 1994a,b). 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 methodologically different advantages and disadvantages, seem to confirm that the 9-intersection model is able to characterize human categorization of static spatial relationships.

However, further studies of the cognitive adequacy of topological relationships have drawn a somewhat different picture. Riedemann (2005) analyzed the correspondence of operators used in current GIS packages, their formal specification, and the mismatch between the human user's conceptualization of these operators and their linguistic labels. Her results from a simple agreement task (only "yes" or "no" answers 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.

Region connection calculi (RCC) (Randell et al. 1992) and Egenhofer's intersection models (Egenhofer 1991) have been analyzed in a study by Knauff et al. (1997). Their results show that participants adhere to the topological relations specified by RCC-8 but not to the coarser mereological relations characterized by RCC-5. In fact, Knauff et al. conclude that RCC-5 and a coarsening of the 9-intersection to 4-intersection relations (which does not exactly correspond to the RCC-5, see Figure 1) may be cognitively irrelevant.

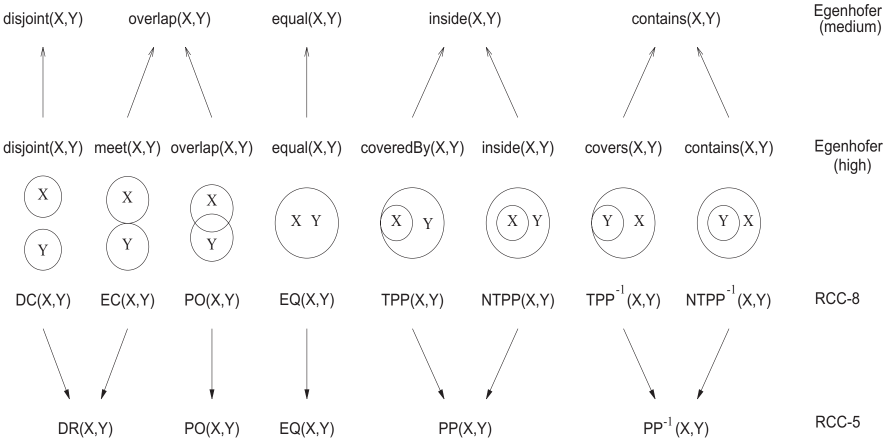

Figure 1. Comparing different granularities in the 9-intersection model and RCC-5 and RCC-8, reproduced from Knauff et al. (1997).

One problem that becomes apparent by looking at the stimulus material used in experiments by Knauff et al. (1997) is an overemphasis on 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 et al. uses regions which are completely defined by their boundaries. The regions consist of two circles of two different colors drawn on a gray background. Such an experimental design grants boundaries their own ontological status upfront. The conclusion that RCC-8 shows cognitive adequacy, while RCC-5 does not, is consequently open to criticism. Arguably, the explicit boundary representation used by Knauff et al. could mask subjects' identification of conceptual categories, by making the fine-grained RCC-8 relations perceptually easier to differentiate than the coarse-grained RCC-5 relations (e.g., explicit boundaries might make it perceptually harder to merge DC and EC into DR, see Figure 1).

In summary, previous studies have shown that formal topological models of spatial relations (i.e., the 8 basic relations specified by the 9-intersection model and RCC-8) do, to varying degrees, correspond with human spatial cognition of these relations. However, the results of these studies need to be interpreted with care, especially with respect to the representation of the boundaries of regions and their applicability to dynamic aspects of geographic space.

2.2 *Motion/change events*

Research into the characterization of cognitive events has a long history within several sciences (for an overview see Zacks and Tversky 2001, Casati and Varzi 1996). However, past research has not yet yielded a clear understanding of the conceptualization of *geographic* events. While the development of an explicit representation of geographic events is the objective of current research (Hornsby and Egenhofer 2000b, Worboys 2005a), the cognitive foundations of geographic event conceptualization have not been addressed sufficiently. Recent research has investigated the perception of the structure of events (Zacks et al. 2001) and how perceptual characteristics induce the conceptualization of event boundaries. A contrasting approach is the presumption of event boundaries, for example, on the basis of formal characterizations in artificial intelligence (Allen 1983) and qualitative spatial reasoning. Behavioral studies are then employed as validation means by which the cognitive adequacy of formal event characterizations is assessed. An example for this approach can be found in Lu and Harter (2006) which discusses whether Allen's intervals are equally prominent in the cognitive conceptualization of events (in this case, fish swimming in a tank). The research reported in this paper has a similar goal as the research reported here as it does not intend to identify event boundaries "from scratch." Instead, the existence of event classes are assumed that can be derived from topological models of geographic regions, such as RCC (Randell et al. 1992) and the 9-intersection model (Egenhofer 1991). Since the 8 topological relations defined in these models have demonstrated cognitive adequacy for static spatial relations, it seems sensible to ask to what extent the same can be said for dynamic relations.

In summary, a question that has not been sufficiently addressed in the literature is to what extent existing topological models, such as proposed by Egenhofer (1991) or Freksa (1992a), are able to characterize human conceptualization of changing relationships between moving geographic regions. This is the main thrust of research reported in this work.

2.3 *Geographic event conceptualization*

A general treatment of spatial change is provided by Galton (1986). More specifially, RCC-8 and the 9-intersection model describe the same set of eight topological relations for two-dimensional disks in the plane (Cohn 1997, Egenhofer 1991). The conceptual neighborhood graph in Figure 2 is adapted from Egenhofer and Al-Taha (1992), with labels taken from RCC-8. Using the RCC-8 labels avoids any confusion that might arise by using linguistic labels like *overlap* or *covers* (for example, the WordNet definitions of "covers" suggest a subtly different meaning for the term than the topological definition of Egenhofer 1991).

The related illustration in Figure 3 shows a sequence of topologically distinct stages resulting from translation of one region relative to another. The figure shows *three basic scenarios*, identified for translation by Egenhofer and Al-Taha (1992):

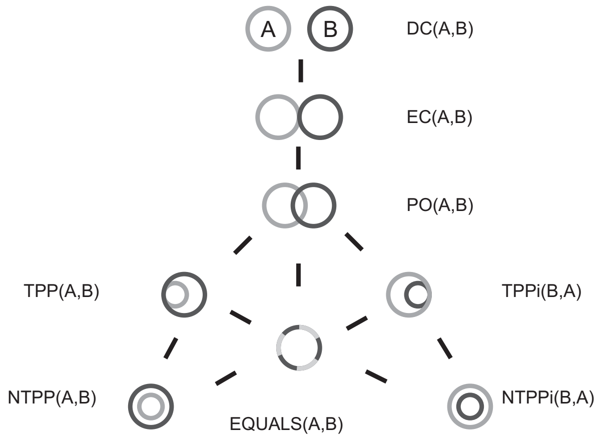

Figure 2. Modified conceptual neighborhood graph for topological relations after Egenhofer and Al-Taha (1992).

