

# Geographic Event Conceptualization: Where Spatial and Cognitive Sciences Meet

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## Abstract

We present the results of two behavioral experiments on the conceptualization of geographic events (here, the movements of hurricanes). The focus is on juxtaposing two types of presentation: static versus animated trajectories. We designed 72 animated and 72 static icons of the same hurricane movements and asked participants to group them. Within each condition we distinguished paths of hurricanes using topological equivalence classes. Topology allows for differentiating ending relations that are potentially relevant for event conceptualization (Regier, 2007). Results show that motion matters. Participants constructed static icon groups more distinctly and focused more on ending relations. The presentation mode additionally influenced linguistic descriptions. These findings contribute to understanding and formalizing geographic event conceptualization.

**Keywords:** Category construction; geographic event conceptualization; topological relations; movement patterns.

## Introduction

Event cognition is addressed in several research fields and as such, this article caters to an interdisciplinary community. Cognitive scientists address questions of event segmentation (Zacks, et al., 2001), the role of causal relationships (Wolff, 2008), or how events are related to language (Talmy, 1988); spatial scientists are interested in formally characterizing movement patterns (Gottfried, 2008), analyzing spatio-temporal information (Yuan & Hornsby, 2008), and more recently, using formal characterization to ground the semantics of movement patterns by formally capturing those aspects of movement patterns which are meaningful to a cognitive agent (Kurata & Egenhofer, 2009). Topology, as one aspect of the spatial characterization of events, has long been a topic of interest to both spatial science and cognitive science communities. This article uses a topological framework to provide a formalized understanding of geographic event conceptualization, and discusses topology from a multidisciplinary perspective.

The importance of topology is based on two main aspects. First, topological characterizations are qualitative and offer an abstract-level characterization of spatial information, which is potentially relevant to higher-level cognition, as knowledge is created through

abstraction. Second, topology offers a formal basis for identifying invariants in spatial information. These invariants might be the very basis of event cognition. One critical aspect in event cognition is coherence, which allows for the determination of meaningful units/segments of events (Tversky, et al., 2008). Identifying topologically equivalent events (or parts thereof) may therefore contribute to rendering the notion of coherence more precise.

In this article we focus on geographic events and more specifically on the paths of hurricane movements. From a formal, topological perspective, path characteristics can be captured using either of the two most prominent topological frameworks in spatial information science, the region connection calculus, RCC (Randell, et al., 1992), or Egenhofer's intersection models (Egenhofer & Franzosa, 1991). An assumption we need to make is that both entities (figure or moving entity, and ground or reference entity) are spatially extended (see Figure 1). The central question that we address here is whether the mode of presentation (dynamic or static) results in different conceptualizations of this geographic event.

This question has been addressed in multidisciplinary search efforts; for example, Tversky and collaborators (2002) questioned whether animation facilitates learning and information processing; Gentner and Boroditsky (2001) found that learning verbs poses more difficulties than learning names of objects; and, closely related to our research here, Maguire and collaborators (in press) found that geometric path characteristics are used differently to segment events depending on the presentation mode (static or dynamic).

To operationalize this research question from a topological perspective, we employ a modification of the endpoint hypothesis (Regier, 1996; Regier & Zheng, 2007). The essence of this hypothesis states that a focus (by a cognitive agent) is placed on ending relations in processing spatio-temporal information. Within the framework of topological characterization, ending relations of events can be formally characterized by different topological relations (as identified by the RCC or intersection models).

Here we focus exclusively on topological relations and the mode of presentation while excluding other aspects such as shape or speed changes. Our goal is to use a multi-methodological, formally grounded

approach to demonstrate how the mode of presentation affects event conceptualization.

