VARIOUS EVENTS INVOLVED IN SPATIO-TEMPORAL DATABASES

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ABSTRACT

In general, time has two kinds of semantic, i.e., time-scale semantic and event-sequence semantic (Shu Hong, 1998). In spatio-temporal databases (STDB), time-scale semantic refers to the time positioning of geographical objects, and event-sequence semantic to spatial and thematic change description. Here event and change are alternatively termed without further meaning distinction. Almost a decade's STDB research has been conducted, but few results have been brought into practice (Timos Sellis, 1999). This somewhat indicates that a gap exists between our theoretical research and users' application requirements. In bridging this gap, spatio-temporal semantic modeling plays an important role, not only because semantics are derived from our understanding of practical problems, but also because they make sense our theoretical research. The objective of this paper is to explore primary events involved in spatio-temporal databases for various spatio-temporal phenomena modeling quantitatively or qualitatively. The paper is constrained to exploration of spatial events for the time being. Spatial changes are identified at three levels (scene change, object change and property change). At the level of property change, a set of primary spatial property changes (location change, distance change, direction change, size change, shape change), together with geometrical dimensionality changes (point change, line change, area change), are proposed. At the level of object change, in terms of mapping relationships between source objects and result objects, six kinds of object change are given. At the level of scene change, several primary scene changes and distribution type change are addressed. Various advanced spatial changes will surely enrich spatio-temporal semantic modeling in spatio-temporal databases.

1 MOTIVATION

In the early 1990s, Gail Langran, in her recognized book "Time in Geographical Information Systems", began initial studies of spatio-temporal data modeling from concepts to implementations. In 1996, CHOROCHRONOS project claims the formal start of spatio-temporal data modeling research from all aspects of spatio-temporal databases, including concepts, data models, query languages, physical data structures, indexing methods and DBMS frameworks. A large number of papers are contributed to seeking an extensive theoretical foundation of spatio-temporal database management systems. However, few results have been brought into practice (Timos Sellis, 1999). This somewhat indicates that a gap exists between our theoretical research and users' practical application requirements. In our opinion, the efficient way to bridge this gap is to further research of spatio-temporal semantic modeling, because semantics originate from our understandings of practical problems, and simultaneously they make sense our theoretical research.

Among ongoing research, two topics are receiving more and more attention recently. There are moving object data types (Sistla, A.P., O. Wolfson, et al., 1997; Erwig, M., R.H. Gueting, et al., 1997) and constraint-based spatio-temporal data models (Chomicki, J., P.Z. Revesz, 1997; Grumbach, S., P. Rigaus, L. Segoufin, 1998). Moving object types consist of moving points and moving regions, which have been embedded in Gueting's geo-relational algebra. Mathematically, moving object types are defined as mappings of time to spatial extent. It is easy to see that moving object types directly aim at location change modeling. A typical example is moving vehicles, which change their location over time continuously. On the other hand, in constraint-based spatio-temporal data models, space and time are modeled as two variables in a linear constraint equality or inequality, denoted by $f(x,y,t)>=0$. $f(x,y,t)>=0$ can be transformed to $h(x, y)>=g(t)$, where $h(x,y)$ represents the spatial extent of an object and $g(t)$ is a function of time. Usually, $h(x,y)$ itself is treated as another constraint of coordinate variables x and y. Likewise, constraint-based spatio-temporal data models only describe the location change of an object directly. The difference between moving object types and constraint-based spatio-temporal data models is that moving object type modeling is at the high level of abstraction without specified storage structures, but spatio-temporal constraint modeling at the low level of abstract with apparent constraint representations. In short, both moving object types and spatio-temporal constraints explicitly reveal only one spatio-temporal semantic, i.e., location change semantic. In a sense of geometry or point-set theory, location as a coordinate point is the atomic unit to describe spatial objects, and location change is the most basic spatial change. However, it is known that point set or point-string or coordinate-sequence data structures not only increase difficulties of data storage and access, but also reveal less spatial semantics explicitly. This means more useful semantic information depend on algorithms or users' understandings. To overcome this shortcoming of poor semantics, hierarchical data structures, e.g., node-arc-polygon and point-edge-triangle with connectivity and neighborhood relationships, are preferred in practice. Again, in a human perceptual sense, location change is only a basic concept in human spatio-temporal mental models. Reginald G. Golledge (1995) put out that location is only one of spatial primitives. Amazingly, direction is being identified as an independent spatial object (Shashi Shekhar and Xuan Liu, 1998). More, we take forest management as example, enlarging planting area of certain tree species intuitively presents human an image of area change of a tree stand, rather than location change of a tree stand, and changing tree-planting stand from square to strip intuitively is shape change of a tree stand. All these remind us of more spatio-temporal semantics to be modeled in spatio-temporal databases.