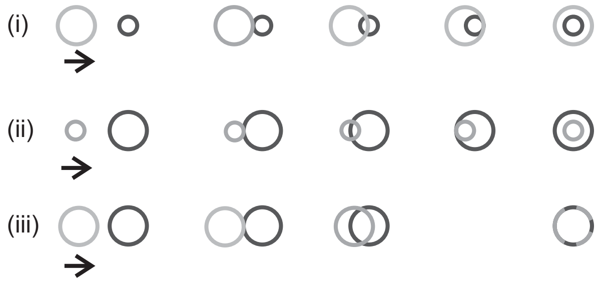

Figure 3. Three translations (corresponding to the 3 scenarios by Egenhofer and Al-Taha (1992)) that give rise to gradual changes in topological relations describe by Figure 2.

(i) B is larger than A and one region is moved over the other.
(ii) A is larger than B and one region is moved over the other.
(iii) A and B are the same size and one region is moved over the other.

After Egenhofer and Al-Taha (1992), we refer to the sequence of topologically distinct changes as *gradual* changes in topological relations. These gradual changes correspond to pathways through the conceptual neighborhood graph (e.g., (i) corresponds to pathway DC, EC, PO, TPP, NTTP). Egenhofer and Al-Taha (1992) discuss a variety of *continuous transformations* (also called topological transformations or homeomorphisms) which give rise to different gradual changes in topological relations between two regions. However, in this paper we restrict the discussion to translations alone.

The contribution of this research is to investigate to what extent these gradual changes in topological relations correspond to human conceptualization of the geographic change events. Specifically, the questions that are addressed by this work include:

- Is it sufficient to take only the topological characteristics of continuous transformations into account?
- Does the identity of regions, which leads to the distinction between TPP/TPPi and NTPP/NTTPi in the conceptual neighborhood graph, influence human conceptualization?
- What other factors influence the conceptualization of gradual topological change? For example, what effect do the relative sizes of the regions involved or the availability of a referent (i.e., where one region's movement is related to the fixed position of the other) have on human conceptualization of the changes?

3 Experiment 1

In experiment 1 participants were asked to group a range of animated icons showing two geographic regions moving relative to each other. The relative movement results in gradual changes in the topological relations between the two regions, as summarized in Figures 2 and 3. The results were analyzed by investigating the incidence of icons grouped together across the group of participants.

3.1 *Methods*

Participants. The participants were 14 male and 5 female graduate and postgraduate students of the Department of Geomatics at the University of Melbourne, with an average age of 27.5. They received a $20AUD book voucher for their participation. [1]

Grouping tool. A purpose-built software tool was developed to enable sets of icons to be displayed and grouped on a computer. In contrast to other card sorting or grouping tools (cf. Harper et al. 2003, Knauff et al. 1997) the tool developed for this experiment is especially designed to display animated icons. Most of the experimental data was collected directly through the tool. Instruction texts were presented to participants on-line to minimize potential interference by the experimenter.

The interface of the tool was designed to be simple (see Figure 5). The screen is split in two parts. All icons together are initially presented on the

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[1] After the experiment participants were questioned regarding their knowledge of topology. None of them reported to have detailed knowledge of topology, 32% reported to have no knowledge about topology. In a subsequent linguistic labelling tasks none of the participants used RCC terminology. Additionally, the results of experiment 1 and 2 do not indicate a bias toward topological knowledge.

left hand side of the screen using a simple in-built randomization function. The right hand side contained only a single, empty group at the beginning of the experiment. Animated icons could be placed into groups using a simple drag and drop procedure. Three buttons were available at the bottom of the screen: “New Group,” “Delete Active Group,” and “Finish”. The experiment was finished when all icons were placed into groups. Deleting an active group (which was marked by a red frame) returned all icons in this group to the left hand side of the screen again. Figure 5 shows the interface at a partially completed stage of the grouping task, with some icons on the left-hand side still unallocated to groups. The tool interface was displayed to subjects on a Dell 20” UltraSharp wide-screen flat-panel LCD Monitor. No problems with the interface were reported by the participants during the experiment.

Stimulus. The detailed animation setup is described in the following paragraphs. However, to summarize the stimulus, 144 animated icons were generated showing two circular regions that move over one another. Each animation requires approximately 5 seconds to complete, followed by a short break of 1 second before that animation restarts. All the animated icons were presented to the user at the same time. The different animations were staggered so they did not synchronize. Human subjects were asked to group similar animations in the interface using familiar drag-and-drop mouse actions.

As discussed previously, continuous transformations of regions results in gradual changes in the topological relationship between the two figures. The continuous transformation investigated in this research was restricted to *translation* of the regions, specifically the translations described by Egenhofer and Al-Taha (1992) (the three scenarios in Figure 3). This restriction was necessary to ensure a reasonably high number of variations for the same gradual changes in topology, while at the same time resulting in a total number of icons that was manageable for the participants.

Of the three scenarios in Egenhofer and Al-Taha (1992) (i.e., 1. B is larger than A and one region is moved over the other; 2. A is larger than B and one region is moved over the other; 3. A and B are the same size and one region is moved over the other), scenarios 1 and 2 are conceptually similar. Differentiating these cases only makes sense if the two regions have their own, constant identities. To avoid an overemphasis on boundaries, the experiment used different levels of transparency (*alpha* values) to distinguish the two regions from one another. Region A had an alpha value of 65% (i.e., appears darker), region B had an alpha value of 45% (i.e., appears lighter). Using this approach provided a mechanism for depicting regions without drawing an explicit boundary, which we regard as an important difficulty with earlier experiments (see section 2.1). When the regions overlap, the alpha values combine to clearly indicate the area occupied by both regions without leading to any impression of one region necessarily being in front of another.

Two other factors in the icons were varied. First, the different icons showed regions with different sizes, in order to test whether the relative sizes of regions has an influence on the conceptualization of the changes. This factor relates to an ongoing discussion in cognitive science about reference objects, and whether the larger object or the locationally fixed object is the reference (Levinson 2003, Bryant et al. 1992). In this first experiment two different size ratios were chosen for the cases A/B bigger than B/A, 40:10 and 40:30 (measured in screen pixels). For the case that both icons were of the same size, i.e., A equals B, the sizes ratios used were 10:10 and 30:30 pixels. Second, different animated icons were used to represent the situations where two regions move toward each other and those situations where one region is moving toward the other region.

