The Pennsylvania State University

The Graduate School

College of Earth and Mineral Sciences

DOES TOPOLOGY PREDICT GEOGRAPHIC (2D) EVENT SEGMENTATION?

A Thesis in

Geography

by

Elaine Guidero

Submitted in Partial Fulfillment
of the Requirements
for the Degree of

Master of Science

December 2012

The thesis of Elaine Guidero was reviewed and approved* by the following:

Alexander Klippel
Associate Professor of Geography.
Thesis Advisor

Donna Peuquet
Professor of Geography

Karl Zimmerer
Professor of Geography.
Head of the Department of Geography

*Signatures are on file in the Graduate School

ABSTRACT

Qualitative spatiotemporal calculi are theoretical, formal descriptions of space and time. These calculi can be applied in the fields of artificial intelligence and machine learning, in the sense that computers can be programmed to evaluate events in space and time using these formal constructs, and make subsequent decisions. There are currently several applications in the real world that make use of formal calculi as a way to describe human behavior and automatically evaluate and act upon that, but to date, these calculi have not been extensively validated experimentally. Thus we do not know if these calculi mesh well with the way that humans conceptualize space/time. Experimental validation of these calculi, especially those making explicit use of topological constructs, could be a boon to use for automated processing and monitoring of events and actions by autonomous agents. Event segmentation is a fundamental process by which humans conceptualize events. Temporal aspects of this process have been extensively examined, but not spatial ones. In this study, I evaluate the Region Connection Calculus (RCC-8), one such calculus, in the context of event segmentation and its spatial aspects. The RCC-8 encodes topological changes—the progression between topological coherence and incoherence between relations—for two objects. My twofold goal is to experimentally validate the RCC-8 as an adequate descriptor of event segmentation strategy, and to establish whether topological change is a predictor of event breakpoints (the points where people segment events) and thus, perceptually salient. To do so, I constructed the study to determine if participants segmented graphical events (animations) at the moments of topological incoherence, which are distinct types of topological relation within the RCC-8. In a three-part analysis, I find that participants significantly placed segment breakpoints at these moments of incoherence; the RCC-8 does function as an adequate calculus for describing event segmentation. I thus find that spatial information theory—the basis for qualitative spatiotemporal calculi—can be used to refine the

idea of what constitutes an event boundary. I conclude that topology is perceptually salient in events, change in topology is a significant predictor of event segmentation, and that topology should be taken into account in any discussion of events.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The author gratefully acknowledges the input and assistance of Dr. Alexander Klippel, Dr. Donna Peuquet, Dr. Thomas Shipley, Jinlong Yang, and Rui Li.

Chapter 1

Introduction

One aim of spatial cognitive science is to formalize the way we think about the world around us. A major contribution of the spatial sciences toward this goal is the creation of qualitative spatiotemporal calculi, hereafter, QSTC (e.g., Egenhofer and Franzosa 1991; Galton 2000; Hornsby and Li 2009; Kurata and Egenhofer 2007; Wood and Galton 2009). A qualitative spatiotemporal calculus is a set of discrete representations—distinctions—of spacetime that can be used for formal, high-level reasoning (Cohn 1996); that describe universal principles in a particular domain (Freksa and Röhrig 1993); that capture the richness of human spatial cognition to be used to reason about or solve problems in various domains (Freksa 1991). These calculi can be used to create algorithms that serve automated report systems for geographic phenomena, such as weather; interface design for geographic information systems; behavioral modeling; sports analysis of human and inanimate objects; and other 'intelligent' systems that make use of object and event recognition. While various kinds of calculi have already been applied in such systems (Han et al. 2007; Mo et al. 2006; Naftel and Khalid 2006; Wang, Velipasalar, and Casares 2010; Chu and Tsai 2010), these and other applications would benefit from the experimental testing of calculi to measure their usefulness in describing human conceptualizations of space and time.

The Region Connection Calculus (Randell, Cui, and Cohn 1992) defines topological relations between objects and/or regions as a function of the connectedness of those regions; for simplicity's sake, I will use just one term, *object,* to refer to any two-dimensional figure, whether it be defined as an object or as a region elsewhere. The variation of the RCC being tested for this article defines eight discrete mereotopological relations which can be derived from types of connectedness between objects (non-connection included), and will be referred to as RCC-8 throughout this paper. It bears noting here that Egenhofer and Franzosa (1991) created a similar spatiotemporal calculus, the 9-intersection model, based on intersections between object interiors, boundaries, and exteriors, which identifies the same topological relations defined in the RCC-8. I chose to test the RCC-8 to continue the work that has been done on that calculus (e.g., Klippel and Li 2009).

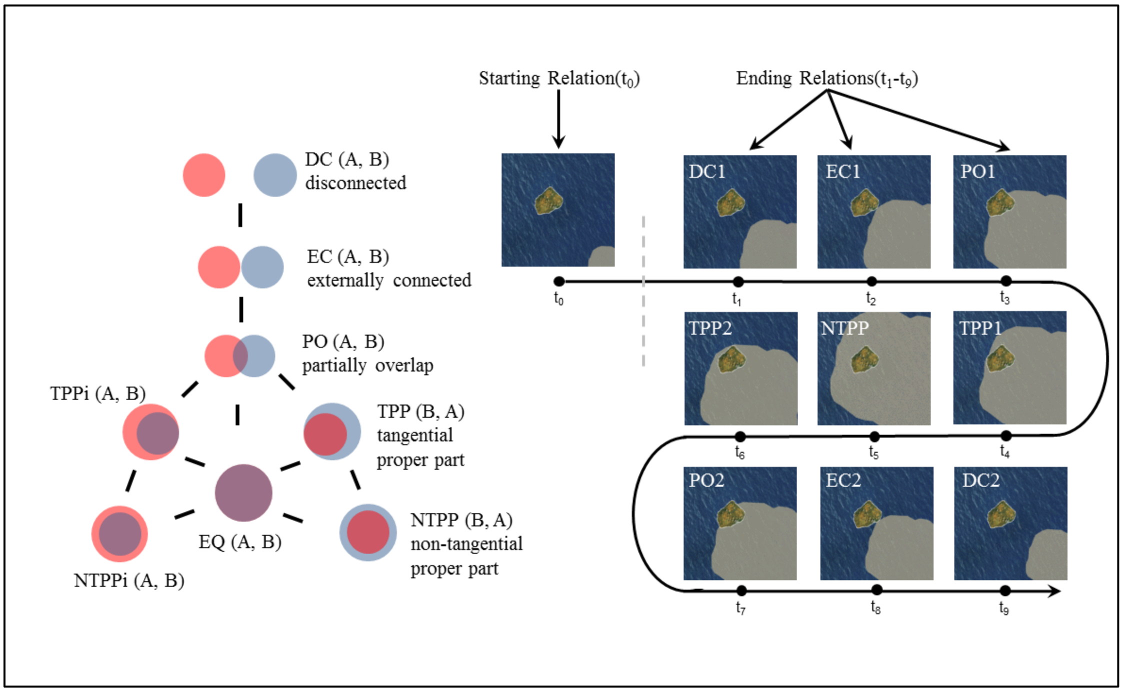

Figure **1-1**: Topological relations as described by the RCC-8 (Randell, Cui, and Cohn 1992); figure designed by Jinlong Yang.