In general, time has two kinds of semantic, i.e., time-scale semantic and event-sequence semantic. By these two kinds of time semantic, accordingly, M.F. Worboys (1994) developed a spatio-temporal complex model, where time and space are two semantically independent dimensions unified in a mathematical form of complex, and D. J. Peuquet et al. (1995) designed an event-based spatio-temporal data model TRIAD. To some extent, event-sequence time semantics seem more important than time-scale time semantics. Therefore, to develop spatio-temporal semantics of spatial event, we examine existing classifications of spatial change in section 2. In section 3, three levels of spatial change (scene change, object change and property change) are identified in detail. In the concluding section, further discussion is made.

2 PREVIOUS WORK ON CHANGE CLASSIFICATIONS BY DIFFERENT CRITERIA

As stated above, event sequence presents human an image of time. In other words, events reveal an inherent time semantic. The structure of events implies time semantics. In databases, an event is generally represented with a function of state change. The spatial event is a function of spatial state change. That is, spatial changes indicate spatio-temporal semantics. For this reason, we investigate previous work on change classifications based on different criteria first.

2.1 The Criterion of Time-varying Patterns

Patterns are distribution laws of elements in a set. Time-varying patterns refer to distribution laws of time sequence data spatial or thematic. Basic time-varying patterns have discrete, stepwise and continuous changes. These time-varying patterns are firstly examined by Segev A and Shoshani, A (1987), who called them time-series types. Afterwards, Yeh, T.S. and B. De Cambray (1993) introduced them into Temporal GIS, and called them behavior functions of data. Formally, assume a time sequence of data, {(a1, t1), (a2, t2), …, (an, tn)}, t1<t2<…<tn, we can define three time-varying patterns:

- Discrete change. The data value sequence {a1, a2, …, an} completely depends on observation or measurement, and no computational laws are available. For example, wood product volumes of a tree stand are recorded at different times.
- Stepwise change. In the time sequence {(a1, t1), …, (ai, ti), …, (an, tn)}, the data value ai remains constant from an time instant ti through next instant ti+1. For example, tree stand changes (splitting, merging, enlargement or reshaping) are stepwise changes.
- Continuous change. The data value ai can be computed by mathematical functions such as a spline function, a linear functions, etc. For example, temperature change in forestry is a kind of continuous changes.

In fact, three kinds of change can be viewed as three forms of a time-varying function at different discretization degrees, that is, continuous function for continuous change, segmented function for stepwise change and approximated function with a set of discrete values for discrete change. Meanwhile, discrete change at a small scale can be generalized into continuous change at a larger scale. Anyway, in a semantic modeling sense, three time-varying patterns reveal three time-varying laws or three time semantics, which facilitate human time information comprehension.