As a result of these considerations, 9 general cases (plus two different size ratios) were distinguished in this experiment. The following numbers will be later used to analyze the grouping of the participants (for example, in Figures 6 and 9):

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.

Cases 3, 6, and 9 are not differentiated by Egenhofer and Al-Taha (1992), since this earlier work considers only the case where one region is moved over the other. Likewise, case 8 does not appear in the original characterization by Egenhofer and Al-Taha, since it leads to the same pathway through the conceptual neighborhood graph as case 7. As discussed above, we consider these distinctions potentially important to the conceptualization of moving regions (see section 2.3).

Based on these 9 general cases, a range of animated icons were generated. Each icon was square and 100×100 pixels in size. At the start of each animation, the pair regions A and B were positioned near opposite borders of the icon. The initial distance from the border to the center of each region was set to 25 pixels (thus leaving at least a 5 pixel margin for even the largest regions, with a diameter of 40 pixels). The starting position of each region along the icon boundary was offset using a random number, generated using the website random.org. Each moving region then moved on a straight vector from its starting location to the starting location of its pair. As a result, although regions moved across the icon from one border to the opposite border, the precise direction of movement was randomized.

Note that this experimental design only considers animations with region trajectories that are at 180° to each other. The more general cases of trajectories at other angles were excluded in the interests of a manageable experimental setup and because including additional trajectories does not increase the possible range of topological changes exhibited by the animations. Figure 4 summarizes the dimensions and construction of one animated icon for A bigger than B, where A is moved over B starting from the left hand boundary of the icon. The dashed arrow in Figure 4 represents the movement vector of A, while “rnd(50)” represents a random integer number of pixels in the range 0–50.

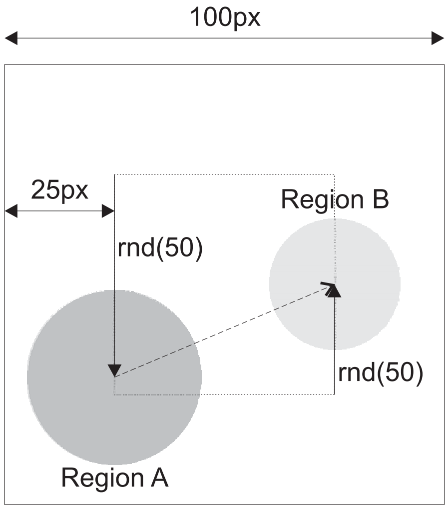


Figure 4. Summary of how the animated icons were constructed.

In total, each of the 9 cases above were generated using the two different sizes, with randomized starting positions at each of the four different icon borders, resulting in 9×2×4=72 distinct animations. Two of each icon were generated to test whether the same icons would be placed into the same group, resulting in a total of 144 animated icons presented to users.

Macromedia Flash was used to create the animations, which were subsequently exported as animated GIF icons. One further difference was introduced into the animations at this stage. The total number of frames in each animation was varied slightly, from 50 to 70 frames. This ensured that relative speeds of the animations were slightly different, so avoiding any possible perceptual effects from synchronous movement. The experiment was run on an

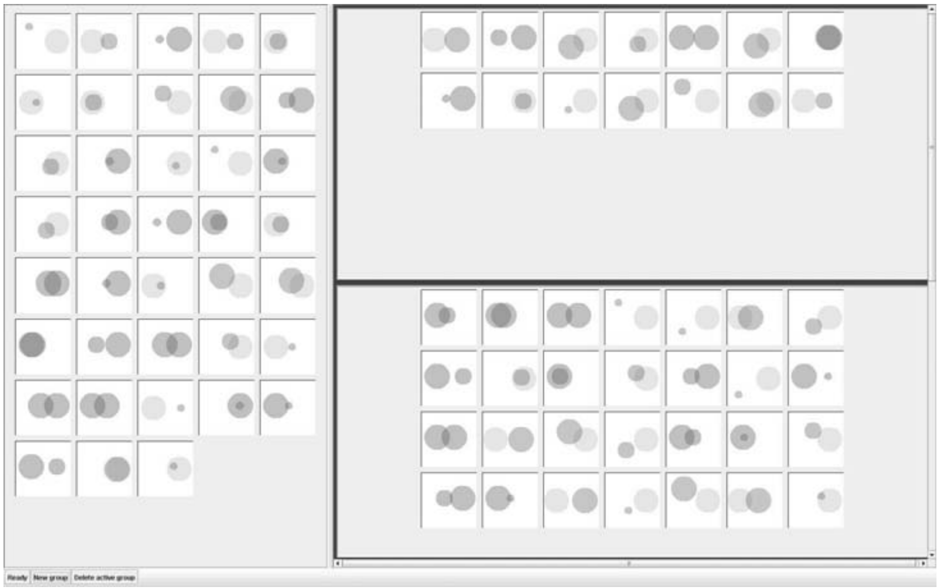


Figure 5. Screenshot of the grouping tool interface with (in the experiment) animated icons.

Intel Celeron 2.33GHz computer with 1GB ram. In the customized grouping tool, the animations were tuned to take approximately four to five seconds to complete. At the end of each animation, 10 additional frames were added to indicate perceptually the endpoint of this movement, i.e., the animation stopped at the end position for about 1 second. Figure 5 shows a screenshot of the user interface for the grouping tool and animated icons. Note that this screenshot contains less than 144 animated icons because some icons already allocated to groups are scrolled beyond the bottom of the grouping window on the right hand side. In the experiment all icons were animated at the same time.

Procedure. The experiment took place in a lab at the CRCSI, University of Melbourne. Participants were tested individually and were required to complete the experiment in one sitting. The instructions that were given to the participants asked them to sort the animated icons into groups based on their similarity. Similarity was not specified further. The participants were advised that there was no right or wrong answer, and that the number of groups was their decision. Research has shown that participants are likely to imagine that geometric figures such as used in the experiment represent the behavior of cognitive agents, i.e., they interpret the movements as something meaningful (Michotte 1963, Newtson 1973). For this reason, we primed the participants by explicitly advising them in the instruction text to think of the animated icons as abstract representations of geographic regions. The following instructions were provided: "You may think, for example, of an oil slick approaching a coastline, a high pressure zone, clouds and so forth."

After recording their personal data and reading the instructions, the participants then performed a trial grouping exercise to acquaint themselves with the interface and the task. The icons used for this trial showed animals of different categories. None of the categories contained the same number of animals. Upon completion of this warm-up task, the participants were able to access the main task. As described above, all 144 animated icons were displayed on the left (requiring users to scroll), and one empty group was displayed on the right (also possibly requiring users to scroll as more groups were added).