In Figure 1-1, the eight topological relations of RCC-8 are identified on the left, and then shown in a continuum on the right; they are illustrated as an oil spill approaching and engulfing an island, then reversing its movement. DC, disconnection, is the relation between objects that have no connection; EC, external connection, is the relation between two objects where just the edges of the objects are connected. PO, partial overlap, is the relation where one part of one object overlaps a part of another object; TPP, tangential proper part, is the relation where one object is completely inside the other, but is also externally connected. NTPP, non-tangential proper part, is the topological relation where one object is completely inside the other (in the calculus, two variations, NTPP and NTPPi, define the difference between *A* inside *B* and *B* inside *A*) with no external connection, and finally EQ, equality, is the relation where two objects completely coincide. In this figure, numeric suffixes designate whether it is the first instance of that topological relation occurring between objects or the second; NTPP in this particular example has only one realization.

This study was informed by an event segmentation framework. Event segmentation is the cognitive process in which humans mentally (although not always consciously) divide into discrete units the continuous stream of data that makes up our daily lives (Kurby and Zacks 2008; Schwan and Garsoffky 2008; Shipley 2008). This process has been argued to be an essential part of how people filter out unimportant information to prevent neural processing overload (Zacks and Swallow, 2007). Event theory (and event segmentation theory, a derivative) is an attempt to apply theories about objects and object recognition to the conceptualization and recognition of events (Tversky, Zacks, and Hard 2008). Recent studies of event segmentation have identified different types of breakpoints, or segment boundaries, derived from object theory: 1) activity contours, that is, the distinction of the "main" activity against "background" activity, which is analogical to object contours (object boundaries relative to the background scene, i.e. the figure/ground distinction) (Tversky, Zacks, and Hard 2008); 2) predictability of action (Wilder 1978a, 1978b); 3) coherence, defined as the persistence of objects in an "action-object couplet" within a segment (once the object changes or disappears, the breakpoint happens) (Tversky, Zacks, and Hard 2008); and 4) geometry, the salience of the geometric shape of a path or trajectory taken by an object (Maguire et al. 2011). However, none of these approaches to event segmentation explicitly take into account the changing topological relations between two or more objects moving relative to each other, and topology has been shown by recent work (Klippel, Worboys, and Duckham 2008; Klippel and Li 2009; Li, Klippel, and Yang 2011) to significantly influence event conceptualization.

This study centers on the hypothesis that changes in topological relations between objects are a predictor of spatial event segmentation strategies. Of the four breakpoint types described above, I find one especially germane to the study of 2D event segmentation, in that it can be extended to event segmentation in the topological realm. Tversky and collaborators (2008) defined the concept of *coherence* as the essential quality that allows humans to create event segments. According to them, coherence of objects through multiple frames (also known as object persistence) provides the breakpoints by which humans segment events. When objects disappear, or have incoherence from one frame to the next, a breakpoint occurs. In topology, then, we can define coherence as the persistence of a topological relation between objects. A movement involving two objects, or movement segment, is coherent as long as the topological relation between the two does not change. Coherence is broken when the topological relation changes. Within the framework of event segmentation, then, the concept of coherence can be reimagined as the persistence of object-to-object topological relations within an event involving two (or more) objects. Once the topological relation *changes*, the event is segmented at that point. As long as the topological relation persists, there will be no segmentation. The RCC-8 implicitly encodes topological coherence and incoherence; the EC and TPP relations are moments of incoherence in a scenario with two moving objects, while the other relations represent constant states of topological connection in such a dynamic scenario.

Groundwork for a formal description of event cognition has been laid in previous papers on trajectory segmentation (Lautenschütz, 2010; Maguire et al., 2011), and on general models for knowledge representation (Hornsby and Egenhofer, 2000; Peuquet 2002). The formalization of cognitive models is a major step towards creating viable artificial intelligence and automated analysis of actions by an autonomous agent; here I specifically refer to AI expert systems as described by Peuquet (2002). A system for understanding events (as trajectories) and event segments (especially in terms of topological boundaries, i.e. actions occurring with respect to specific objects) is valuable to any effort at large-scale modeling or evaluation of events. A cognitive approach to validating QSTC might afford AI systems such as these more accurate interpretations of human movement. Furthermore, the top-down models used to implement these AI systems are complex; using true bottom-up cognitive models would be more efficient. Top-down refers to a model (or system) derived purely from theory; bottom-up models arise from or are defined by actual human behavior. Theoretically-driven models can be validated through experiments with human participants, however. For a review of previous experiments to this end, see Klippel et al. (in press). This study is a behavioral validation of just one QSTC, to determine how well the calculus actually captures the way humans conceptualize events in space.

Chapter 2

Background

A formal approach to event segmentation reveals the need to define "event" and "segmentation," which has been shown to be a surprisingly complex task. Bennett (2002) defines an event as a thing that happens, with a necessary position in space and time; although, of course, an event has to take place somewhere in space, not all events have an explicit or a relevant spatial component. Thus only some events are relevant to this study—those with an explicit spatial component. Within this domain, Shipley (2008: 4) defines the concept event by distinguishing it from the concept object: "Things that exist outside of a temporal reference –let's call them objects—are not events...an event requires reference to time." Casati and Varzi (2006) explore the major arguments raised for defining events: events vs. objects, events vs. facts, events vs. properties, and events vs. times, and still cannot distill a clear definition.

Although there is some ambiguity over the definition of an event, from a descriptive perspective, there is general agreement that "humans treat events as temporally well-bounded" (Shipley 2008: 12); in practice, Zacks and Tversky (2001) prefer to treat events as dynamic objects due to the massive catalogue of similarities between events and objects (Casati and Varzi, 1999). While it is possible to delve much deeper into the formal definitions of events, I shall leave that to the philosophers and metaphysical thinkers, as I am not concerned here with questions of how to or what does constitute an event. I therefore take the assumption, based on previous studies of event perception (Maguire et al. 2011; Zacks 2004; Zacks and Swallow 2007; Zacks and Tversky 2001), that a discrete *thing that happens* that can be named is an event (e.g., "brewing coffee" is a temporally and spatially bounded event). For the purposes of this experiment, I define the event, the *thing that happens,* as the entire spatiotemporal process of an object-object interaction, that is, what is captured in a single animation. The event begins when the animation starts, and ends when the animation finishes. Now that I have established that events do exist and are spatiotemporally bounded, I can turn to the question of segmenting them.

Segmentation can be defined in two ways (Bennett, 2002). First, the whole event—the spatiotemporal process of a *thing that happens*, such as brewing coffee—is creating by segmenting that process out of the continuous stream of motion and time that constitutes the context of that event. To continue with the coffee example, we use segmentation to distinguish the event of *brewing coffee* out of the entire morning routine—itself an event—of getting ready for work. Second, segmentation occurs within the event, defining discrete sub-events. To brew coffee, discrete sub-events occur, such as filling the coffeemaker with water, adding a filter, and so on. For this study, I am interested only in the second definition, the segmentation of sub-events within a defined and bounded event. Zacks and Tversky (2001) and Schwan and Garsoffky (2008) confirm the second definition experimentally, in that most experiment participants tended to agree on which specific happenings constitute individual segments, and where breakpoints (event or sub-event boundaries) are. There is also neurological evidence for temporal event segmentation. Using fMRI (functional magnetic resonance imaging), which is a common medical imaging technique that uses a special device to surround the brain with a magnetic field and measure resulting brain activity (Logothetis 2008), Zacks et al. (2001) analyzed the brain function of participants who viewed depictions of common events, including making a bed and washing dishes. Brain activity was measured both during initial viewing of the scenes (without a task to perform) and during a task where participants had to tap a button to indicate meaningful event segment boundaries. The study linked brain activity to event boundaries, as brain activity patterns were similar both when participants were passive viewers of scenes and when they performed an active task. Humans practice segmentation every day, and it is thought of as a strategy that humans employ to reduce cognitive load (Kurby and Zacks, 2008). If one is familiar with an event and knows its sub-events, it is not necessary to observe or remember every sub-event to understand or predict the outcome of the main event.