2.2 The Joint Criterion of Geometrical Dimensionality and Time-varying Patterns

In Nancy J. Yattaw's thesis, geographic movements are categorized by characteristics of change in space and time. Spatially, geographic phenomena are abstracted with geometrical point, line, area and volume, and spatial changes are categorized into point change, line change, area change and volume change. For simplicity, volume phenomenon is omitted in this paper. Temporally, dynamic phenomena are characterized by continuous, cyclical and intermittent changes. Continuous change indicates that a phenomenon moves uninterruptedly throughout a period of examination. Movement, which is discontinuous during examination and stops periodically, is said to be fluctuating. For cyclical change (periodical fluctuation), the frequency of every movement is predictable and regular. Intermittent change is a fluctuation, which is sporadic or irregular. By combining three kinds of spatial change with three kinds of temporal change, geographic movements are categorized into nine groups, in the mathematical form, {point change, line change, area change} X {continuous change, cyclical change, intermittent change}= {continuous point change, continuous line change, continuous area change, cyclical point change, cyclical line change, cyclical area change, intermittent point change, intermittent line change, intermittent area change}, where "X" is Cartesian Product (Nancy J. Yattaw, 1997).

It is evident that point, line and area are classified by criterion of geometrical dimensionality. Point, denoted by geometric coordinate (x, y), is a zero-dimensional geometric object without extent. Line, with a certain length and zero width, is a one-dimensional geometric object. Area is two-dimensional extended geometric object. In general, we coarsely group time-varying patterns into continuous change and discontinuous change first, then finely group discontinuous changes into cyclical change and intermittent change in terms of whether the frequency of change is predictable. Change with an unpredictable frequency is intermittent, whereas change with a predictable frequency is cyclical. Intermittent change and cyclical change are similar to discrete change and stepwise change respectively in section 2.1. Nancy J. Yattaw's change classification is based on the joint criterion of geometrical dimensionality and time-varying patterns.

2.3 The Joint Criterion of Geometrical Dimensionality and Location Movement

It is realized that spatial data is varying over time discretely or continuously. In the course of mobile computation, Sistla, A.P., O. Wolfson et al. (1997) put forward the concept of moving object, whose location is varying over time. In their moving object spatio-temporal data model (MOST), dynamic spatial property (changing location) is represented with a motion vector. The motion vector aims to support continuous change modeling, to facilitate future queries, and simultaneously to reduce data storage volume. MOST model makes possible real-time update of spatial locations of object, but it doesn't emphasize keeping the whole history of spatial data. In contrast, Erwig, M., R.H. Gueting et al. (1997) designed the abstract data type of moving object into their geo-relational algebra. Extended geo-relational algebra has formally defined two abstract data types of moving object (moving point *mpoint* and moving region *mregion*) and relevant operators. The types *mpoint* and *mregion* are defined as mappings from time to space mathematically, that is,

mpoint = time ->point
mregion = time ->region

The type *mpoint* indicates that the location of object is varying over time. The type *mregion* indicates that extent of object is varying over time, e.g., shrinking or expanding. The authors insist that moving line is the trajectory of moving point, so it is somewhat unnecessary to define moving line type.

As opposed to MOST model, extended geo-relational algebra put special emphasis on history maintenance of time-varying spatial data. Another difference is that MOST model pays more attention to implementation with motion vector data structure, but extended geo-relational algebra mainly focuses on conceptual abstraction of time-varying property of geographical objects. It is obvious that both MOST model and extended geo-relational algebra classify spatial changes by the joint criterion of geometrical dimensionality and location movement.

2.4 The Criterion of Spatial Variables

Pierre Gagnon, Yvan Bedard and Geoffrey Edwards (1992) categorized spatial changes into three groups, one-entity change, two-entity change and multi-entity change. One-entity changes consist of existence, extinction, location (position) change, direction (orientation) change, shape change and size change of an entity. Two-entity changes consist of spatial relationship (topological relationship) changes between two entities. Multi-entity changes are population changes formed with 3 entities or more, including location (position) change, direction (orientation) change, shape change and size change (cumulative size change or population size change) and change of spatial distribution type of a population. The cumulative size is the summation of all individual sizes of entities of a population. When combined with the number of entities, it provides "presence rate". The spatial population size corresponds to the size of distribution area, when combined with the number of entities, it provides "occupation rate", and when combined with cumulative size, it provides “spatial density”. There are three types of spatial distribution, regular, random and grouped distributions. This change classification is referred to be based on the criterion of spatial variables, spatial variables of a single entity (location, direction, shape and size) and spatial variables of multi-entity (cumulative size, population size and spatial distribution type).