Following the experiment, participants were also interviewed about:

- the criteria they used to group the animated icons;
- the geographic scenario they imagined;
- whether they were thinking of the icons moving in 2D or 3D space;
- their native language; and
- their knowledge about topology.

The results of these interviews are still being analyzed, and so are not discussed further in this paper.

3.2 *Results*

Participants created between three and 18 groups. The average of the number of groups created by the set of all participants was 8.47. In preparation for analysis, each participant's groupings were compiled into a data matrix comprising 144 rows and 144 columns representing all combinations of the 144 different icons. For any pair of icons, the corresponding cell in the data matrix contained a "1" if the participant put both the icons in the same group, and a "0" if the participant put the icons in different groups. As a result, every participant's data matrix was symmetric and by definition contained 1s along its diagonal.

The individual participants' matrices were summed to give a *group matrix*. Consequently, each cell of the group matrix contains a value between 0 and 19, indicating how often a pair of icons were grouped together. For example, in the case where two items were placed in the same group by 14 participants, the corresponding cell in the matrix would contain the value 14.

This data was subjected to agglomerative hierarchical cluster analysis. Cluster analysis identifies "natural" groupings within data that minimize within-group and maximize between-group variation. Agglomerative cluster analysis initially treats each case as a separate cluster, recursively combining the most similar clusters until all clusters are combined. After Aldenderfer and Blashfield (1984), the cluster analysis used can be summarized according to the following five criteria:

1. **Software**: SPSS and CLUSTAN software were used to perform the cluster analysis. The software produced the same results, but offer different visualization capabilities.
2. **Similarity measure**: Squared Euclidean distance was used as the analysis similarity measure.
3. **Cluster method**: Four common cluster methods were used and compared: complete linkage (minimizes the maximum distance between clusters), single linkage (minimizes the minimum distance between clusters), average linkage (minimizes the average distance between clusters), and Ward's methods (minimizes the distance to the center mean).
4. **Number of clusters**: In many studies, deciding on the appropriate number of clusters is a critical step in the analysis. However, spatial relationships are naturally hierarchical (for example, see Figure 1). As a result, it is the hierarchical structure of the clustering that reveals which clusters (spatial relationships) are regarded as more similar to one another. We therefore focus on both the agglomeration schedule that reveals the clustering process and the number of clusters.
5. **Validation**: The results were initially validated through the comparison of the results of multiple cluster methods (see 3. above, Kos and Psenicka 2000). Further validation was performed by repeating the analysis with two randomly selected sub-groups (see Clatworthy et al. 2005).

Figure 6 shows an example dendrogram resulting from an average linkage cluster analysis, produced using CLUSTAN. The case number refers to the 9 cases (listed on page 9, based on Egenhofer and Al-Taha 1992) plus two different size classes, a and b (see section 3.1). The icons in the center of Figure 6 provide a static, graphical summary of the dynamic scenarios specified by the case number (region *A* darker, region *B* lighter). The three types of lines connecting cases on the left hand side of Figure 6 highlight the three similar classes predicted by formal characterization of gradual topological changes (i.e., the three scenarios distinguished by Egenhofer and Al-Taha (1992) discussed previously, *A* larger than *B*; *B* larger than *A*; *A* and *B* same size). The right hand side displays the actual results of the average linkage cluster analysis.

The results shown in Figure 6 are typical of all the clustering methods tested (see Figure 7). All the clustering methods formed 18 basic clusters within the first 3 agglomeration steps (see Figure 6). Looking more closely at the extreme behaviors of the participants, three participants created only three groups. All three of these participants made the same distinctions between which region (A or B) is moving, resulting in two groups, and additionally distinguished the