Event segmentation theory can and should be tightly linked to formal models of geography and space. However, the explicitly spatial part has figured very little into much of the recent work on event segmentation, being only briefly acknowledged (Casati and Varzi 2006; Zacks and Tversky 2001). Space is either considered a mere property or attribute that aids in distinguishing discrete events from each other, or not considered at all. In this paper, I argue that the spatial aspect of an event is an inherently important and perceptually salient aspect of events, which significantly affect event segmentation. Outside the event segmentation literature, temporal calculi have been discussed in the literature for over twenty years (e.g., Allen 1983; Freksa 1992; Rodríguez, Weghe, and Maeyer 2004). In this tradition, many formal models do include an explicitly spatial or spatiotemporal element (Claramunt and Jiang 2001; Sridhar, Cohn, and Hogg 2011; Muller 1998), or incorporate object/event dynamics (Hornsby and Egenhofer 2002; Hornsby and Cole 2007; Laube and Imfeld 2002; Worboys and Hornsby 2004). So far, however, segmentation has not been connected to these models—and they have not been tested for their cognitive adequacy.

Most experiments on event segmentation focus on the temporally defined, specific behaviors such as doing dishes or cooking (see Zacks and Tversky 2001 for an overview; see also Zacks and Swallow 2007), although Zacks and Tversky (2001: 11) left open the range of interpretation of "event" by saying that "event structure perception is driven by changes in motion, path, or ground relative to the currently attended figure," terms which are generally used for geometric or graphic representations rather than real-world events. Casati and Varzi (2006; 2008) and Bennett (2002) both give the example of a sunrise in London being an event distinct from a sunrise in Paris. It is the same sun, but a different event, because the act of the sun rising occurs in a different location at a different time. That is not a very satisfactory treatment of space, especially because space does not come into play to differentiate the two sunrises from the perspective of the viewer of this event—the sun rises in Paris in a different part of the sky than in London, for one. (There are further problems with this example; namely, if a viewer in Paris understands that it is the same sun that rose in London, would he or she still spatially differentiate the actual "sunrise" event into two events? Or would s/he differentiate the event based on time only? Or not at all?) Zacks and Tversky (2001: 8) also wrote that "for events, however, part boundaries occur primarily with respect to time." This conclusion, that segmentation is based on temporal aspects, ignores the possibility that part boundary assignments made on spatial markers are occurring as well (or are just as strong as temporal markers)—part boundaries that are an integral part of the RCC. Casati and Varzi rather unhelpfully said "The relation events have to space are more problematic [than to time]" (2008: 45). In their previous book (1999) treating the subject more in-depth, they state that although events cannot take up space, events can have both spatial and temporal boundaries (again, using the object as a starting point for making analogous claims). They continue by saying that due to the presence of common words for (usually) temporally-based events that are conflated with objects (e.g., *fire, hurricane, soccer match, season*), it is feasible that spatial object concepts can be applied to events. In fact, judging from the existence of such object-event all-in-one terms, it is done so automatically, in everyday thought and language. While Casati and Varzi operate strictly in the theoretical and linguistic realm, this study centers around their claim that static (object-based) spatial concepts can be applied to spatial dynamics (events)—that segmentation of a spatiotemporal event can be a result of spatial aspects, too, not just the temporal.

Some work has indeed been done on the spatial aspects of event segmentation. Swallow et al. (2009) performed a set of experiments on event boundaries that mixed spatiotemporal aspects. Shipley and Maguire (2008) discussed geometric event segmentation (also called path or trajectory segmentation), which is dependent upon the perception of salient geometric properties, such as convexities, concavities, twists, turns, corners, and the like. Schwan and Garsoffky (2008) in a related vein mention that perceptual saliency is a key factor in determining cues for segmenting events, although the cues are not necessarily breakpoints themselves. They also do not go into detail about what perceptual saliency is beyond citing an example using value (i.e. black and white) from Newtson et al. (1977). Zacks' (2004) study examined path segmentation, but in light of whether intentions, i.e., with a context of an agent, affected segmentation strategies. Lautenschütz (2010) previously looked at geometric segmentation of static trajectories (see Shipley and Maguire, 2008); following that study, Maguire et al. (2011) studied path segmentation from a geometric perspective, drawing on the object theory of Casati and Varzi (1999), and object perception theory (e.g., Hoffman and Singh, 1997), to examine differences between object and event segmentation. This study involved three separate experiments, mainly focused on segmentation of static trajectories, and how geometric construction of the trajectories influenced the segmentation. They found that geometric extrema (convexities and concavities) are significant predictors for assignment of event boundaries. However, the authors did not test dynamic stimuli, and concluded that "distinguishing between minima and maxima may be conceptually and ecologically less useful and cognitively more difficult to maintain given the added temporal aspects of events" (2011: 274). My study was an attempt to show that topological change could fill that gap—a conceptually and cognitively simple way that people segment events. To rephrase it, I attempted to show that topological change could function as a breakpoint predictor and is thus perceptually salient. My study contributes a useful addition to the event segmentation literature in two ways: by explicitly addressing the spatial aspect of events, and by establishing another type of perceptual salience.

Chapter 3

Research Goals

The principal goals of this study were to experimentally evaluate the RCC-8 as an adequate descriptor of spatial event segmentation, and to determine if topology is a perceptually salient factor in event segmentation. Two questions sprang from this goal:

1) Does topological incoherence (the moment of topological change) act as a predictor of segment boundary assignment? In other words, is a change in topological relation a factor in event segmentation?

2) Does the assignation of event boundaries vary with type of object movement (translation vs. scaling)?

Question 1 represents the heart of my attempt to apply the RCC-8 to questions of spatial event segmentation. The RCC-8 implicitly describes states of topological (in)coherence; the spatial relations which represent incoherence are EC (externally connected) and TPP (tangential proper part). Question 1 inquires whether participants segment events in accordance with the relations in the RCC-8. Much like Tversky's temporally-based object (in)coherence, where incoherence of object from frame to frame generates a segment breakpoint, I hypothesized that a spatially-based topological (in)coherence is an additional basis for event segmentation, in that the frames including a topological incoherence will be marked as breakpoints. Thus I anticipated that a significant majority of boundaries will be placed at frames which contain these spatial relations.

Question 2 builds on other related work on conceptualization and categorization of dynamic scenarios showing these two kinds of movements. Klippel and Li (2009) investigated how humans categorize these kinds of events (translation movements only), based on topological ending relation, and Yang and Klippel (2010) evaluated the RCC-8 as to its adequacy with respect to categorization of scaling movements. In this study, I compared both types of movement to determine whether movement type was a significant influence on segment boundary assignment, and thus, whether movement type should be explicitly accounted for in QSTC. However, I hypothesized that movement type will have no significant effect on boundary assignment, in that participants will assign boundaries at the relations involving topological incoherence for all events regardless of movement type.

Chapter 4

Method

Overview

To answer these research questions, I performed an experiment using a within-subject design loosely based on that used by Maguire et al. (2011). Participants watched 16 short animations, and then viewed their individual frames, selecting frames that corresponded to self-identified event boundaries.

Participants

I recruited 20 undergraduate students (mean age=21.45; 6 females) enrolled in at least one geography class at Penn State. Each participant was paid $10.

