Spatial Analysis to Capture Person Environment Interactions through Spatio-Temporally Extended Topology

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시공간적으로 확장된 토폴로지를 이용한 개인 환경간 상호작용 파악 공간 분석

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Abstract : The goal of this study is to propose a new method to capture the qualitative person spatial behavior. Beyond tracking or indexing the change of the location of a person, the changes in the relationships between a person and its environment are considered as the main source for the formal model of this study. Specifically, this paper focuses on the movement behavior of a person near the boundary of a region. To capture the behavior of person near the boundary of regions, a new formal approach for integrating an object's scope of influence is described. Such an object, a spatio-temporally extended point (STEP), is considered here by addressing its scope of influence as potential events or interactions area in conjunction with its location. The formalism presented is based on a topological data model and introduces a 12-intersection model to represent the topological relations between a region and the STEP in 2-dimensional space. From the perspective of STEP concept, a prototype analysis results are provided by using GPS tracking data in real world.

Key Words : Moving Object, Person Environment Interactions, Spatial Cognition, Qualitative Spatial Reasoning, Spatio-Temporally Extended Point (STEP), Scope of Influence

요약 : 본 연구의 목적은 정성적인 개인의 공간 행동을 파악하고 행동 원인을 유추해 볼 수 있는 새로운 방법을 제안하는 것이다. 이동 객체의 단순한 기하학적인 움직임에 초점을 맞추는 것을 넘어서서, 사람과 환경 사이의 관계 변화 내지는 상호작용을 파악하여 이동 객체의 행동 특성을 분석할 수 있는 모델을 제시하고자 한다. 특히, 본 연구에서는 특정 지역의 경계 근처에서의 이동 객체의 움직임에 중점을 두고 분석하였다. 이동 객체의 영향력 범위를 적용하는 새로운 접근 방법을 이용하여 정성적인 개인 공간행위 특성을 파악하였다. 본 연구에서는, 이러한 객체를 시공간적으로 확장된 점(STEP)이라 명명하였으며, 그 영향력 범위를 그 객체의 위치와 함께 잠재적 사건이나 주변과의 상호작용이 가능한 구역으로 정의한다. STEP과 특정공간간의 관계 정량화를 위해, 위상 데이터 모델을 기반으로 2차원 공간에서의 특정 영역과 STEP 사이의 위상 관계를 나타내는 12 교차점 모델이 이용되었다. 이 연구에서는 이러한 STEP 개념의 관점에서, GPS추적 데이터를 이용한 프로토타입 응용 분석결과가 제공되었다.

주요어 : 이동 개체, 개인–환경 상호작용, 공간 인지, 정성적 공간 추론, 시공간적으로 확장된 점(STEP), 영향력 범위

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1. INTRODUCTION

The meaning of motion is generally understood as a change in the location of a spatial object (Forbus, 1980). This straightforward approach does not adequately consider the change of relationships between a spatial object and what is around it (Lee, 2006). Even though it is natural that motion accompanies a change of spatial relationship, current approaches with regard to the spatial behavior of a spatial object are limited to detecting the change of spatial configuration. To overcome this limitation, the idea of "environment context" which means that spatiotemporal phenomena are influenced by the environment in which they exist is noteworthy (Prager, 2007). Prager said "For an object moving through a given environment, the ability of that object to move is constrained by the manner in which environmental characteristics influence that movement."

The goal of this study is to answer an important question: how do we best describe the spatial behavior of point objects around the significant region? Geographers are mainly interested in the overt behavior of individuals. To explain it, abundant descriptive data and normative theories about the properties of distributions, interactions, network connections, patterns, nodes, surface properties, and hierarchical elements of spatial systems were needed (Golledge and Stimson, 1997). According to them, at disaggregate levels, all we can manage to understand spatial behavior is to assign ranges of probabilities to individual decision choices. In this study, those probabilities are represented as the scope of influence around point object or human being. This concept of scope of influence comprehends both physical ranges and psychological variables like cognitive attitudes and emotions. With regard to near boundary behavior, this study focuses on capturing hidden behaviors or interactions near the boundary of the region. For instance, it is assumed that there can be invisible relationships even if the space between the point object and the boundary of the region is visually empty. Thus, the point object can affect the region or be affected by the region without contacting the region.

In this paper, the formal model is provided for capturing the qualitative human spatial behavior near the boundary of a region. There are many cases in which a sense of apprehension or resistance is felt when we cross the boundary of a region. Here, the boundary of the region can be described to have a certain threshold with a critical limit needed in order to cross. To cross such a boundary, a minimum level of effort or cost is required. To represent such human behavior near the boundary of the region, a new formal approach about the scope of influence for an object is described. A scope of influence is defined as the conceptual area where there is a possibility of a phenomenon or event occurring because of this object. Such an object can be considered a spatio-temporally extended point (STEP) by considering its scope of influence as potential events or interactions area in conjunction with its location. This study uses GPS tracking data from a local public golf course. By using a prototype application with golf course data, the feasibility of the STEP concept is tested. Moreover, the analysis helps to find which STEP object shows exceptional or suspicious behavior.