2.5 The Joint Criterion of Spatial Variables and Geographical Functions

Christophe Claramunt and Marius Theriaut (1995, 1996) posed three types of spatio-temporal process: (1) the evolution of a single entity; (2) the processes involving functional relationships between several entities; (3) the evolution of spatial structures involving several entities.

For the evolution of a single entity, there exist three types of process:

- Basic processes including appearance, disappearance and spatial stability to allow representation of attribute variation without spatial effects;
- Transformation processes involving changes in shape or size, including expansion, contraction and deformation (shape modification without size change);
- Movement processes involving only position changes, including displacement and rotation.

For the processes involving functional relationships, it can be grouped into two categories:

- Replacement processes involving a sequence of entities of comparable types that accomplish the same function or occupy the same position in space (without necessarily having identical locations), e.g., succession and permutation.
- Diffusion processes involving a transfer of characteristics between two or more spatial entities. It seems useful to distinguish between production (creation of new entities by actions of one or more entities of different natures), reproduction (creation of new entities by actions of essentially identical entities called parents) and transmission (modification of characteristics of a receiver due to influence of a transmitter). Each process carries a precedence constraint. Contagion is a specific form of diffusion.

For the evolution of spatial structures involving several entities, three restructuring processes are introduced. They are splitting, union and reallocation.

It is easy to know that the change classification of single entity is mainly based on spatial variables (shape, size, location, direction), and functional relationship evolutions on geographical functions. Also, some basic processes of single entity and spatial structure evolutions are associated with changes of object identity

2.6 The Joint Criterion of Entity Identity and Geographical Functions

Kathleen Hornsby and Max J.Egenhofer (1997, 1998) proposed a change classification based on object identity and a set of operations that preserve or change object identity. In conjunction with geographical functions, they defined four kinds of change (or operation): (1) transitions (concretely, transition between object existence and object extinction, issue transition, and separate transition); (2) identity operations on a single object (creation, destruction, continuing existence, continuing non-existence, and equivalent reincarnation, same reincarnation); issuing operations (spawning and metamorphosis); operations of combining single objects (merge, generate and mix); splitting operations (splinter and division); (3) Operations on a single object and a composite object, i.e., operations of forming composite object (aggregation, compound, union, amalgamation and combination), operations of splitting composite objects (secession and dissolution); (4) Operations of selecting an object or a portion of an object.

3 PRIMARY SPATIAL CHANGES

From the above investigations, we can see that spatial changes are usually described in four respects, i.e., spatial property change, object identity change, spatial distribution change and functional change. Among them, functional change is application dependent, and is number-varying. In practice, functional changes can be explained at different levels of abstraction. Thus, in a general form, we can define various changes at three levels, property change, object change and scene change. Scene change is similar to spatial distribution change, which is an overall change composed of object changes and property changes. At the same time, we can recognize time semantics with three time-varying patterns, discrete change, stepwise change and continuous change.

3.1 Three Levels of Spatial Change

In the bottom-up order, three levels of spatial change are spatial property change, spatial object change and spatial scene change (Figure 1). Spatial property change refers to geometrical property change and geometrical dimensionality change. Spatial object change is related to change of object identity. Spatial scene change is composed of spatial property changes and spatial object changes, and at the same time spatial scene change as a whole has its own properties, as given in previous population change.