Materials

The scenarios used in this experiment were based on those created for previous experiments (Klippel in press), and were generated in Adobe® Flash® CS5. Each scenario had both a looping animation, and its component frames; the animation was split into frames automatically in Flash®. Six types of animations were selected, and for each type two variations were shown to participants, one which demonstrated the topological relations described in RCC-8 starting at DC1 and ending at NTPP; another which comprised all topological relations from DC1 through DC2 (see Figure 1). The six types of animations were:

- abstract translation, a circle moving across a static triangle
- contextualized translation$_a$, a hurricane tracking across a peninsula
- contextualized translation$_b$, a boat moving across a shoal
- abstract scaling, a gray region enclosing a filled circle
- contextualized scaling$_a$, an oil spill encroaching on an island
- contextualized scaling$_b$, a lake encroaching on a house

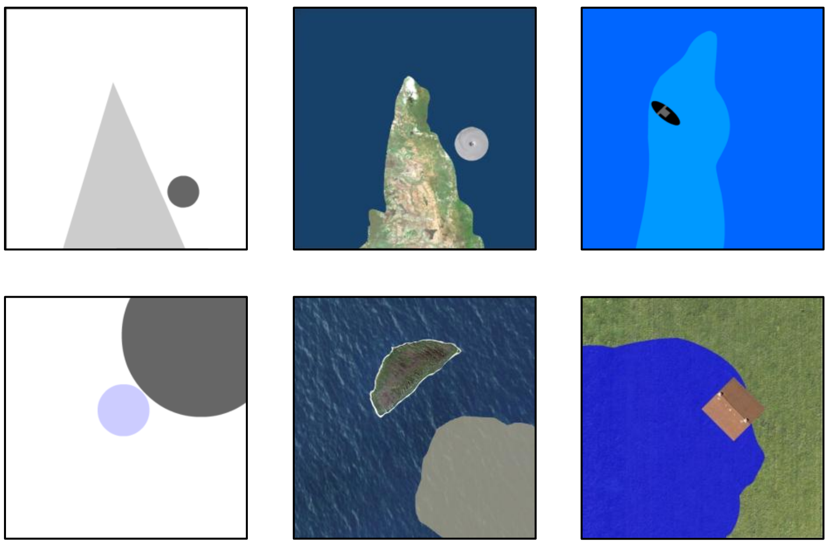

Figure **4-1**: Still frames from the animations used in the experiment. From L to R, top to bottom: abstract translation, contextualized translation$_a$, contextualized translation$_b$, abstract scaling, contextualized scaling$_a$, contextualized scaling$_b$.

The remaining four animations were control animations absent any interactions, where one object performed translation or scaling without a second object or region.

Within these animations, I delineated a conceptual "topological transition zone," a construct created for the use of analysis (Figure 4-2). The zones are the four to six frames covering the change from one continuous period of topological relation, to the moment of topological incoherence indicating change, to the next continuous period of topological relation. Due to ambiguities in the process of splitting each animation into frames, the topological relations representing incoherence (EC and TPP) that would theoretically be instantaneous, taking up only one frame each, were sometimes equally apparent in more than one frame. The purpose of the zones was to capture the slight variation in participant response that may occur due to this ambiguity. These zones were not indicated to participants nor were they in anyway shown in the stimuli; they were a conceptual way of grouping frames for the analysis.

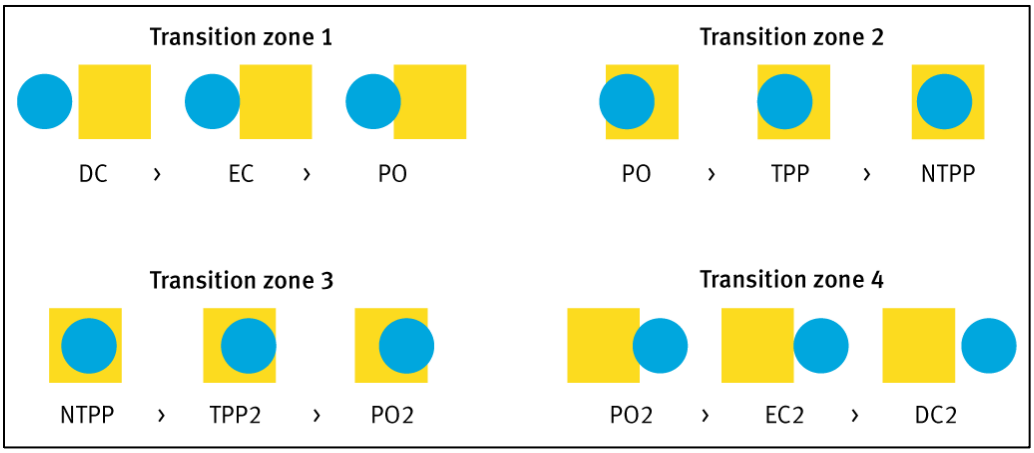

Figure **4-2**: Topological stages within the four transition zones.

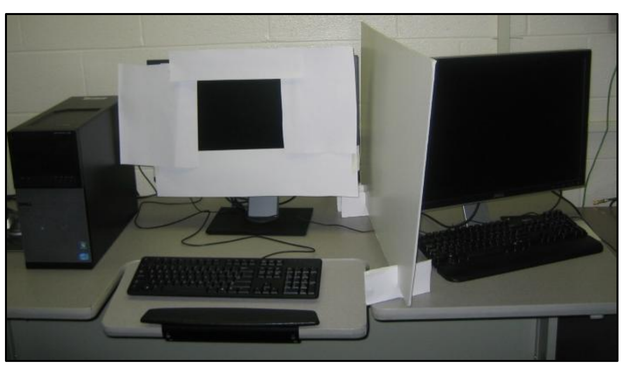

Figure **4-3**: Physical experiment setup.

The experiment was run on a Dell Optiplex 790 desktop computer (Intel Core i7 processor, at 3.4 GHz x 2, 8 GB RAM) with a dual-monitor display. Participants sat at the left-side monitor (24” LCD, 1920x1080), and viewblocks were put in place to ensure that the participant only saw a small portion of the screen (Figure 4-3). Animations were arranged so that they appeared in that portion of the screen; additional data about the animations and frames were only visible to the experimenter sitting at the right-side monitor.

Design

This was an untimed within-subject experiment design, with each participant viewing each of the 16 animations. The order of animations was randomly varied for each participant, using 20 separate random sequences generated by random.org, with the current date and time as a seed (Haar 2012).

Procedure

Participants were asked to assign event boundaries to short animations. They were told they would watch a series of short animations, and to find the logical breaks or points of state change within each animation, if any occurred. They were told they would view the animation three times, then be shown the individual frames that made up the animation. They were told that they would then select the individual frame(s) that, to them, represented the clearest and most logical points of change within the animation sequence. They were told they could select no frames if they did not believe that there was a logical point of change in the animation.

First, they completed a brief training module to show them how to perform these tasks. They watched a ten-second movie clip of a man walking through a subway station and sitting down on a bench, and were asked to identify logical breaks or changes in the film. Next, they watched a short Flash animation of an object translating through space, which looped three times. They were then shown a collection of all the individual frames comprising the animation. The experimenter was able to see the exact frame numbers, and noted down each frame number the participant identified.

Once each participant completed the training module, they repeated the procedure described for the Flash animation, above, for each of 16 different animations. Participants were shown three loops of the animation. In a separate software program, participants were told to use the keyboards' arrow keys to go through the individual frames step by step, and point out the frames of the boundaries they had previously identified from watching the animation. Afterward, participants were asked basic demographic questions about age, gender, and major.