The remainder of this paper is structured as follows: the next section reviews previous works about moving point object. Section 3 introduces a formal approach for spatio-temporally extended point (STEP). Section 4 describes the prototype application of STEP with GPS tracking data. Section 5 shows the comparison of point-based approach and STEP-based approach. Section 6 presents the conclusions and discusses more complex situations.

2. SPATIAL BEHAVIOR OF A MOVING POINT OBJECT

As a point object moves through space, a track or path can be recorded in the database to represent its past and present positions and its attributes. Because of the development of technology for collecting the point object movement data, such as the Global Positioning System (GPS) or cellular/mobile phones, the quantity and quality of the data relating time geography and activity theory have improved while their cost has been reduced (Kim, J. and Um, J., 2010; Miller, 2003). Thus, creating a customized data model and database for a moving point object has subsequently become a more significant issue.

There are a lot of moving point objects in the real world. For example, in the military, moving-objects-database applications are used in the context of the digital battlefield (Wolfson *et al*., 1998), while space-time activity (STA) data is collected and used by location-based services (LBS) to sell and promote their products and programs (Miller, 2003).

Sistla *et al*. (1997) used a spatial index for the dynamic attribute, including a hierarchical recursive decomposition of space, usually into rectangles. Šaltenis *et al*. (2000), meanwhile, proposed the time-parameterized R-tree (TPR-tree). It was designed for the indexes of the current and anticipated future positions of moving point objects. In the TPR-tree, the bounding rectangles in the tree are functions of time, as are the moving points being indexed.

A regular query language such as SQL or OQL can be used for expressing temporal queries on moving point objects. However, these languages do not have temporal operators, meaning that there are no keywords that are natural and intuitive in the temporal domain (Cheng *et al*., 2004).

A good example of temporal operators, the Future Temporal Logic (FTL) query language enables queries focused on the future states of the system. It also supports proximity queries on moving objects (Agarwal *et al*., 2003). The formulas of FTL use two basic future temporal operators: 'Until' and 'Nexttime'. Other temporal operators, such as 'Eventually', can be expressed in terms of the basic operators (Sistla *et al*., 1997).

Today's Spatio-Temporal GIS research mostly concentrates on data representation and queries, while analysis receives less attention (Imfeld, 2000). Moreover, the analytical methods for moving points objects (MPO) are based on snapshot-oriented sampling schemes (Wolfson *et al*., 1998). Therefore, there is no distinction between the analysis of static and mobile objects (Imfeld, 2000). Methods of collecting MPO data are: direct observation, use of a spool-line, sensors put directly on an MPO, photographs of an MPO taken at regular intervals, and satellites (Wentz *et al*., 2003).

Furthermore, previous location-based methods of organizing data and information from the GIS have stuck to the placed-based theories and models. Placed-based methods ignore the basic spatio-temporal conditions of human existence and organization (Miller, 2003). In contrast, Miller postulates expanding GIS from the place-based perspective to encompass a people-based perspective taking into account time geography (Laube *et al*., 2005).

In Hägerstrand's time geography, activities occur at specific locations for limited time periods. The time geographic perspective is useful to apply a people-oriented approach. The basic conceptual tool can be presented as the space-time path, which traces the simultaneous movement of an individual in space and time. A space-time prism (STP) is an extension of the space-time path that measures accessibility to events in space and time. Based on an average travel velocity, it can create the potential path space (PPS) showing all locations that the person can occupy in space and time. The potential path area (PPA) can be created by projecting the PPS onto the two-dimensional geographic plane (Miller, 2003). PPS concept is useful to infer moving object's real path or analyze the moving pattern geometrically. In contrast, STEP concept can be utilized to infer the reason of moving object's behavior by assuming that the moving object already recognized its scope of influence and can be affected by the cognition.

A closely-related area is activity theory, which also focuses on people rather than places as the source of travel and location demands (Mountain and Raper, 2001). This concerns the theoretical basis, measurement and analysis of how people organize activities in space and time, the relationship between these activity patterns, and the influence of evolving systems (Miller, 2003).

The main difference, however, is that time geography conceptualizes its entities as moving through space and time in a theoretically continuous way, while activity theory treats time and space as discrete (Imfeld, 2000).

In addition to time geographic perspective and activity theory, there are several other methods for analyzing moving point object data. Traditionally, the most popular way of analyzing spatio-temporal data is to plot the data on a separate map for each observation period (Imfeld, 2000). This method of exploring and visualizing space-time activity data now includes data mining and exploratory visualization techniques, a decision tree, and multidimensional sequencing methods (Miller, 2003). However, it depends on a user's ability to distinguish eye-catching patterns or trends in the data (Laube *et al.*, 2005). Common descriptive statistics also have several limitations. For example, collapsing the data into a set of descriptive measures makes it impossible to detect inter-object relations and spatially or temporally delimited motion patterns (Mountain and Raper, 2001).