## Methods

### Materials

We followed a design from our previous experiments (Klippel & Li, 2009). This design is inspired by the endpoint hypothesis (Regier, 1996; Regier & Zheng, 2007) and we distinguished movement patterns on the basis of the topological relations at the end of the movement. The basis for this distinction is a *conceptual neighborhood graph*, CNG (Freksa, 1992), that is derived from eight topologically distinguished spatial relations as part of either Egenhofer's intersection models (Egenhofer & Franzosa, 1991) or the region connection calculus, RCC (Randell, *et al.*, 1992). This conceptual neighborhood graph is shown in Figure 1.

We created eight icons (both static and dynamic) for each of the following nine topological equivalence classes derived from paths through the conceptual neighborhood graph:

- DC1 – the hurricane does not make a landfall (CNG path: DC);
- EC1 – the hurricane kind of bumps into the peninsula (CNG path: DC-EC);
- PO1 – the hurricane just reaches land such that half of the hurricane is on land and the other half is over water (CNG path: DC-EC-PO);
- TPP1 – the hurricane makes landfall but is still 'connected' to the water (CNG path: DC-EC-PO-TPP);
- NTPP – the hurricane makes landfall and is completely over land (CNG path: DC-EC-PO-TPP-NTPP);
- TPP2 – same as TPP1 but the hurricane nearly made it out to the water again (CNG path: DC-EC-PO-TPP-NTPP-TPP);
- PO2 – same as PO1 but on the other side of the peninsula (CNG path: DC-EC-PO-TPP-NTPP-TPP-PO);
- EC2 – same as EC1 but on the other side of the Peninsula (CNG path: DC-EC-PO-TPP-NTPP-TPP-PO-EC);
- DC2 – same as DC1 but has crossed the peninsula completely (CNG path: DC-EC-PO-TPP-NTPP-TPP-PO-EC-DC).

Within each icon the starting and ending locations of the hurricanes were randomized without violating topological information. In total, two sets of 72 icons each were created showing either an animation of a hurricane or a static image in which a hurricane symbol demarcated the ending relation and a line represented the trajectory (see Figure 1).

### Participants

40 undergraduate students, 20 per condition (mean age=21.65, 9 females in the dynamic condition and mean age=19.80, 11 females in the static condition). All participants received a cash reimbursement of \$10.

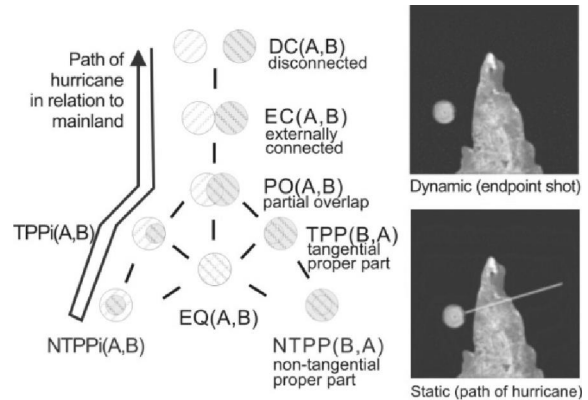


Figure 1. Conceptual neighborhood graph (left) and examples of icons representing the same topological relations (DC2) in the two conditions (right).

### Procedure

Both experiments were carried out as group experiments in a computer lab. The lab was equipped with 16 Dell desktops (Model: Optiplex 755, CPU: Duo E8200, 2.66GHz) with 24" widescreen LCD monitors. We used view blocks to make sure that participants could only see their own screens. Each participant performed two tasks: a category construction task and a linguistic labeling task.

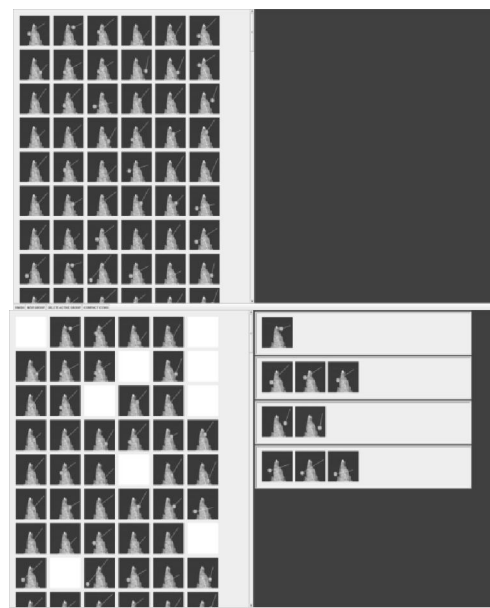


Figure 2. Top: initial interface, bottom: ongoing (mock) experiment.