Chapter 5

Results

Main analysis

I proceeded with three stages of analysis. First, I determined if boundary assignments were clustered in specific parts of the scenario or not. Then, I analyzed the effects of two factors on boundary assignment; animation type, and presence of transition zone; that is, I tested whether boundaries were assigned differently between translation and scaling animations, and I tested whether participants assigned boundaries significantly more (or less) inside transition zones versus outside transition zones. Finally, I tested whether the various topological relations within the transition zones had a significant effect on boundary placement.

In stage one, I employed a statistical method comparable to quadrat counts to determine whether or not the placement of event segments (boundaries) was overall random or not random across the frames of each scenario. First, for each scenario, I binned the individual frames into groups of three frames each. Binning was done to account for slight variations between frames, and across scenarios. Because the process of creating animations introduced a small measure of ambiguity—the scenarios had differing numbers of frames, and in some scenarios the topological relations of incoherence, EC and TPP, could be effectively seen in more than one frame—binning helped to reduce that ambiguity somewhat, as a direct frame-to-frame comparison would be inaccurate. I then tabulated the number of boundaries assigned to each frame, and thus the number of boundaries in each bin of three frames. I then determined whether the distribution of boundaries across bins matched the Poisson distribution, using boundary density (number of boundaries assigned per number of bins) as the test metric for a sum-of-squares calculation. The calculation results were compared to a standard chi-square distribution table to determine significance. A significant result would indicate that boundaries are placed non-randomly; an insignificant result would indicate that boundaries are placed randomly. I found that boundary densities for each scenario were significantly different from the Poisson distribution (Table 5-1)—that is, participants' boundary assignments were not placed at random.

Table **5-1**: Quadrat counts test results for a chi-square distribution.

Scenario	No. Bins (all participants)	Sum of squares	Degrees of freedom	Critical value (for p<.001)	p value
Abstract NTPP translation	640	130.88	31	61.098	<.001
Abstract DC2 translation	1240	330.34	61	100.888	<.001
Hurricane NTPP translation	1420	553.06	70	112.317	<.001
Hurricane DC2 translation	680	339.49	33	63.870	<.001
Ship NTPP translation	620	176.22	30	593703	<.001
Ship DC2 translation	680	207.49	33	63.870	<.001
Abstract NTPP scaling	680	266.64	33	63.870	<.001
Abstract DC2 scaling	680	346.28	33	63.870	<.001
Lake NTPP scaling	1240	234.62	61	100.888	<.001
Lake DC2 scaling	1360	271.82	67	108.526	<.001
Oil NTPP scaling	1420	544.46	70	112.317	<.001
Oil DC2 scaling	1420	524.46	70	112.317	<.001

After determining in stage one that boundary placement was not random, in stage two, I analyzed whether the two independent variables of the experiment affected boundary placement: animation type (translation or scaling), and presence of a topological transition zone (yes or no). I performed a 2x2 factorial repeated-measures ANOVA on each of two datasets: the animations ending in a DC2 relation, and the animations ending in an NTPP relation. I analyzed NTPP-ending animations separately from DC2-ending animations, because the DC2 animations had double the number of transition zones, which would skew the averages in an ANOVA. I found that in DC2 animations (Table 5-2), the transition zone had a significant effect on boundary placement, $F(1,19)=7.461$, $p<.05$, while the animation type did not, $F(1,19)=2.021$, $p>.05$. Partial eta squared results show that transition accounted for 28.2% of the variance. Similarly, I found that in NTPP animations (Table 5-3), transition zone had a significant effect on boundary placement, $F(1,19=7.080$, $p<.05$, while the animation type did not, $F(1,19)=.121$, $p>.05$. Partial eta squared results show that transition accounted for 27.1% of the variance.

Table **5-2**: Descriptive statistics of boundaries inside and outside transition zones (DC2 ending animations only). Boundaries are divided by animation type. “Outzone” represents number of boundaries placed outside the transition zone; “inzone” represents number of boundaries placed inside the transition zone, where the frames are that contain the specific topological relation that signals change. The mean numbers of boundaries inside zones are much higher than the mean numbers of boundaries outsize zones.

	Mean	Std. Deviation	N
Outzone-scaling	3.80	2.505	20
Outzone-translation	2.95	3.628	20
Inzone-scaling	6.10	6.043	20
Inzone-translation	5.70	4.485	20

Table **5-3**: Descriptive statistics of boundaries inside and outside transition zones (NTPP ending animations only). Boundaries are divided by animation type. “Outzone” represents number of boundaries placed outside the transition zone; “inzone” represents number of boundaries placed inside the transition zone, where the frames are that contain the specific topological relation that signals change. The mean numbers of boundaries inside zones are much higher than the mean numbers of boundaries outsize zones.

	Mean	Std. Deviation	N
Outzone-scaling	1.65	1.348	20
Outzone-translation	2.45	2.114	20
Inzone-scaling	3.85	2.739	20
Inzone-translation	2.85	2.346	20

In the last stage of analysis, I wanted to delve inside the transition zone. As previously noted, each zone encompassed three distinct topological relations as defined in the RCC-8 (Figure 1-1). For each frame in the transition zone, I assigned the appropriate topological relation which described the two objects in the frame. Examining all data combined together (DC2 and NTPP endings, both translation and scaling animation types), I used a one-way repeated-measures

ANOVA to determine whether participants assigned boundaries significantly differently between frames of differing topological relations (Table 5-4). I found that the specific topological relation had a significant effect on boundary placement, $F(1,19)=14.531$, $p<.001$ (partial eta squared showing that topological relation accounted for 43.3% of the variance), and that participants assigned significantly more boundaries at the EC (externally connected) and the TPP (transitional proper part) relations than to any other relation within the transition zone.

Figures 5-1 and 5-2 each show a chart of the number of boundaries assigned per topological relation, within the transition zone, and a value-by-alpha visualization of those numbers. One circle per each relation is placed appropriately in relation to the gray box (the "region" or "background object" with which the moving object interacted). I tabulated the number of boundaries assigned at each relation as a percentage of all the boundaries assigned, and each circle has its transparency set to this percentage.

Table **5-4**: Descriptive statistics of the number of boundaries within transition zones. "DC boundaries" are boundaries assigned at frames in which objects were at a DC (disconnected) relation, "EC boundaries" are boundaries assigned at an EC relation, and so forth. Most boundaries were assigned at the EC and TPP relations.

	Mean	Std. Deviation	N
DC boundaries	1.45	1.669	20
EC boundaries	7.90	5.990	20
PO boundaries	1.65	2.084	20
TPP boundaries	6.20	6.558	20
NTPP boundaries	1.30	1.750	20

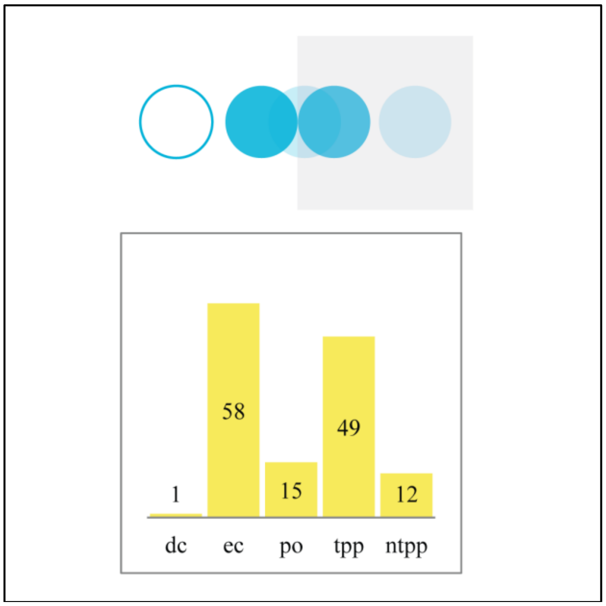

Figure **5-1**: Value-by-alpha of boundaries assigned per topological relation within transition zones, NTPP scenarios. The gray box represents the second object or region.