However, previous work on this subject has generally involved top-down approaches. This means trying to develop a data model and create a database for a moving point object first and then finding some pattern or information based on the shape or trend of its movements. In contrast, the concept of the STEP involves setting up a hypothesis to explain why the moving point object is behaving as it is then examining the significance of the hypothesis. One scope of influence would imply one possible hypothesis, making it a bottom-up approach.

3. QUALITATIVE HUMAN SPATIAL BEHAVIOR NEAR BOUNDARY

Moving point objects generally have clear patterns in their behaviors, but sometimes these patterns are too complex to be identified with simple methods (Laube *et al.*, 2005). This leaves one wondering, "What is the pattern related to this moving point object?" In the case of point objects, the spatial pattern is expressed as random, clustered or evenly distributed. This kind of spatial change does not contain temporal regularities. In contrast, a spatio-temporal pattern has to show both spatial and temporal regularities (Imfeld, 2000). Moreover, moving point objects can have species-specific patterns. For example, flying butterflies show punctuation with periodic halts, while ants and deer move in continuous ways without offering the analyst convenient stopping points (Laube *et al.*, 2005).

1) Spatio-Temporally Extended Point (STEP)

In GIScience research discipline, there is a tendency to describe point objects only as 0-dimensional ob-

Figure 1. Spatial behaviors of a point object and spatio-temporally extended point object.

jects; represented to be within a region or line, on the boundary, and outside a region or off the line. Between two point objects, only an identity relation is considered (Clementini *et al*., 1993; Cohn *et al*., 1997; Egenhofer, 1989). To meet the analytical scale of geographic information systems, a large number of spatial objects are treated as conceptual locations linked to time, theme, and value (i.e. a point). This concept is too generic to represent the qualitative spatial behavior of a point object or a phenomenon occurring because of a point object. In Figure 1(a), the movement of a point object near a region shows such behavior. Currently, there is no way to represent this topologic behavior in a qualitative manner because the relationship between a region and a point object is essentially unchanged. The point object is always outside the region.

If a scope of influence is added to this point object, we can detect a change of topological relation between the region and the spatio-temporally extended point object (Figure 1(b)). Here, the scope of influence for the point object can be defined as the conceptual area wherein there is a possibility of the phenomenon or event occurring because of this point object. Lee and Flewelling (2004) introduce this kind of point object as a spatially extended point object.

As mentioned, various definitions for the same point object are possible when applying the concept of Spatio-Temporally Extended Points (STEP). Against snapshot-oriented approaches, the scope of influence implies the future possibility of a moving point object. This means that the concept of the STEP can be considered a relationship-based spatio-temporal approach. Different from place-based or people-oriented approaches, it focuses on changes in the relationship between the point object and the other objects around it. Thus, in this study, the transactions from disjoint to joint and vice versa are considered as the start and end of the movement behavior of a point object. Moreover, the flexibility of the STEP concept can provide computational advantages for achieving qualitative spatial reasoning about the behavior of a point object.

Conventionally, a point object has been defined by a conceptual location linked to a time, theme, and value. The basic definition is that a point object has no length, area, volume, or any other range. In this study, a point object is spatio-temporally extended by adding the concept of its own interior, boundary, and exterior. Here, a point object is renamed a pivot. The pivot is conceptually similar to a 0-dimensional object. Major differences between an ordinary point and a pivot are that a pivot has additionally a function as a future possibility of movement behaviors or actions. The interior of the STEP object should be understood as the sum of infinite possibilities of phenomena or events occurring because of the point object. By contrast, the exterior can be understood as the sum of the possibilities which are 0 or below the acceptable level to be included in the scope of influence. The boundary of the STEP object is described as a threshold line which is neither the interior nor exterior. It should be understood as both a limit of the scope of influence and a start of the non-influencing area. Furthermore, the boundary of the STEP object plays an important role in qualifying a limit of the other objects such a region or line. That is, if a boundary of the STEP object is sharing a common point with a boundary of the other objects without any overlap between them, the STEP object is detecting the existence of that object as a prior step of 'overlap' (Egenhofer, 1989) or 'connection' (Clarke, 1985; Randell *et al.*, 1992).

A scope of influence for a point object is not a physical area but an area of potential interaction. It is an invisible and conceptual area which is defined for a specific purpose of analysis. That is the point object represents the current status, and the scope of influence implies future status as potential event or interaction area. The scope of influence for the point object can be defined as the conceptual area wherein there is a possibility of the phenomenon or event occurring because of this point object. Thus, it is functionally dependent on the point object. Based on its own definition, there can be various types of the scope of influence for a point object. For example, a distance which a person's hand can reach can be a scope of influence for this person who will be represented as a point object in spatial database or a transmission range around a Radio Frequency Identification Device (RFID) can be defined as a scope of influence for the RFID. Moreover, various definitions for the same point object are possible, like the distance which a person can see and the distance which this person can reach in one minute. This flexibility can provide computational advantages for qualitative spatial reasoning about a behavior of a point object. By using the same data which is storing the change of location of a specific point object, different behavior can be represented based on the definition of a scope of influence associated with this point object.