We used our custom-made grouping software CatScan that allows for the presentation of both static and dynamic stimuli (see Figure 2). All 72 hurricane icons in each condition were initially displayed on the left side of the screen. Participants were required to create groups on the right side of the screen. After creating at least one empty group they were able to drag icons from the left side into a group on the right side. They were explicitly advised that there was no right or wrong answer regarding either the number of groups or which icons belong to which group. They also had the opportunity to move icons between groups, move icons back to the left side, or delete whole groups. The main grouping experiment was preceded by a warm up task (sorting animals) to acquaint participants with the software. Participants performed a linguistic labeling task upon finishing the main grouping experiment. They were presented with the groups they created and provided two linguistic descriptions: a short name of no more than five words, and a longer description detailing their rationale for placing icons into a particular group.

## Results

The category construction of participants is recorded in individual similarity matrices. In these similarity matrices a value of '0' indicates that two icons of a pair of icons are not placed into the same group. Correspondingly, a value of '1' indicates two icons are placed into the same group. The total number of cells in each similarity matrix is 5184 (2556 cells after removing redundancy). We created an overall similarity matrix (OSM) by summing over individual matrices of all 20 participants in each condition. Similarity in the OSM is represented by a number ranging from 0 to 20, where 0 indicates the least similarity between two icons and 20 indicates the highest similarity between two icons. Figure 3 shows a visualization of the raw similarities using a tool we implemented called Matrix Visualizer (Klippel, et al., accepted). We started our analysis by examining the patterns in Matrix Visualizer. Darker regions in each matrix indicate that corresponding icons (intersection of row and column) were considered similar by more participants. For example, cells at the intersection of EC2 and DC2 in the dynamic condition are darker than that in the static condition. This indicates that there are more participants in the dynamic condition who grouped icons of EC2 and DC2 together.

Next, we used cluster analysis to analyze the similarities with the goal to reveal natural groupings. We used Ward's method, average linkage, and complete linkage (Romesburg, 2004). Clatworthy and collaborators (2005) suggested comparing different cluster analysis methods in order to cross validate the interpretation of clustering results. The comparison of

these three methods shows that their results are comparable. Here we represent the clustering analysis using Ward's method; the results of using complete linkage and average linkage are posted on our website (<http://www.cognitive-science.psu.edu/cogsci2011>).

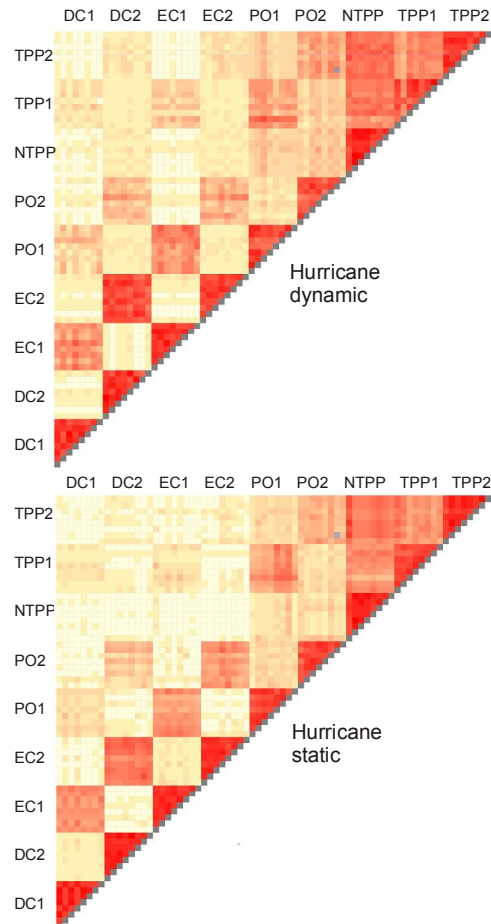


Figure 3. Similarity matrices for dynamic and static presentation. The darker the color, the more similar two icons (at the intersection of rows and columns) are.