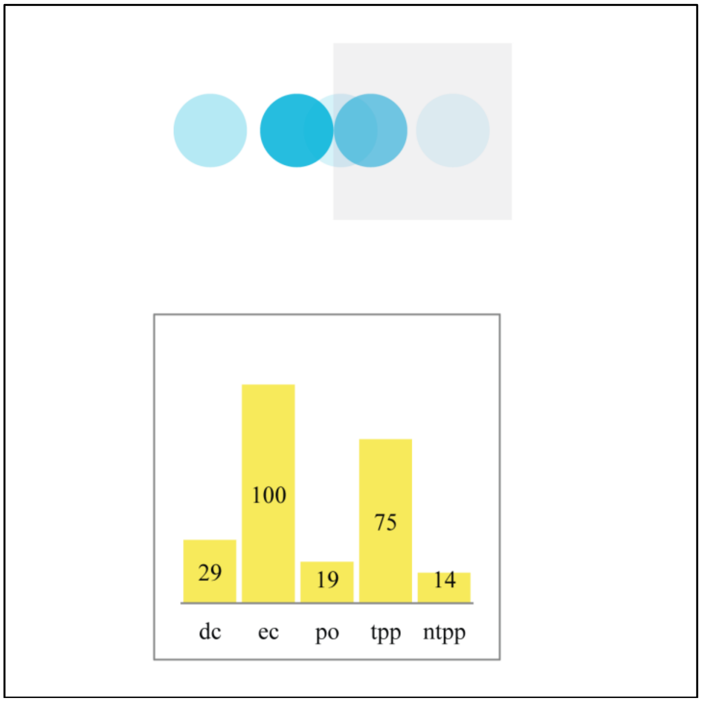

Figure **5-2**: Value-by-alpha of boundaries assigned per topological relation within transition zones, DC2 scenarios. The gray box represents the second object or region.

Other findings

In analyzing the data, I found a curious phenomenon: some participants assigned boundaries to the start, end, and "apex" of animations. By apex, I mean the point in a DC2 scaling animation where the object was at maximum growth, and began shrinking again. I saw enough congruence between participants that I decided to investigate this as well, and so I ran an additional one-way repeated-measures ANOVA, this time on all boundaries assigned (not just inside transition zones), recoding some of the frames as start, end, and apex (Table 5-5). I ran this test only on the DC2-ending scaling animations (see Figure 4-1). I found that even with these added relations, overall the topological relation still produced a significant effect in boundary assignment, $F(1,19)=10.110$, $p<.001$. And in this test, with the extra frames included, partial eta squared was .811, or, topological relation account for 81.1% of the variance. Post hoc tests show that participants placed boundaries significantly more often at EC and TPP, and PO (partial overlap) than at all other relations, however, participants did assign boundaries significantly more often at the apex of animations than at the start.

Table **5-5**: Descriptive statistics for recoded boundaries, including boundaries assigned at the start, end, and apex of DC2 scaling animations.

	Mean	Std. Deviation	N
DC boundaries	2.30	2.273	20
EC boundaries	7.90	5.990	20
PO boundaries	6.00	5.311	20
TPP boundaries	6.20	6.558	20
NTPP boundaries	2.80	3.270	20
Start boundaries	.40	.995	20
End boundaries	2.00	2.938	20
Apex boundaries	1.75	1.446	20

Chapter 6

Discussion

Overall, I found that topology had a significant influence on event boundary assignment. Study participants placed boundaries significantly more often at frames representing topological incoherence, which are the topological relations EC (externally connected) and TPP (transitional proper part). Because the topological aspect was significant, for the rest of this paper, I refer to the strategy of segmenting events as assigning topological event boundaries (TEBs), a wording I take from Jiang and Worboys (2009) who coined the term *topological events*.

With stages one and two of my analysis, I determined that TEBs were significantly clustered within what I called transition zones, the four to six frames surrounding the moment of topological change (the relations EC and TPP). Participants assigned far more boundaries inside than outside the zone. The zone captured much of the individual variation of assignment of TEBs. Again, while the transition zone was primarily a tool for directing my analysis of boundary assignment, it is a concept, validated by my results, that could be added back to a qualitative spatiotemporal calculus.

In stage three, I found that, within the zones, TEBs were assigned significantly more often at frames specifically representing topological incoherence, the relations EC and TPP. Consider again the sequence of topological relations in the animations (Figure 4-2). The objects remain in DC for quite some time; there is an abrupt change at the EC transition; the objects remain in PO for quite some time; there is another abrupt transition at TPP; and then the objects remain in NTPP for quite some time. Boundaries were assigned more often to frames indicating the abrupt change. I consider that some participants did not place TEBs at all, or did not place them where expected; perhaps that is due to the fact that they did not perceive any incoherence, and thus they did not perceive the topological change as salient.

I did not find that there was any significant difference between the scaling or translation animation; I believe this makes my results more robust, as the TEB assignments held similar regardless of animation type.

I found that I can use spatial information theory—the basis for qualitative spatiotemporal calculi—to refine the idea of what constitutes an event boundary, and predict placement of event boundaries. Segmentation happens at spatial markers, not just temporal markers. Therefore, qualitative spatiotemporal calculi which explicitly capture topologically salient markers, such as topological incoherence, can be valid and useful tools to predict or describe event segmentation. The RCC-8, just one of many calculi, neatly encapsulates the stages of an event (vis-à-vis two objects), and I have concretely shown that segmentation occurs predominantly at two different relations in the RCC-8.

This work also has certain implications for artificial intelligence and machine vision research. AI requires formalized descriptions of human behavior, because computer programs are simply sets of specific instructions. I found that segmentation occurs primarily at certain topological relations; thus this segmentation behavior can be formalized in a number of ways—whether as an RCC-type calculus, or a calculus of topological equivalence classes. A computer could be programmed to recognize topologically salient junctures, which would be defined by object relations which were topologically incoherent (relative to other relations).

The analytical construct of the transition zone could be extended somewhat to a new understanding of event segmentation, using the concept of *process modeling*. Process modeling is a way of modeling events. In contrast to data models, process models describe sequences instead of structures; in the context of an event with defined segments, a process model would allow the capture of the conditions and outcomes of the change between segments, whereas a data model might have simply a series of static observations at various times—“snapshots” of individual segments (Brown et al. 2005; Smith, Pellegrino, and Golledge 1982; Peuquet and Duan 1995). For example, Hornsby and Egenhofer (2000) created one such process model of object identity change, and their model included a transition state; the “event” their model describes is the change of identity of an object. The identity transition is an elegant way to model the break between event *segments* in the topological realm. The state of topological incoherence, instead of being a single, instantaneous change, becomes a process of change—the *transition* between states of topological coherence—analogous to Hornsby and Egenhofer’s transition between states of identity. Segmenting an event can be thought of as a process of transition from segment to segment. While currently the RCC-8 does not really allow for an explicit concept of a process or transition, as the states of topological change are captured only as instantaneous moments where the topological relation is either EC or TPP, the idea of segmentation as a transitional process rather than a moment could be useful for events where the transitions between segments are not crisp and clear—a common occurrence in everyday life.