A STEP has its own interior, boundary, and exterior to represent its own scope of influence. In addition to interior (P°), boundary (∂P), and exterior (P^-) from the 9-intersection model, a pivot ($P^\bullet$) can be added as the major factors for representing a STEP. Lee and Flewelling (Lee and Flewelling, 2004) introduced a 3×4-matrix, M_{step} shows the criteria for the region-STEP relations (Equation 1.). The first row of Mstep refers to the relations between the pivot of the STEP and the region. The other rows of M_{step} refer to the relations between the scope of influence of the STEP and the region.

2) Topological Relations

The relationships between a region and spatio-temporally extended object can be described by extending the concept of eight topological relations between two regions (Bennett *et al.*, 2000).

$$M_{step} = \begin{bmatrix} P^\bullet \cap R^\circ & P^\bullet \cap \partial R & P^\bullet \cap R^- \\ P^\circ \cap R^\circ & P^\circ \cap \partial R & P^\circ \cap R^- \\ \partial P \cap R^\circ & \partial P \cap \partial R & \partial P \cap R^- \\ P^- \cap R^\circ & P^- \cap \partial R & P^- \cap R^- \end{bmatrix} \quad (1)$$

Between a region and a STEP, fourteen topological relations were found (Lee and Flewelling, 2004). These fourteen topological relations can be divided into three parts based on the location of the pivot of the STEP: pivot within the region (Figure 2(a)), pivot outside the region (Figure 2(b)), and pivot on the boundary of the region (Figure 2(c)). These scope-region labels match those used by Egenhofer and Franzosa (1991) for topological relations between two regions.