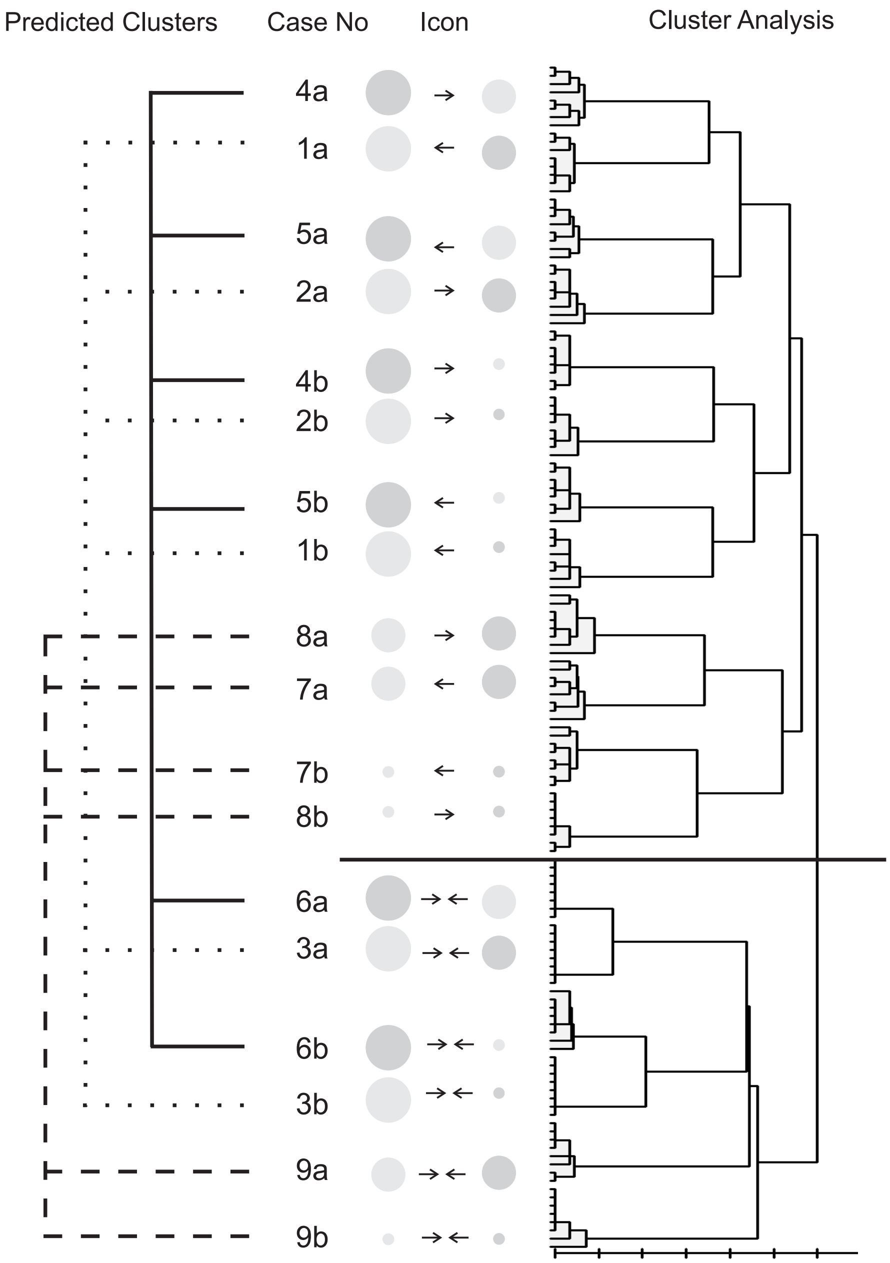


Figure 6. Summary of experiment 1 results, average linkage cluster method. The case numbers refer to the 9 cases (listed on page 9. Cases 1-3 belong to scenario 1, 4-6 to scenario 2, and 7-9 to scenario 3) plus two different size classes, a and b (see section 3.1).

case that both regions are moving. Two participants created 18 groups. Both participants used the 9 basic cases discussed previously in combination with the two size ratios.

3.2.1 *Validation of results.*

As discussed in section 3.2, the results were validated first by comparing multiple clustering methods (Kos and Psenicka 2000, Ketchen and Hult 2000). Figure 7 juxtaposes the results of the four clustering methods used in this experiment. As all clustering algorithms (single linkage, complete linkage, average linkage and Ward's method) identified 18 groups at early stages in the agglomeration schedule, we truncated the dendrograms in Figure 7 at 18 clusters.

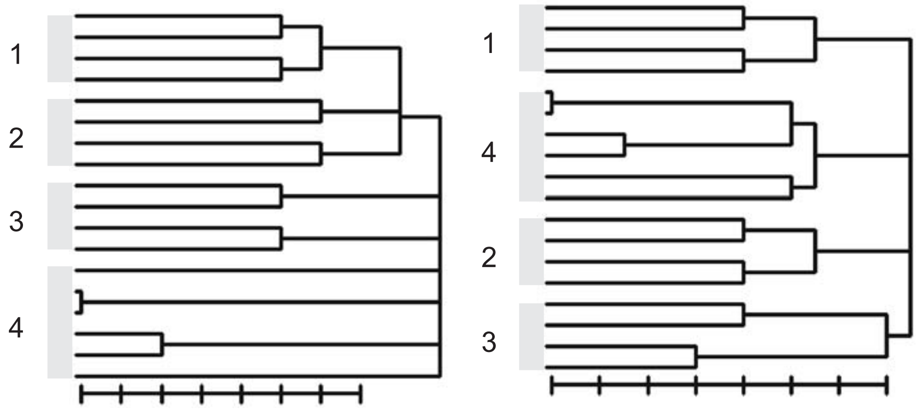
In Figure 7, four key groups are highlighted using gray bars:

1. One region (A or B) is bigger than the other and only one region is moving;
2. One region (A or B) is much bigger than the other and only one region is moving;
3. Both regions have the same size and only one region is moving;
4. Both regions (same size, large and small size difference) are moving toward each other.

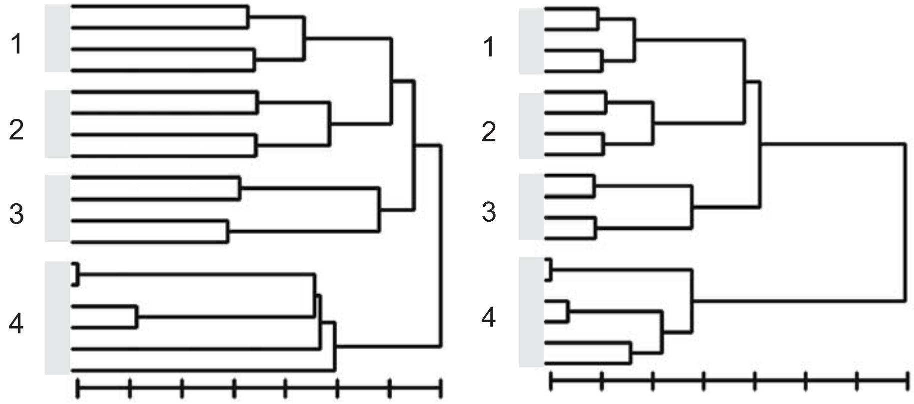
With the exception of the single linkage method (which is known to be susceptible to "chaining" effects where clusters may be combined based on a single pair of close data items) these groups are clearly distinguished across different clustering methods. While the single linkage methods identifies only one grouping on the higher level identical to the other methods (group 1), it also points to the special status of dynamic aspect, i.e., the case where both regions are moving (group 4). The comparison of the other three clustering methods appears to validate the conclusion that the distinction between one and both regions moving is highly salient to participants.

A second method to validate the results of cluster analysis, discussed by Clatworthy et al. (2005), is the random separation of the experimental data into two groups. Cluster analysis is performed separately on the two groups and the results are then compared. Although in our experiment the number of participants was comparatively low (N=19), this validation method was also adopted. The participants were randomly allocated to one of two groups, comprising 9 and 10 participants respectively, using random numbers from random.org. A Ward's method cluster analysis was performed on both groups.

The results of the validation procedure are shown in Figure 8. Figure 7d shows the corresponding results for the same clustering procedure with all participants. The groups indicated in the upper part of Figure 8 are the same as in Figure 7. To be able to depict both dendrograms, these were again truncated at the 18 cluster point, which was identical for both the dendrograms



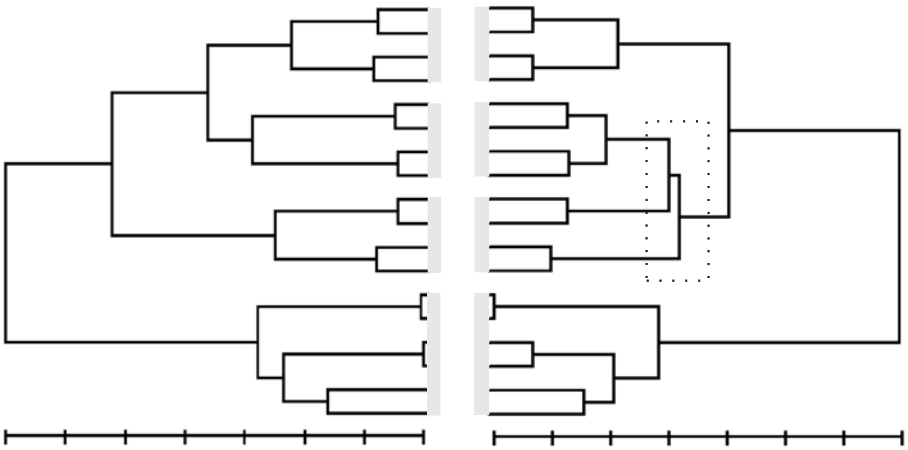
a. Single linkage b. Complete linkage



c. Average linkage d. Ward's method

Figure 7. Comparison of four dendrograms from experiment 1: single linkage, complete linkage, average linkage, and Ward's method.