My research results may be limited in scope due to the issue of geometric salience—the same concept that provided a basis for Maguire and collaborators’ path segmentation (2011). The objects I used in my animations were for the most part either convex or neutral (a straight line at the area of object interaction); only animation contextualized scaling_b (the lake animation) contained a variation in shape at the moment of object interaction. However, as Hoffman and Singh (1997) might argue, the high salience of the object itself at the moment of interaction with the other object, being at maximum convexity (as was true for all other animations), may have influenced the results in my favor. In the path segmentation experiment by Maguire et al. (2011), “event path boundaries were frequently seen at local maxima” (273). Thus I may have biased participants to choose boundaries at the edge-touching topological relations simply because at those moments, at least one of the objects was at maximum curvature. Indeed, my results for the number of boundaries assigned at the “apex” in the DC2-ending scaling animations seem to support this. I decided to use these mostly convex objects to avoid introducing a convex/concave factor into the experiment; a second follow-up experiment would include both convex and concave objects, and would incorporate an analysis between the two types of geometry. However, I confident in my results, which significantly show that event segmentation is predicted, at least in part, by a break in topological coherence.

Future work would include experiments with more than two objects. While that increases the complexity of the experiment, it would be a valuable finding if my results held true for multiple object interactions. As noted, other experiments could be performed to firmly establish whether my findings hold true for several types and shapes of 2D objects, with multiple kinds of convexity and concavity. On a similar note, segmentation strategies could also be tested with interactions involving 1D or 3D objects. And, to test whether my idea of event segments as zones surrounding moments of principal topological incoherence, more tests should be run with distractions involved, such as a blinking object off in the corner away from the “main” event. In this way one could determine whether the change in topological relations is salient when the viewer is presented with multiple stimuli.

Chapter 7

Conclusion

As part of a larger attempt to formalize the way that humans perceive the spatial division and organization of events, the goal of this paper was to experimentally evaluate the utility of the RCC as it can describe or predict human understanding of events in space. In this study, I attempted to determine if people employ a predominant strategy for segmenting events in accordance with topological distinctions, and whether these strategies conform to the RCC-8's description of topology between two objects. In doing so, I attempted to experimentally validate the RCC-8 as a description of conceptualization of events in addition to its current function of describing static objects.

Two main conclusions can be drawn from this study. First, I have empirically shown that topology has a significant effect on event segmentation, specifically, that topological incoherence does predict segmentation—that segmentation occurs at the moment where relations stop being coherent with each other. Thus, I believe that event segmentation theory should be expanded to take into account the effect of topology on segmentation strategies. Second, I have shown that at least one spatiotemporal calculus can be used to describe segmentation strategy, and thus specific information on highly salient moments (edge-touching) should be fed back into the calculus. This additional information could make calculi more robust and yield a wider applicability.

Future work could include the application of these results back to spatial information theory—a spatiotemporal calculus such as the RCC-8 could be refined to include distinctions of high versus low salience, as shown by segmentation behavior. It could be further refined to include transition zones. I note here that a different version of the RCC, RCC-5, was developed by Cohn and Gotts (1994). In the RCC-5, however, TPP and NTPP (and, thus, TPPi and NTPPi) are subsumed under PP (proper part) and PPi, and EC and DC are subsumed under DR (distinct regions). The 5-relation model does not allow for the finer topological distinction of the 8-relation model, and so would be an improper calculus to use for describing event segmentation.

The concept of “event” is crucial to the understanding of geographic phenomena. Various other fields have incorporated events into their formal modeling of the world. This study builds on previous event research, and helps contribute to the literature on human conception of events and event segmentation, by incorporating spatial, topological relations. Topology should be considered an essential part of any system for geographic knowledge representations, and qualitative spatiotemporal calculi are ideal for encapsulating and formally describing this kind of knowledge—if not explicitly, topological event boundaries are at least implicitly coded therein. By widening theories of events into the explicitly spatial realm, I can arrive at a more complete description of what an event is, and how to formalize it, categorize it, and analyze it from various perspectives in artificial intelligence, automatic surveillance, and political science.

REFERENCES

Allen, J. 1983. Maintaining knowledge about temporal intervals. *Communications of the ACM* 26 (11):823–843.

Bennett, J. 2002. What events are. In *The Blackwell Guide to Metaphysics*, ed. R. M. Gale, 43–65. Oxford, UK: Blackwell Publishing.

Brown, D. G., R. Riolo, D. T. Robinson, M. North, et al. 2005. Spatial process and data models: Toward integration of agent-based models and GIS. *Journal of Geographical Systems* 7 (1):25–47. http://www.springerlink.com/index/10.1007/s10109-005-0148-5 (last accessed 10 March 2012).

Casati, R., and A. C. Varzi. 2006. Events (Stanford Encyclopedia of Philosophy). 2011 (05/02):1. http://plato.stanford.edu/entries/events/.

———. 1999. *Parts and Places*. Cambridge, MA: MIT Press.

Chu, W.-T., and W.-H. Tsai. 2010. Modeling spatiotemporal relationships between moving objects for event tactics analysis in tennis videos. *Journal of Multimedia Tools and Applications* 50 (1):149–171.

Claramunt, C., and B. Jiang. 2001. An integrated representation of spatial and temporal relationships between evolving regions. *Journal of Geographical Systems* 3 (4):411–428. http://www.springerlink.com/openurl.asp?genre=article&id=doi:10.1007/s101090100066.

Cohn, A. G. 1996. Calculi for qualitative spatial reasoning. In *Artificial Intelligence and Symbolic Mathematical Computation*, eds. J. Calmet, J. A. Campbell, and J. Pfalzgraf, 124–143. Springer.

Cohn, A. G., and N. M. Gotts. 1994. Spatial regions with undetermined boundaries. In *Proceedings of the Gaitheburg Workshop on GIS, ACM*.

Egenhofer, M. J., and R. D. Franzosa. 1991. Point-set topological spatial relations. *International journal of geographical information systems* 5 (2):161–174. http://www.tandfonline.com/doi/abs/10.1080/02693799108927841.

Freksa, C. 1991. Qualitative spatial reasoning. *Cognitive and linguistic aspects of geographic space* 63:361–372.

———. 1992. Temporal reasoning based on semi-intervals. *Artificial Intelligence* 54 (1):199–227.

Freksa, C., and R. Röhrig. 1993. Dimensions of qualitative spatial reasoning. In *Qualitative Reasoning in Decision Technologies, Proceedings QUARDET*, eds. N. P. Carreté and M. G. Singh, 483–492. CIMNE, Barcelona, Spain.

Galton, A. 2000. Space. In *Qualitative spatial change*, 34–102. New York: Oxford University Press.

Haar, M. 2012. Random.org. http://www.random.org (last accessed 16 May 2012).

Han, M., W. Xu, H. Tao, and Y. Gong. 2007. Multi-object trajectory tracking. *Machine Vision and Applications* 18:221–232.

Hoffman, D. D., and M. Singh. 1997. Salience of visual parts. *Cognition* 63 (1):29–78. http://www.ncbi.nlm.nih.gov/pubmed/9187064.

Hornsby, K., and M. J Egenhofer. 2002. Modeling moving objects over multiple granularities. *Annals of Mathematics and Artificial Intelligence* 36:177–194.

Hornsby, K. S., and M. J. Egenhofer. 2000. Identity-based change: a foundation for spatio-temporal knowledge representation. *International Journal of Geographical Information Science* 14 (3):207–224.

Hornsby, K.S., and S. Cole. 2007. Modeling moving geospatial objects from an event-based perspective. *Transactions in GIS* 11 (4):555–573.

Hornsby, K.S., and N. Li. 2009. Conceptual framework for modeling dynamic paths from natural language expressions. *Transactions in GIS* 13(s1):27–45.