We found that the category constructions are different between static and dynamic presentation (see Figure 4). In the static condition, overall, we found that participants created more distinct groups with the topologically distinguished paths, i.e., the topological ending relations are clearly separable. A good example is the ending relations EC2 and DC2, which are barely distinguishable (in fact mixed) in the dynamic group, but separated in the static group. Likewise, we find a change in the similarities between individual topological equivalence classes and how and when they are grouped together. Most strikingly, in the dynamic condition, EC1 and PO1 are grouped together before DC1 is added. In contrast, in the static condition, the two non-overlapping ending relations DC1 and EC1 are

grouped together, while PO1 is considered closer to the proper part relations (TPP1 and NTPP).

Following the cluster analysis of grouping patterns, we looked into the actual numbers of participants who placed icons of the same topological equivalence class into the same group. Using the tool KlipArt (Clatworthy, et al., 2005), we counted the number of participants who placed a) all icons of the same topological equivalence class (Figure 5) and b) icons that are conceptual neighbors into the same group (Figure 6).

A paired samples t-test shows a statistically significant difference between static and dynamic presentation. Icons in the static condition are grouped together more often than are the corresponding icons in the dynamic condition (dynamic:  $M = 10.22$ ,  $SD = 2.22$ ; static:  $M = 12.89$ ,  $SD = 2.37$ ;  $t(8) = -6.532$ ,  $p < 0.001$ ). This indicates that the mode of presentation influences the conceptualization of events.

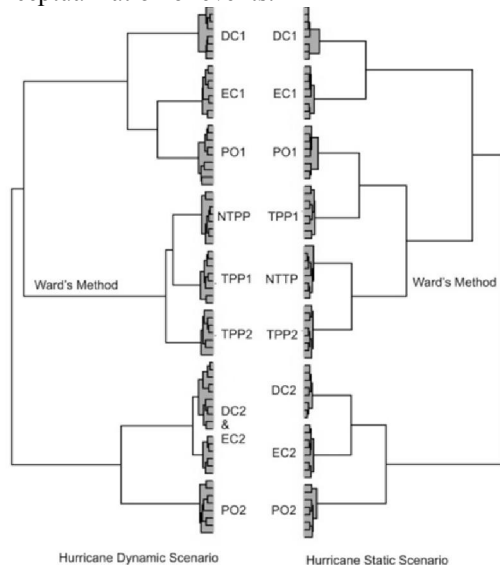


Figure 4. Results of cluster analysis.

We were also interested in seeing how conceptual neighbors were grouped. We paired topological equivalence classes that are conceptual neighbors, and counted the number of participants who grouped them together. The paired equivalence classes are: DC1&EC1, EC1&PO1, PO1&TPP1, TPP1&NTPP, NTPP&TPP2, TPP2&PO2, PO2&EC2, and EC2&DC2 (Figure 6).

Overall, we did not find significant differences between the two conditions. However, the results offer additional insights into the interpretation of the results of the cluster analysis and Matrix Viewer. For example, DC1&EC1 are conceptually closer (they have a higher number) in the static condition than in the dynamic condition. Likewise, the pair PO1&TPP1 is considered more similar in the static condition than in the dynamic

condition. In contrast, proper part relations are more similar in the dynamic condition. At the end of the movement patterns (EC2&DC2), differences become smaller. Please note that this analysis is rigorous in the sense that only participants who place all icons belonging to a topological equivalence class are counted, while cluster analysis takes into account individual icon similarities.