in Figure 8 as well as the complete results in Figure 7d. The dendrograms, from there on, show a high correspondence for all three groups. The first clustering steps are identical for all three dendrograms. The distinction between the cases where one regions is moving versus the cases where both regions are moving are clearly separated. The only difference between the results appeared in the analysis of group 2 (9 participants). In this group, the cases of the regions having the same size and one region is moving are grouped together with the cluster that contains the cases where one region is much bigger than the other one and one region is moving (marked by a dotted box in Figure 8b). We infer from this relatively minor discrepancy uncovered in the validation process that the results of the cluster analysis are remarkably stable, especially given the small size of the data set (and so the possibility for outliers to affect the



a. Group 1 (10 participants) b. Group 2 (9 participants)

Figure 8. Validation of results using Ward's method cluster analysis.

validation process).

3.3 *Discussion*

At the lower levels, all dendrogram results exhibit 18 clusters. These clusters correspond to the 9 topologically distinct cases identified theoretically, in combination with the two different sizes that were used in the experiments. This indicates that gradual changes in topological relations to some extent are a driving force behind the participants' grouping of the animated icons. This result appears highly stable, with different clustering methods exhibiting the same behavior. Using direction as a criterion for the grouping was performed by one participant (P02), but did not affect the overall result.

While the participants did identify the predicted clusters at the lowest levels, it is the highest levels of the dendrogram that correspond to the greatest dissimilarity between cases, and so arguably the most salient distinctions for participants. Looking at the highest levels of the dendrogram, the most striking feature is the distinction that participants made between those cases where one region is moving and those cases where both regions are moving. This distinction is highlighted in the dendrogram of the average linkage analysis in Figure 6 using the horizontal line above case 6a. Again, this result was stable across the different clustering methods, being even more pronounced in the Ward's method. This result was empirically validated using a k-means cluster analysis with 2 groups, which as expected confirmed this observation. The implication of this result is that topologically identical cases are judged, at the highest level, as being conceptually dissimilar. For example, cases 1a, 1b, 2a, 2b, 3a, 3b are topologically identical. However, cases 3a and 3b, where both regions move, are distinguished at the highest level from the other cases, where only one region moves.

Excluding the cases where both regions are moving, some matches between the topologically predicted grouping and the similarity ratings by the participants were revealed by the cluster analysis. Inspection of the cases where only one region moves (Figure 6 above the horizontal line) shows that those gradual topological changes that included the EQ relation (7a, 7b, 8a, 8b) were distinguished from those that did not (1a, 1b, 2a, 2b, 4a, 4b, 5a, 5b) at relatively high levels in the dendrogram.

Further, one might expect this latter group of cases to be distinguished by participants based on the following topological distinction: whether the cases correspond to a pathway through the conceptual neighborhood graph that includes the TPP/NTPP or the TPPi/NTPPi relationships (i.e., 1a, 1b, 2a, 2b forming a strong group and 4a, 4b, 5a, 5b forming another strong group). In contrast, the experiment did not support this expectation. The highest level distinction for this set of cases is between instances where one region is much larger than another (cases 1b, 2b, 4b, 5b) and instances where one region is somewhat larger than another (cases 1a, 2a, 4a, 5a). For the former cluster, whether the small region moves (cases 1b, 5b) or the large region moves (cases 2b, 4b) is used to refine this distinction. For the latter cluster, whether region *A* moves (cases 1a, 4a) or region *B* moves (2a, 5a) is the basis for further refinement. Only the lower levels of the dendrogram—in the absence of other grouping criteria—identify the topological distinction between pathways through the conceptual neighborhood graph that include TPP/NTPP versus the TPPi/NTPPi relationships.

In summary, the participants' grouping of the animated icons does reflect certain expected topological distinctions between those icons. However, in several ways participants grouped icons more strongly on the basis of non-topological distinctions, including whether one or both regions were moving; whether a larger or a smaller region was moving; and whether region *A* or region *B* moves.

4 Experiment 2

As discussed above, an unexpected result of experiment 1 was that the grouping behavior of the participants reflected the two clearly distinguishable size classes used in the experiment (i.e., 1a, 2a, 4a, 5a versus 1b, 2b, 4b, 5b and 7a, 8a versus 7b, 8b). However, the actual sizes used in experiment 1 (40:30 versus 40:10 and 30:30 versus 10:10 pixels) were arbitrarily chosen. So, to investigate further the effect of region size, a second experiment was conducted in which size was randomized at the same time as maintaining the qualitative differences between regions, such as A bigger than B.

4.1 *Methods*

Participants. The participants were graduate students of the Department of Geomatics at the University of Melbourne, 12 male, 8 female, average age 24.3. They received a \$20AUD book voucher for their participation. [1]

Grouping tool. The same grouping tool as in experiment 1 was used for experiment 2.

Stimulus. The icons were modified such that they did not display two clearly differentiable sizes. The groups A bigger than B and A much bigger than B (similarly for B bigger than A and B much bigger than A) were combined into one group, A bigger than B (similarly B bigger than A). Pairs of random integers (x_i, y_i), where $15 \leq x_i \leq 40$ and $10 \leq y_i \leq 35$, were generated using random numbers from random.org. Only those pairs where $x_i - y_i \geq 5$ were chosen, others discarded. New icons were then generated using the integer pairs, with the value x_i defining the diameter of the larger region and the value y_i defining the diameter of the smaller region. Consequently, for any pair of regions in an animation, the larger region was between 15 and 40 pixels in diameter. The smaller region was at least 10 pixels in diameter and at least 5 pixels smaller than the larger region. Otherwise, the relative sizes of the regions were random.

For animations where the two regions were the same size, a single list of random integers between 10 and 40 was created, defining the diameter of both regions. The direction of movement was again randomized as for experiment 1. The icons were not duplicated in this experiment.