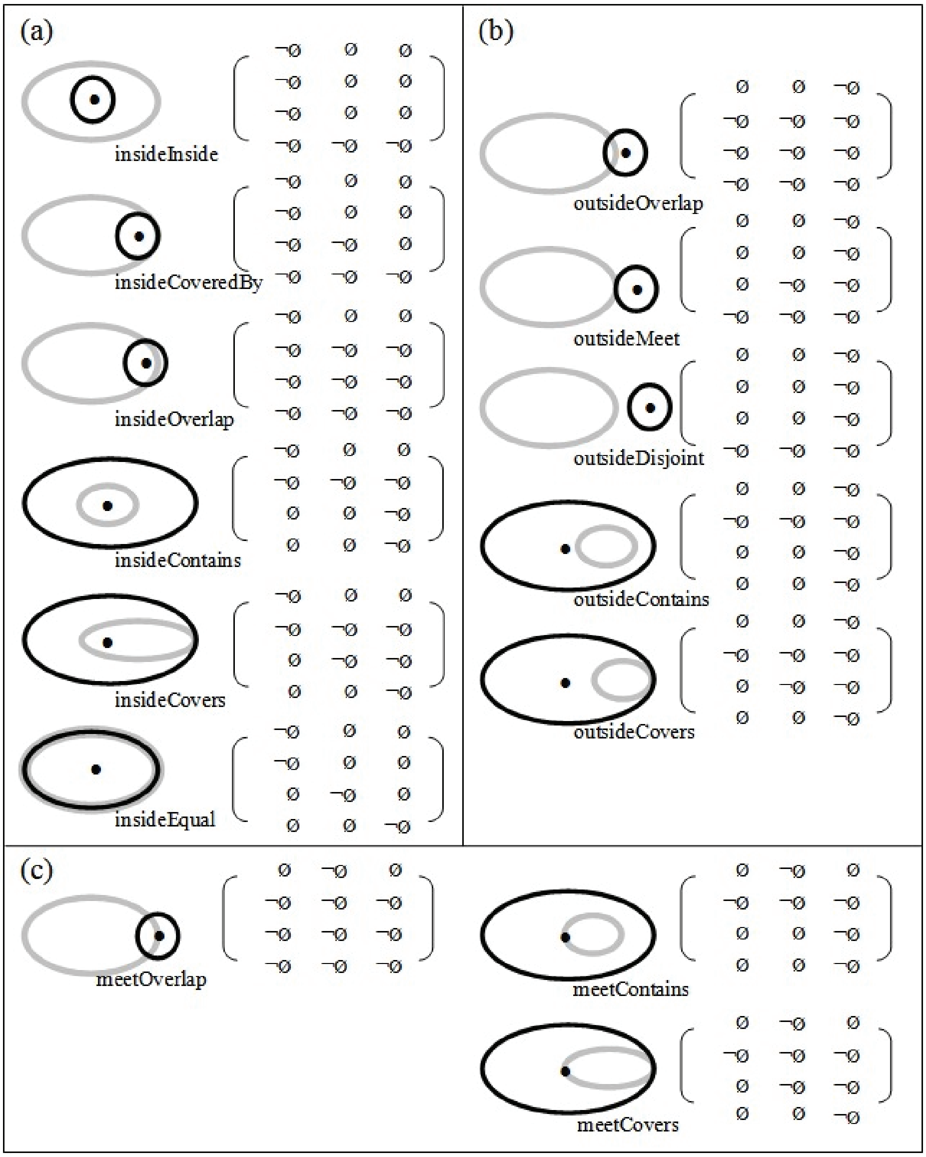

Figure 2. Binary (¬Ø: existence, Ø: non-existence) topological relations between a region and a spatio-temporally extended point ((a): Pivot within the region, (b): Pivot outside the region, (c): Pivot on the boundary of the region) (Lee and Flewelling, 2004).

3) Qualitative Spatial Behavior

Compositions of gradual changes between topological relations show how to represent the movement of a spatio-temporally extended point object in relation to a region. By examining a set of topological relations between a STEP and a region it may be possible to detect behaviors, or reoccurring patterns. The actual semantic character of the object being represented may also imply specific goals or intents that could be assigned to a behavioral signature. The model presented here provides a richer vocabulary to describe these near-boundary behaviors. Gradual changes of topological relations can be described more qualitatively as the behaviors of a STEP object.

By using the same data which is storing the change of location of a specific point object, different behavior can be represented based on an appropriate definition of a scope of influence associated with this point object behavior.

An important benefit of the STEP concept is that current geospatial database which is storing temporal changes of the location can be used to capture the behaviors of the various point objects.

4. DETECTING PATTERNS IN GOLF CART MOVEMENT

The purpose of the prototype application is to exercise the relations between a synthetic STEP and discrete regions in a real-world setting. To apply the STEP concept to a real-world case, this work uses tracking data from golf carts that have been equipped with Global Positioning System (GPS) receivers by a local public golf course. The tracking data with a total of sixty-six rounds played were collected. And, there are a total of 202 regions created for eight prototypes including teeing grounds, bunkers, putting greens, fairways, water hazards, buildings, cart paths, and parking lots.

Most golf carts are on the cart path while their golfers are playing golf. Some golf carts go beyond the cart path and demonstrate some driver behavior such as approaching a bunker or crossing the fairway. If the managers of the golf course are trying to analyze the actions of the golfers, it would be helpful to have summaries of the movement behavior of golf carts on the golf course. In effect, it is providing less data and more information.

To begin a more thorough analysis, the layers for the scopes of influence were added to the cart tracks. In this study, the scope of influence used in this proof of concept is the turning radius of the golf cart. On site tests of the golf carts determined that a turning radius of 3.048m (10 feet) was typical.

5. RESULTS

The synthesized STEP data is analyzed by looking into STEP-region relations. To verify the usefulness of the STEP concept, the comparison with current point-only approach is provided. The analysis is generally based on relationship-based approach. The sequences of STEP-Region relations are examined to bring temporal constraints into the analysis.

Not every location recorded for a golf cart is a part of a significant sequence of STEPs. Since *outsideDisjoint* relations are so common in the database and in reality, long sequences of *outsideDisjoint* need to be abbreviated. Table 1 shows the number of significant STEPs for each cart. Here, a turning radius of 3.048m (10 feet) is used as the scope of influence for the STEP in this paper. The second column shows the number of needed recording points to represent each cart's moving path of eighteen hole play. The third column shows the count of those STEPs that have at least one non-*outsideDisjoint* relation with a region on the golf course. These can be considered the number of "interesting" points for the golf cart. The fourth column is the number of times a cart's STEP pivot had a non-outside relation with certain region out of 202 regions in the golf course. Thus, this table is also highly related to the temporal issue. For a given golf cart, the relative number of STEPs that interact with a particular region may be a metric of the importance of that region to the cart. Compared with the number of related points,

Table 1. Number of related STEPs and Points for each golf cart.