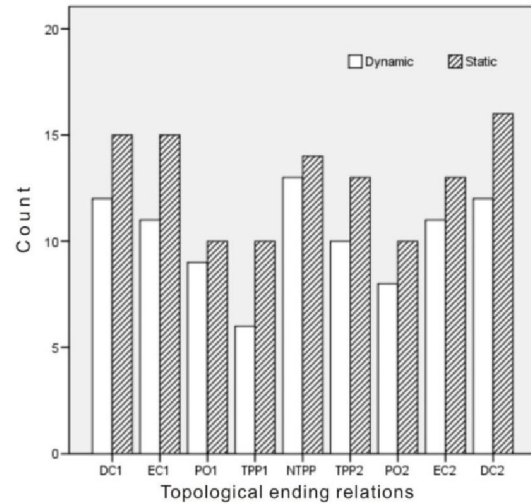


Figure 5. Number of participants who grouped all icons of the same topological ending relation.

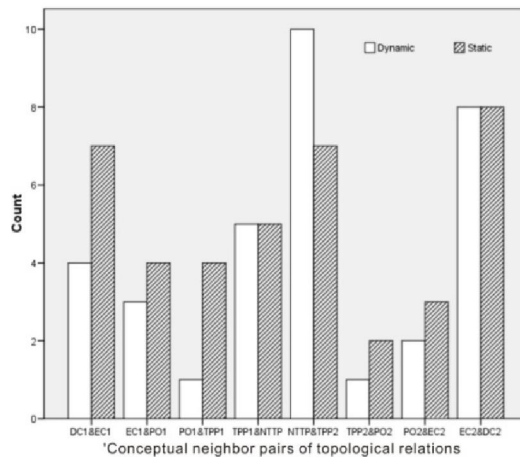


Figure 6. Number of participants who grouped all icons in the same conceptual neighbor pairs

Finally, we investigated the linguistic descriptions that participants provided through the software AntConc (Anthony, 2006). We looked at the top ten most frequently used words in the short names. Within these words, we eliminated the figure (hurricane) and ground (peninsula) to see how participants used words to describe the relations between them. The remaining word frequencies show some interesting differences in how categories (groups) were labeled and linguistically characterized within each condition. The three most frequently used words are shown in Table 1. We found

that while participants in the static condition focused on elements present in the scene as such, for example, the coast or the visualized trajectory (path), participants in the dynamic condition focused on the actual movement and used verbs more frequently.

Table 1. Word frequency in short names.

	“coast”	“path”	“stops”
Dynamic	2	0	8
Static	25	21	0

We then investigated the long descriptions, which showed similar patterns. We used the same tool to rank the frequency of words used. Participants in both conditions used similar numbers of words related to directions (e.g. left, right, north, south, west, east: 51 times in the dynamic condition and 62 times in static condition). Participants in the static condition, however, used the word “path” (43 times) and “coast” (28 times) more often compared to participants in the dynamic condition (5 and 14 times, respectively). Moreover, participants in the dynamic condition used verbs (e.g. stop, end land, touch, or cross) 70 times while participants in the static condition used a verb “located” (14 times) only to describe hurricanes.

### Discussion

The results of these two experiments extend current research on the conceptualization of events in a number of ways. We carried out a comparison of statically and dynamically presented paths of hurricanes. Path characteristics were systematically varied based on formal theories that have developed in spatial information science (and artificial intelligence). This combination allows us to render the influence of the presentation mode more precise.

Through a multi-methodological approach, we found primarily that topologically defined ending relations of geographic movement patterns are important, but that they are salient to different degrees. Not every topological relation is cognitively salient (*adequate* from a modeling perspective) to the same degree. Additionally, we found that the static presentation of paths (of events) adds a focus on ending relations and strengthens topology as a criterion for distinguishing and conceptualizing movement patterns.