Procedure. The procedure was the same as for experiment 1.

4.2 *Results*

The average of the number of groups created by the set of all participants was 7.95. A t-test revealed no significant difference at the 5% level between the number of groups created for experiment 2 and experiment 1 (t: df37, p=0.73).

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[1] After the experiment participants were questioned regarding their knowledge of topology. None of them reported to have detailed knowledge of topology, 74% reported to have no knowledge about topology. In a subsequent linguistic labelling tasks none of the participants used RCC terminology. Additionally, the results of experiment 2 do not indicate a bias toward topological knowledge.

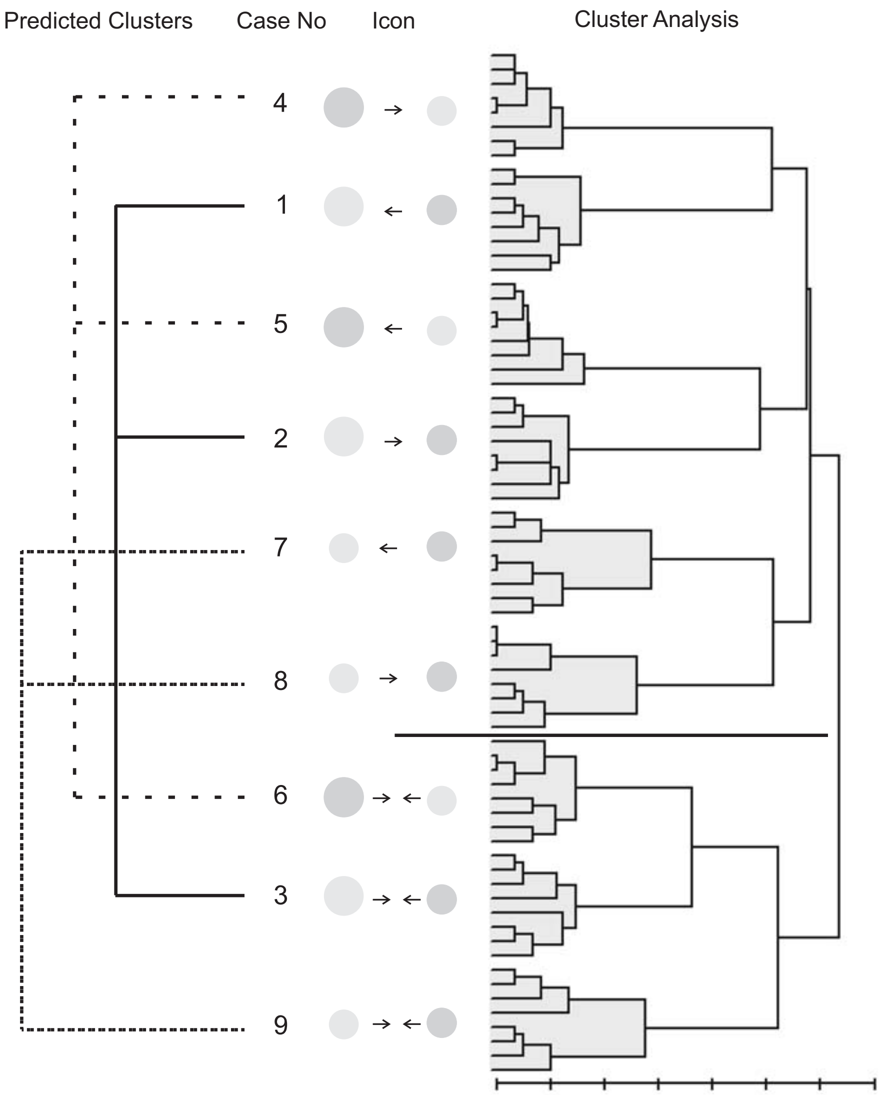

Figure 9. Summary of experiment 2 results. The case number refers to the 9 cases (listed on page 9).

There was also no significant difference between the number of groups that were created by female and male participants.

Figure 9 summarizes the results of experiment 2, again using the average linkage clustering method for ease of comparison with Figure 6. As before, the case number refers to the 9 cases (listed on page 9). The icons in the center of the figure provide a graphical summary of the dynamic relation specified by the case number (region *A* darker, region *B* lighter). The left hand side of Figure 9 highlights the three similar classes predicted by formal characterization of gradual topological changes. The right hand side displays the actual results of the average linkage cluster analysis.

Compared to experiment 1, the participants struggled somewhat more in creating consistent groups and the formation of consistent clusters took up to 9 agglomeration steps for average linkage clustering method, as opposed to three in the first experiment. Despite the increased difficulty in forming consistent groups, the results still draw a similar picture to experiment 1. The 9 formally distinct cases are distinguished from one another at the lower levels. At the highest levels of dendrogram, experiment 2 again showed that participants made a clear distinction between topologically identical animations based on whether one or both regions were moving (cases 1, 2, 4, 5, 7, 8 versus 3, 6, 9).

As for experiment 1, a high level distinction is again made between the topologically distinct cases where the regions are the same size (i.e., the pathway through the conceptual neighborhood graph contains the relation EQ) and where the two regions are different sizes (i.e., the pathway through the conceptual neighborhood graph contains the TPP/NTPP or TPPi/NTPPi relationships). Again, as for experiment 1, animations with regions of different sizes where only one region moves are grouped as more similar depending on the identity of the moving region (whether region A or region B moves). This factor overrides the expected distinction between animations that describe different pathways through the conceptual neighborhood graph through TPP/NTPP or TPPi/NTPPi relationships.

The primary difference between the results of experiments 1 and 2 is that in region size becomes a less obvious grouping factor in experiment 2. The introduction of regions with randomized diameters in experiment 2 effectively leads to a reduction in using size as a basis for judging similarity of animations. A closer look at the data revealed, however, that the finest-grained distinctions made by participants at the lowest levels of the dendrogram (i.e., within the nine different cases, shown shaded in gray in Figure 9) were indeed size based. A detailed analysis of cluster 5 is depicted in Figure 10. It shows that size, even in the absence of two clearly distinguishable size ratios is used as a criterion for rating the similarity of dynamic regions. All the higher level clusters found in the data can be explained in terms of size-independent factors: differences in topology; whether one or both regions move; or whether region A or region B moves.

4.3 *General Discussion*

The results of the two grouping experiments are strongly in agreement and support the assertion that factors other than gradual changes in topological relations are fundamental to the conceptualization of moving geographic regions.