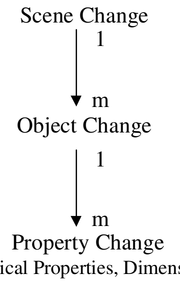

Figure 1. Three levels of spatial change

3.1.1 Spatial Property Change. We argue that primary spatial properties, in a vision sense, consist of location, distance, direction, shape and size. Location may be absolute or relative value of object in relation to a reference framework. Distance may be absolute or relative value between an object and a referent. Direction may be intrinsic, extrinsic or deictic. Size and shape are overall properties of a set of basic spatial units. Absolute size is measured with the number of atomic equivalent spatial units. Relative size is a partial ordering relation between an object and a referent. Shape is often described with contours (convexity, concavity, the chain of vertices), component approximation or compact ratios. Besides, in terms of geometrical dimensionality, spatial objects fall into three groups, point, line and area objects. Accordingly, we can obtain a set of primary spatial property changes, i.e., {location change, distance change, direction change, shape change, size change}, and geometrical dimensionality changes (point change, line change, area change). When geometrical dimensionality changes are combined with location change in set of primary spatial property changes, it turns out to be a set of moving object changes, {moving point, moving line, moving region}, by O. Wolfson, R.H. Gueting, et al (1997). Figure 2 shows a set of primary spatial property changes for a region object.

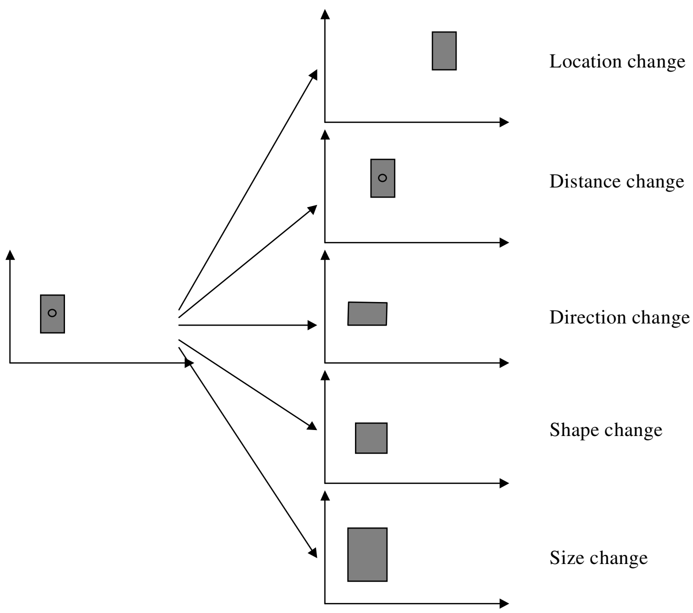

Figure 2. Primary spatial property changes

3.1.2 Spatial Object Change. Spatial object change is associated with object identity. According to mapping relationships between source objects and result objects, we define six kinds of spatial object change (Figure 3):

1) 0:1 change, which indicates that an object is born. Equivalent words have existence, appearance, creation, birth, etc.
2) 1:0 change, which indicates that an object died. Equivalent words have extinction, disappearance, destruction, death, etc.
3) 1:1 change, which indicates that an object is transformed into other object. If source object is the same as result object, then the change is property change. Otherwise, the change is metamorphosis in (Kathleen Hornsby and Max J.Egenhofer, 1997, 1998).
4) 1:m (m≥2) change, which indicates that source object is divided into several result objects in the form. The source object may be included in the set of result objects. If all result objects are the same as source object in essence, then the change is reproduction. If one of result objects is the same as source object and others are different essentially, then changes may be spawn, splinter or production. If each result object is different from source object, then changes may be division, dissolution or secession.
5) m:1 (m≥2) change, which indicates that multiple source objects are aggregated into a result object in the form. If result object is the same as one of source objects, then changes may be accommodation or enlargement. If result object is different from anyone of source objects, then changes may be merging or generation.

6) m:n (m,n≥2) change, which indicates that m source objects produce n result objects in the form. Changes may be property inheritance, passing on, permutation, exchange or object reallocation.