These results contribute to the literature in the domain of qualitative spatial and temporal reasoning which relates formal and cognitive conceptualizations of space. For example, research by Knauff et al. (1997) showed that there is basically no difference between topological equivalence classes when the entities in a scene are a) static and b) simple geometric figures. However, if there is both a dynamic and a semantic context, such as in the experiments by Lu et al. (2009), topological equivalence classes are combined into

larger (super-ordinate) categories. They found that relations that do not overlap (DC and EC) are distinguished from those that do overlap<sup>1</sup>.

Based on these findings, we suggest that a) a semantic context changes the conceptualization of spatial relations (both static and dynamic), and b) static presentations of movement patterns place an additional focus on the ending relation of a movement pattern.

Looking at the conceptualization of movement patterns (static or dynamic) through linguistic analysis, we can further corroborate that there are differences in processing the same spatial and semantic information depending on the presentation mode. While dynamic presentations elicit linguistic descriptions that provide accounts of actions, static presentations place a focus on entities involved in a scene.

### Conclusions

Research on the conceptualization of events has become a focus in both the cognitive and the spatial sciences. Now that computational developments allow the use of dynamic events as stimuli, it becomes possible to relate approaches in both areas. We consider this combination mutually beneficial because spatial information science offers formalisms that render notions of spatial information precise, and (behavioral) cognitive science allows for evaluating spatial formalism. Hence, we can address questions on the conceptualization of events and spatial configurations more precisely as a basis for behavioral evaluations.

For example, the notion that topology is central to human thought is omnipresent in the cognitive sciences. Researchers such as Piaget and Inhelder (1948; 1967), Klix (1971), Shaw (1974), and Johnson and Lakoff (1980), to name just a few, intimately and explicitly refer to topology as central to their theories. What this means, however, can scientifically be answered only by rendering the notion of topology precise, on the basis of formal theories. We find that formal topology makes more and richer distinctions than assumed in several cognitive theories. Behavioral evaluations therefore become necessary.

We also showed that the development of new tools for data analysis and the integration of multiple methods allows for an in-depth analysis of behavioral data. We briefly discussed our approach that comprises tools for data collection (CatScan) and data analysis (MatrixViewer, KlipArt) with other tools such as Clustan and AntConc.

Future research directions, suggested by both our results and the literature discussed, should address the influence of semantic contexts on conceptualizing otherwise identical spatial events, the evaluation of

<sup>1</sup> Allen’s (1991) temporal calculus used by Lu and colleagues is isomorphic to the RCC used in this paper.

other formalisms that could capture movement patterns of single agents (Kurata & Egenhofer, 2009), and the integration of further path characteristics (Maguire, et al., in press).