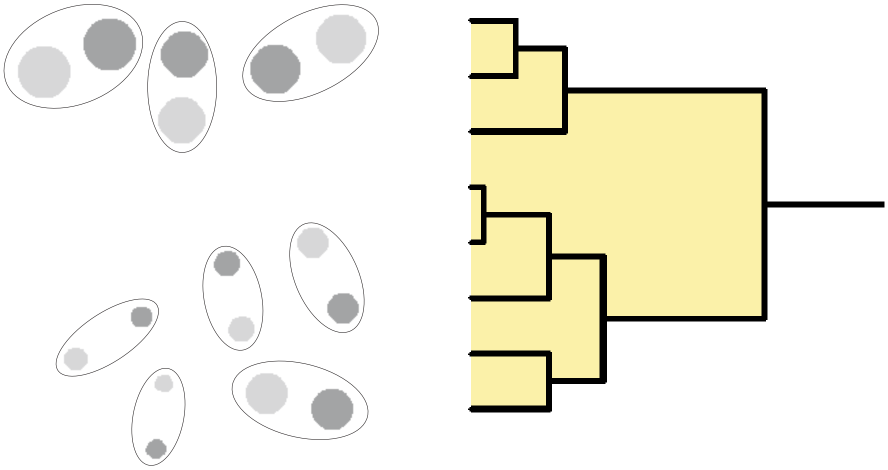

Figure 10. Cluster 5 (see Figure 9) is depicted in greater detail. The Figure shows that despite the randomization of size ratios, equally scaled in the Figure, size is used as a criterion for rating the similarity of dynamic regions.

The strongest other factor appears to be the distinction between whether one region is moving or both, with the identity of the regions (whether *A* moves or *B* moves) being another rather weaker factor. The relative size of the regions was also a factor, especially when clearly distinguishable size classes were in evidence in the animations.

However, topological differences are still evident at different levels in the groupings. Animations which trace a pathway through the conceptual neighborhood graph that includes the EQ relationship—in our experimental setup the case were two regions have the same size—are strongly distinguished from other animations by participants. The topological distinction between the symmetric pathways through the conceptual neighborhood graph, involving distinctions between TPP/TPPi and NTPP/NTPPi, are much less strongly distinguished and appear to be amongst the weakest factors influencing similarity.

5 Outlook

The results of this research support the view that differences in the paths through the conceptual neighborhood graph may be a necessary but not sufficient factor in human conceptualization of moving geographic regions. Topology alone lacks the explanatory power to characterize cognitive conceptualization of events between moving geographic regions. The analysis of the results clearly indicates that other factors, such as the identity of a region (which regions is moving), the concept of a referent region (whether a larger or smaller region is moving), and the overall dynamics (whether one or both regions are moving), are also important factors in assessing the similarity of geographic events.

While gradual changes in topological relations are only one dimension along which participants could have grouped the animated icons, there are several further possibilities for the role of topology in the cognitive characterization of geographic events. For the clarity of our experimental setup, this study focused on gradual changes in topological relations induced by translation. An unanswered question is whether different continuous transformations are the conceptual "glue" underlying geographic events. It is conceivable that translation is conceptualized differently from other topological transformations, such as rotation or scaling.

Research in cognitive psychology (Newtson 1973, Zacks and Tversky 2001), however, shows that event boundaries can be induced by movement patterns that do not involve a change in the topological relation between objects at all. An example would be a quick "zigzag" movement (buzzing) of one of the regions involved, although such buzzing movements may not be relevant in the domain of geographic events. Nonetheless, the simple change of direction, for example, when Hurricane Katrina turned toward the coast, is most certainly conceptualized as an event. Similarly the early research on the perception of causation by Michotte (1963) indicates that conceptualization of events is distinct from change in topological relations.

5.1 *Further research directions*

Behavioral research on the perception and conceptualization of static as well as dynamic spatial relations strongly supports the view that humans *schematize* environmental information (Herskovits 1986). Whether we learn, judge, perceive, or communicate static or dynamic spatial relations, these relations are simplified, idealized, abstracted, or schematized. Static spatial relations are commonly schematized by humans using topological relations to abstract from (or ignore) metric details. Our results indicate that the situation may be different for dynamically changing spatial relations, with topology being only one of a number of factors used to schematize events. A natural question for future research is then: What are the dominant topological relations that anchor human schematization of events?

Some indications may be found in Lu and Harter (2006). Lu and coworkers found that the interval relations in Allen's temporal calculus (Allen 1983) have a different status in the perception and conceptualization of events. In their experiments, some relations were more likely to be confused than others. Specifically, the results indicate that relations that describe some kind of overlap (START, DURING, FINISHES, EQUAL) are distinguished from those relations that do not (BEFORE, MEET). Lu and coworkers interpret these results as a challenge and complement to an earlier hypothesis that states that the perception and conceptualization of events is endpoint focused (Regier 2003).

Another important aspect for future work to consider concerns research on *causation.* A key concept in Talmy's (1988) work on causation is that of *force dynamics.* In force dynamics, events are characterized and conceptualized using graphical figures that show the starting configuration of an agonist and an antagonist together with the forces that act on them. While not nearly as sophisticated as Talmy's graphic representation system, initial impressions of the drawings made by participants after our grouping experiment (yet to be analyzed) suggest similar principles may be evident. Figure 11 shows one of the drawings that can be regarded as prototypical for a graphical summary of a group created by a participant. It shows a stylized symbolic representation: In this case, two medium size regions move toward each other (verbal description the participant used: *medium regions merging*) and a medium size regions moves toward a large region (verbal description the participant used: *medium to inside large*). Future work will analyze these results further, investigating the hypothesis that force dynamics provide an explanation of the participants' sketches.

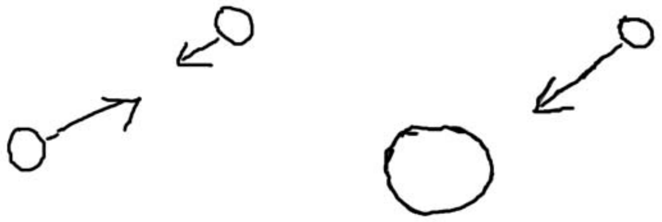

Figure 11. Sketches drawn by a participant representing symbolically two groups that she created.

Finally, more research is needed to shed light on the nature of what the conceptual anchor points for the mental conceptualization of geographic events are and how they can be captured formally. This research should contribute to a high-level cognitive framework for the conceptual characterization of geographic events. Such a framework will provide comprehensive formalisms that are able to capture cognitive conceptualization processes. It will also be relevant to issues of multimodality in geographic information systems in which the goal is that different input and output channels are able to communicate efficiently.

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