Cart	# of Points	STEP	Point	(STEP-Point)/STEP	Cart	# of Points	STEP	Point	(STEP-Point)/STEP
1	1142	1052	525	0.501	34	1084	894	361	0.596
2	938	728	315	0.567	35	965	785	356	0.546
3	940	817	356	0.564	36	786	676	264	0.609
4	886	727	404	0.444	37	983	778	427	0.451
5	1000	762	314	0.588	38	921	814	381	0.532
6	906	837	431	0.485	39	979	757	385	0.491
7	964	717	323	0.550	40	788	676	264	0.609
8	974	827	405	0.510	41	981	778	427	0.451
9	990	823	323	0.608	42	893	794	306	0.615
10	931	784	329	0.580	43	947	851	417	0.510
11	940	874	385	0.559	44	891	789	409	0.482
12	1079	911	422	0.537	45	842	754	385	0.489
13	964	830	372	0.552	46	886	856	409	0.522
14	1144	891	404	0.547	47	799	736	357	0.515
15	936	796	402	0.495	48	805	713	354	0.504
16	1050	794	353	0.555	49	1101	988	445	0.550
17	917	813	417	0.487	50	881	818	329	0.598
18	926	842	465	0.448	51	856	693	288	0.584
19	961	780	338	0.567	52	968	874	420	0.519
20	996	748	323	0.568	53	728	597	225	0.623
21	1098	957	448	0.532	54	807	763	414	0.457
22	930	849	396	0.534	55	1141	869	388	0.554
23	961	858	416	0.515	56	750	597	310	0.481
24	970	817	314	0.616	57	861	743	297	0.600
25	931	749	359	0.521	58	1008	870	396	0.545
26	790	676	264	0.609	59	957	852	353	0.586
27	979	778	427	0.451	60	937	834	403	0.517
28	856	749	374	0.501	61	967	813	402	0.506
29	981	850	427	0.498	62	942	846	474	0.440
30	1121	860	410	0.523	63	934	797	351	0.560
31	910	830	338	0.593	64	955	790	324	0.590
32	795	701	328	0.532	65	768	679	289	0.574
33	807	681	289	0.576	66	842	761	372	0.511

the STEP object has a relationship with the regions for a longer time. The fifth column, for each cart, describes relatively how many hidden interactions with the regions can be captured through STEP concept comparing with the case of applying generic the point approach.

The t-test results (t=64.337, Sig.=0.001) reveal that 'STEP' and 'Point' happen independently. Moreover, the significant correlation value (0.753) means that there is a tendency to the same ratio with 'STEP' and 'Point.' It means that the ratio of the number of related STEPs and points with the regions is relatively con-

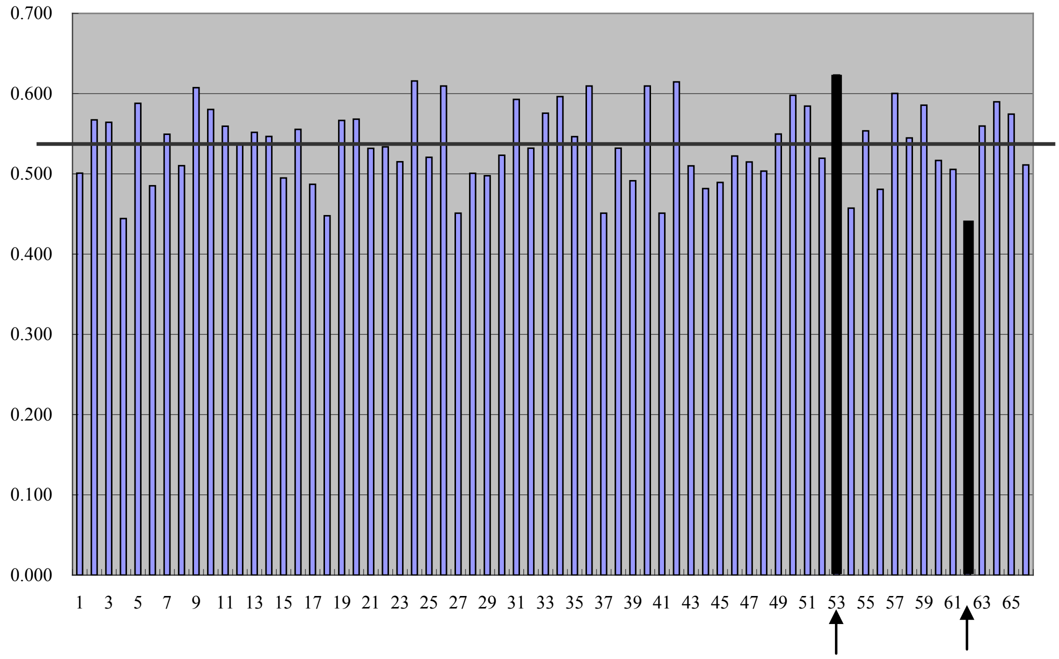

Figure 3. Difference ratio between related STEPs and Points normalized by STEPs.

stant from cart to cart.

Figure 3 shows the difference ratio between related 'STEPs' and 'Points' normalized by STEPs. The thick guide line is the average difference ratio. This graph is helpful for knowing which golf cart shows a relatively big difference between using a STEP for analysis and using Point alone.

For instance, cart 53 shows a large difference while cart 62 is below the mean. Figure 3 can tell us hidden patterns that cart 53 tried relatively more times to approach the regions from outside, and cart 62 tried less times. According to the collected data, cart 53 is showing relatively high ratio of *outsideOverlap* relations (453 of 147784), and cart 62 is showing low ratio (488 of 191226).

The results from Tables 1 explain that there are regular tendencies if we apply the STEP concept. The STEP objects consistently show more information about the relationships with the regions in the golf course. This suggests that there may be some benefit to examining the patterns of movement behavior of STEP objects.