## References

- Allen, J. (1991). Time and time again: The many ways to represent time. *International Journal of Intelligent Systems*, 6(4), 341-355.
- Anthony, L. (2006). Developing a freeware, multiplatform corpus analysis toolkit for the technical writing classroom. *Professional Communication, IEEE Transactions on*, 49(3), 275-286.
- Clatworthy, J., Buick, D., Hankins, M., Weinman, J., & Horne, R. (2005). The use and reporting of cluster analysis in health psychology: A review. *British Journal of Health Psychology*, 10(3), 329-358.
- Egenhofer, M., & Franzosa, R. (1991). Point-set topological spatial relations. *International Journal of Geographical Information Science*, 5(2), 161-174.
- Freksa, C. (1992). Temporal reasoning based on semi-intervals. *Artificial Intelligence*, 54(1), 199-227.
- Gentner, D., & Boroditsky, L. (2001). Individuation, relativity, and early word learning. In M. Bowerman & S. C. Levinson (Eds.), *Language acquisition and conceptual development* (Vol. 3, pp. 215-256). Cambridge: Cambridge Univ. Press.
- Gottfried, B. (2008). Representing short-term observations of moving objects by a simple visual language. *Journal of Visual Languages & Computing*, 19(3), 321-342.
- Klippel, A., & Li, R. (2009). The endpoint hypothesis: A topological-cognitive assessment of geographic scale movement patterns. In K. S. Hornsby, C. Claramunt, M. Denis & G. Ligozat (Eds.), *Spatial Information Theory* (pp. 177-194). Berlin: Springer.
- Klippel, A., Weaver, C., & Robinson, A. (accepted). Analyzing cognitive conceptualizations using interactive visual environments. *Cartography and Geographic Information Science*.
- Klix, F. (1971). *Information und Verhalten: kybernetische Aspekte der organismischen Informationsverarbeitung: Einführung in naturwissenschaftliche Grundlagen der allgemeinen Psychologie*. Bern, Hurber: Deutscher Verlag der Wissenschaften.
- Knaufl, M., Rauh, R., & Renz, J. (1997). A cognitive assessment of topological spatial relations: Results from an empirical investigation. In A. U. Frank (Ed.), *Spatial Information Theory: A Theoretical Basis for GIS*, (pp. 193-206). Heidelberg: Springer.
- Kurata, Y., & Egenhofer, M. (2009). Interpretation of behaviors from a viewpoint of topology. In B. Gottfried & H. Aghajan (Eds.), *Behaviour monitoring and interpretation. Ambient intelligence and smart environments* (pp. 75-97). Amsterdam: IOS Press.
- Lakoff, G., & Johnson, M. (1980). *Metaphors we live by*. Chicago: University of Chicago Press.
- Lu, S., Harter, D., & Graesser, A. C. (2009). An Empirical and Computational Investigation of Perceiving and Remembering Event Temporal Relations. *Cognitive Science*, 33(3), 345-373.
- Maguire, M. J., Brumberg, J., Ennis, M., & Shipley, T. F. (in press). Similarities in object and event segmentation: A geometric approach to event path segmentation. *Spatial Cognition and Computation*.
- Piaget, J., & Inhelder, B. (1948). *Child's Conception of Space*. New York: Norton.
- Piaget, J., & Inhelder, B. (1967). *The children's conception of space*. New York: Norton.
- Randell, D. A., Cui, Z., & Cohn, A. G. (1992). *A spatial logic based on regions and connection*. Paper presented at the The 3rd International Conference on Knowledge Representation and Reasoning, San Francisco.
- Regier, T. (1996). *The human semantic potential: Spatial language and constrained connectionism*. Cambridge (MA), London: The MIT Press.
- Regier, T., & Zheng, M. (2007). Attention to endpoints: A cross linguistic constraint on spatial meaning. *Cognitive Science*, 31(4), 705-719.
- Romesburg, C. (2004). *Cluster analysis for researchers*: Lulu press.
- Shaw, R., McIntyre, M., & Mace, W. (1974). The role of symmetry in event perception. In R. B. MacLeod & H. L. Pick (Eds.), *Perception* (pp. 276-310). Ithaca: Cornell University Press.
- Talmy, L. (1988). Force dynamics in language and cognition. *Cognitive Science*, 12(1), 49-100.
- Tversky, B., Morrison, J., & Betrancourt, M. (2002). Animation: can it facilitate? *International Journal of Human-Computer Studies*, 57(4), 247-262.
- Tversky, B., Zacks, J. M., & Hard, B. M. (2008). The structure of experience. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events* (pp. 436-464). New York: Oxford University Press.
- Wolff, P. (2008). Dynamics and the perception of causal events. In T. F. Shipley & J. M. Zacks (Eds.), *Understanding events: How humans see, represent, and act on events*. New York: Oxford University Press.
- Yuan, M., & Hornsby, K. S. (2008). *Computation and visualization for the understanding dynamics in geographic domains: A research agenda*. Boca Raton, Fla.: CRC Press.
- Zacks, J. M., Tversky, B., & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General*, 130(1), 29-58.