Jiang, J., and M. Worboys. 2009. Event-based topology for dynamic planar areal objects. *International Journal of Geographical Information Science* 23 (1):33–60.

Klippel, A., M. Worboys, and M. Duckham. 2008. Identifying factors of geographic event conceptualisation. *International Journal of Geographical Information Science* 22 (2):183–204. http://www.tandfonline.com/doi/abs/10.1080/13658810701405607.

Klippel, A. In press. Spatial information theory meets spatial thinking - Is topology the Rosetta Stone of spatio-temporal cognition? *Annals of the Association of American Geographers* :67 pp.

Klippel, A., R. Li, J. Yang, F. Hardisty, et al. In press. The Egenhofer-Cohn hypothesis: Or, topological relativity? In *Cognitive and linguistic aspects of geographic space*.

Klippel, A., and R. Li. 2009. The Endpoint Hypothesis: A Topological-Cognitive Assessment of Geographic Scale Movement Patterns eds. K. Hornsby et al. *Spatial Information Theory* 5756:177–194. http://dx.doi.org/10.1007/978-3-642-03832-7_11.

Kurata, Y., and M. J. Egenhofer. 2007. The 9 +-Intersection for topological relations between a directed line segment and a region. In *1st International Symposium for Behavioral Monitoring and Interpretation*, ed. B. Gottfried, 62–76.

Kurby, C. A., and J. M. Zacks. 2008. Segmentation in the perception and memory of events. *Trends in Cognitive Sciences* 12 (2):72–79. http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2263140&tool=pmcentrez&rendertype=abstract (last accessed 26 July 2011).

Laube, P., and S. Imfeld. 2002. Analyzing relative motion within groups of trackable moving point objects. In *GIScience 2004 Lecture Notes in Computer Science*, eds. Max J. Egenhofer and D. M. Mark, 132–144. Boulder, CO: Springer-Verlag.

Lautenschütz, A. 2010. How context influences the segmentation of movement trajectories - an experimental approach for environmental and behavioral context. In *Extended Abstracts Volume, GIScience 2010*, Paper 193. Zurich, Switzerland: GIScience.

Li, R., A. Klippel, and J. Yang. 2011. Geographic event conceptualization: Where spatial and cognitive sciences meet. In *Proceedings of the 33rd Annual Conference of the Cognitive Science Society*, 3168-3173.

Logothetis, N. K. 2008. What we can do and what we cannot do with fMRI. *Nature* 453 (7197):869-878.

Maguire, M. J., J. Brumberg, M. Ennis, and T. Shipley. 2011. Maguire et al 2011 - Similarities in object and event segmentation. *Spatial Cognition and Computation* 11 (3):254–279.

Mo, N., E. Bruno, N. Moënne-Loccoz, and S. Marchand-Maillet. 2006. Local feature trajectories for efficient event-based indexing of video sequences. In *Lecture Notes in Computer Science: Image and Video Retrieval*, eds. H. Sundaram and E. Al., 82–91. NY: Springer-Verlag Berlin Heidelberg.

Muller, P. 1998. A qualitative theory of motion based on spatio-temporal primitives. In *Proceedings of the Sixth International Conference on Knowledge Representation and Reasoning (KR'98)*, eds. Anthony G. Cohn, L. K. Schubert, and S. C. Shapiro, 131–141. Trento, Italy: Morgan Kaufmann.

Naftel, A., and S. Khalid. 2006. Classifying spatiotemporal object trajectories using unsupervised learning in the coefficient feature space. *Multimedia Systems* 12:227–238.

Newtson, D., G. Engquist, and J. Bois. 1977. The objective basis of behaviour units. *Journal of Personality and Social Psychology* 35:847–862.

Peuquet, D. J. 2002. *Representations of Space and Time*. NY: The Guilford Press.

Peuquet, D. J., and N. Duan. 1995. An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. *International Journal of Geographical Information Systems* 9 (1):7–24.

Randell, D. A., Z. Cui, and A. G. Cohn. 1992. A spatial logic based on regions and connections. In *Proceedings of the 3rd International Conference on Principles of Knowledge Representation and Reasoning*, 165–176. San Francisco: Morgan Kaufmann.

Rodríguez, A., N. V. D. Weghe, and P. D. Maeyer. 2004. Simplifying sets of events by selecting temporal relations. In *GIScience 2004 Lecture Notes in Computer Science*, eds. Max J. Egenhofer, C. Freksa, and H. J. Miller, 269–284. Springer-Verlag.

Schwan, S., and B. Garsoffky. 2008. The role of segmentation in perception and understanding of events. In *Understanding Events*, eds. T. Shipley and J. Zacks, 391–414. New York, NY: Oxford University Press.

Shipley, T. 2008. An invitation to an event. In *Understanding Events*, eds. T. Shipley and J. Zacks, 3–30. New York, NY: Oxford University Press.

Shipley, T., and M. Maguire. 2008. Geometric information for segmentation. In *Understanding Events*, eds. T. Shipley and J. Zacks, 415–435. New York, NY: Oxford University Press.

Smith, T. R., J. W. Pellegrino, and R. G. Golledge. 1982. Spatial cognition and behavior. *Geographical Analysis* 14 (4):305–325.

Sridhar, M., A. G Cohn, and D. C. Hogg. 2011. From video to RCC8: exploiting a distance based semantics to stabilise the interpretation of mereotopological relations. *Framework* :110–125.

Tversky, B., J. M. Zacks, and B. M. Hard. 2008. The structure of experience. In *Understanding Events*, eds. T. F. Shipley and J. M. Zacks, 436–464. New York: Oxford University Press.

Wang, Y., S. Velipasalar, and M. Casares. 2010. Cooperative object tracking and composite event detection with wireless embedded smart cameras. *IEEE Transactions on Image Processing* 19 (10):2614–2633.

Wilder, D. A. 1978a. Effect or predictability on units of perception and attribution. *Personality and Social Psychology Bulletin* 4:281–284.

———. 1978b. Predictability of behaviors, goals, and unit of perception. *Personality and Social Psychology Bulletin* 4:604–607.

Wood, Z., and A. Galton. 2009. Classifying collective motion. In *Behaviour Monitoring and Interpretation*, eds. B. Gottfried and H. Aghajan, 129–155. Amsterdamn, The Netherlands: IOS Press.

Worboys, M., and K. Hornsby. 2004. From objects to events: GEM, the geospatial event model. In *GIScience 2004 Lecture Notes in Computer Science*, eds. Max J. Egenhofer, C. Freksa, and H. J. Miller, 327–343. Springer-Verlag.

Yang, J., and A. Klippel. 2010. Assessing the cognitive adequacy of topological calculi in scaling movements. In *Spatial Cognition 2010: Poster Presentations*, ed. D. Rapp, 95–98. University of Bremen.

Yang, J., A. Klippel, and R. Li. In press. Assessing the cognitive salience of topologically identifed discontinuities in earth dynamics. *International Journal of Geographic Information Science*.

Zacks, J. M. et al. 2001. Human brain activity time-locked to perceptual event boundaries. *Nature Neuroscience* 4 (6):651–5. http://www.ncbi.nlm.nih.gov/pubmed/11369948.

Zacks, J. M. 2004. Using movement and intentions to understand simple events. *Cognitive Science* 28:979–1008.

Zacks, J. M., and K. M. Swallow. 2007. Event segmentation. *Current Directions in Psychological Research* 16 (2):80–84.

Zacks, J. M., and B. Tversky. 2001. Event structure in perception and conception. *Psychological bulletin* 127 (1):3–21. http://www.ncbi.nlm.nih.gov/pubmed/11271755.