As it was mentioned in chapter 4, from the perspective of this study, the behavior of moving point objects is described using a relationship-based of approach. Because this study is focusing on the near boundary behavior of moving point object, the 'overlap' or 'connection' between the STEP object and the boundary of the region is an important signal for the qualitative spatial behavior of the STEP object (STEP_Behavior). Thus, the behavior of a STEP object is temporally defined as a series of non-*outsideDisjoint* relations that are bounded by two *outsideDisjoint* relations. The transitions from disjoint to joint and vice versa are considered as the start and end of the movement behavior of a point object (P_Behavior). Thus, the beginning and end of behavior is an *outsideDisjoint* relation.

There are some cases when one behavior of the STEP

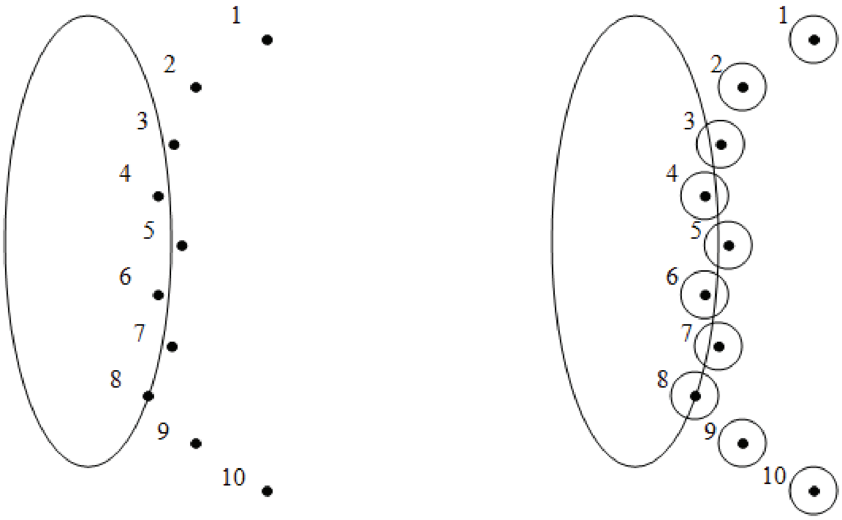

Figure 4. Comparison of the behavior of the STEP object and point object.

object can be divided into several behaviors of the point object. In Figure 4, there is one behavior of the STEP object from 2 to 9. This behavior can be three different behaviors of the point object (2 to 5, 5 to7, and 7 to 9).

Nevertheless, the fact that there is no big difference between two numbers of the STEP object and point object means that there are many behaviors of the STEP object whose pivot does not cross the boundary of the regions. If the pivot does not cross the bound-

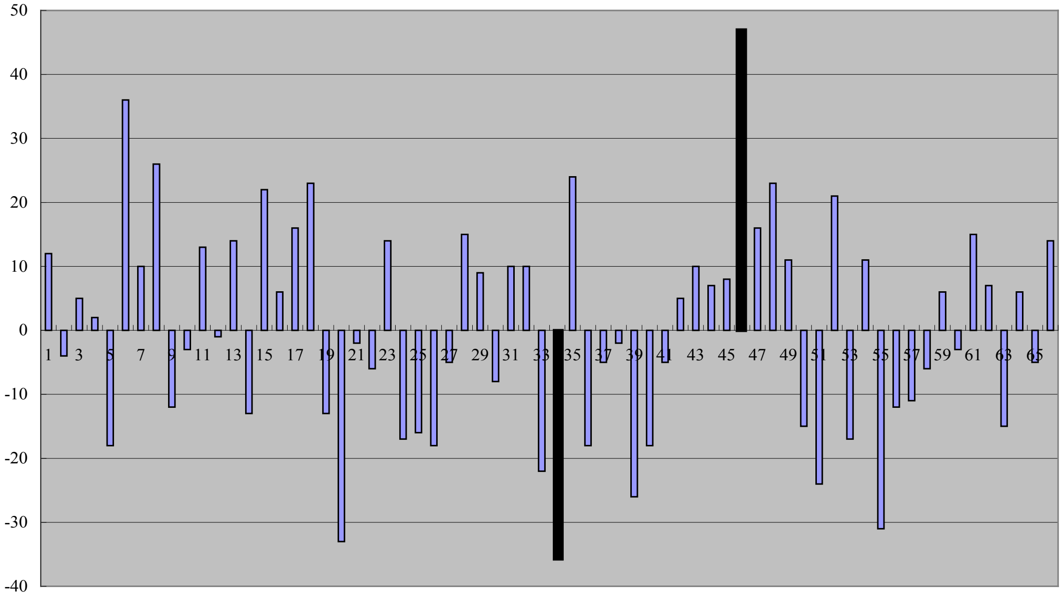

Figure 5. Difference between P_Behavior and STEP_Behavior (Y-axis = P_Behavior – STEP_Behavior).

ary, it is not counted as behavior for the point object. This suggests that there are many hidden behaviors for STEP objects that could not be found by using previous topologic relation approaches.

Figure 5 shows the difference between P_Behavior and STEP_Behavior. With this graph, we can find which golf cart tried often to approach the boundary of the regions without crossing it, such as cart 34, or which golf cart did not, such as cart 46. We can guess that cart 34 behaves a lot like Figure 6(a) and cart 46 behaves a lot like Figure 6(b). Even with the cases of cart 34 and 35 whose (STEP-Point)/STEP are relatively high in Table 1, their moving pattern can be totally different like showing in Figure 5.

If the cart is moving like Figure 6(a), it means that there is some reason that this region attracts this cart, but the driver of this cart feels relatively more moral pressure to enter this region or this region is preventing for the cart from entering. For example, the cart driver tries to check a bunker or water hazard to see whether there is a ball in it. If the cart is moving like Figure 6(b), it means that the driver of this cart feels relatively less moral pressure to enter the region or the region is allowed to be relatively easily entered. For instance, if there is no physical barrier, the cart freely enters the fairway to go to shortcut or go round a puddle on the cart path while the cart keeps following a cart path.

6. CONCLUSION AND DISCUSSION

As we have seen before, the STEP concept helps to call attention to key anomalies in the normal pattern of the golf carts. It also shows the possibility of detecting the degree of hidden behaviors for STEP objects that could not be found by using previous topologic relation approaches. As it turned out, the application of the STEP concept can provide richer vocabulary about the movement behavior of moving point object. Beyond simply tracking the changes of the location of moving point object, the results of this study are showing a good example to understand the behavior of a point object based on the change of the relationship between a point object and associated space.

There can be several possible applications of this concept to ubiquitous computing, including location based services and mobile GIS. For instance, location-specific information or advertisements could be provided based on the qualitative spatial behavior of a per-

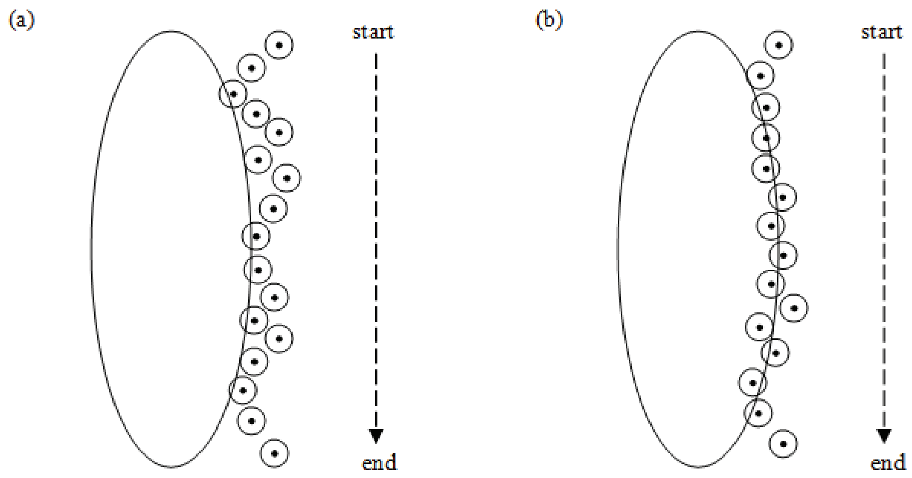

Figure 6. Two types of the near boundary behavior of the STEP object.

son who carries a mobile device based on user's context (Lee, 2007). Moreover, an emergency management system could be alerted after detection of the suspicious behavior of a dangerous point object.

The result of analysis of sequences of STEPs is that the average difference ratio (= (STEP-Point)/Point) is 0.537. Through analysis of STEPs, specific golf carts showing exceptional behavior were detected. For instance, the analysis result is helpful for knowing which golf cart shows a relatively big difference between using a STEP for analysis and using Point alone. The result is also helpful for finding which golf cart tried often to approach the boundary of the regions without crossing it.

1) Future Work

This section discusses the issues related to the implementation of STEPs where the granularity of the underlying geography and the relative size of the scope of influence are mismatched. In addition to enhancements of the spatio-temporally extended point object itself, there are issues related to the granularity of the space in which the STEP is embedded. With regard to the behaviors of spatio-temporally extended point objects, it can be reasoned that spatio-temporally extended point objects cross any number of sub regions that constitute the parent region.

Likewise, issues regarding the temporal granularity of a STEP's movement (Hornsby and Egenhofer, 2002) offer opportunities for using STEP-region relations to infer missing relations in a sequence. For instance, an insideInside relation followed by *outsideDisjoint* implies a missing *insideOverlap-meetOverlap-outsideOverlap* sequence or a more complex variation.

Furthermore, it is possible that there are more complex compositions of topological relations between a region and STEP. For example, if many STEPs try to cross the same boundary at the same time, the topological relations should be described in a different way than a group of individual relations. For example, large numbers of people crossing a national border might be described as an assault, while an individual is simply a border crossing.

Even though there are several opportunities to address various complex situations in future work, this study takes a first step to formalizing the qualitative spatial behavior of point objects beyond the state of the art.

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