Relationships	Object Changes	Graphs	Geographical Functional Changes
Object —0→1— Object	Existence	A (dashed) → A	
Object —1→0— Object	Extinction	A → A (dashed)	
Object —1→1— Object	Transformation	A → B	Property changes (B=A) Metamorphose (B<>A)
Object —1→m— Object	Splitting	A → B_1, B_2, ..., B_m	Reproduce (B1..m=A) Spawn, Splinter, Produce (B1=A, B2<>A) Divide, Dissolve, Secede (B1..m<>A)
Object —m→1— Object	Merging	A_1, A_2, ..., A_m → B	Accomodate, Enlarge (A1=B) Merge, Generate (A1..m<>B)
Object —m→n— Object	Reallocation	A_1, A_2, ..., A_m → B_1, B_2, ..., B_m	Property Succeed, Pass on, Permutate/Exchange Objects Rellocate

Figure 3. Spatial object changes

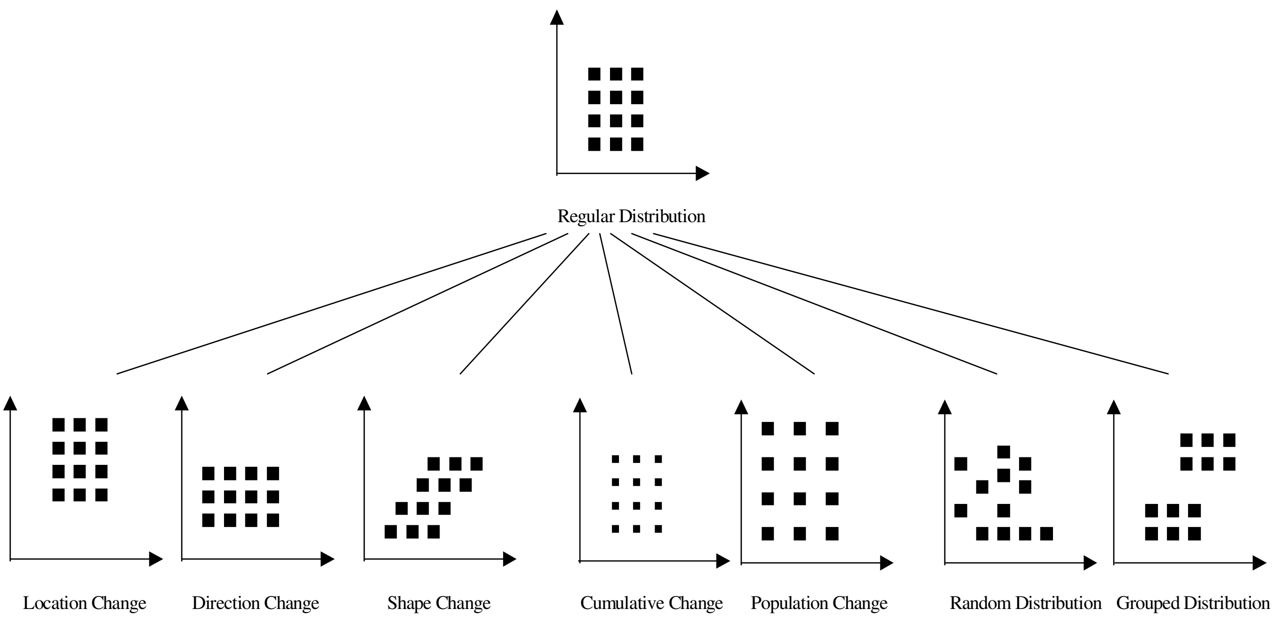

Figure 4. Primary spatial scene changes

3.1.3 Spatial Scene Change. Spatial scene is distribution of a set of spatial objects, but as a whole it has its own properties. Analogous to population by Pierre Gagnon, Yvan Bedard and Geoffrey Edwards (1992), for a spatial scene, its primary changes have location (position) change, direction (orientation) change, shape change and size change (cumulative size change or population size change) and change of spatial distribution type (regular, random or grouped distribution), as shown in Figure 4. Spatial scene change is usually caused by changes of local objects.

3.2 Detailed Time Semantics

In time dimension, time semantics are enriched by three time-varying patterns, i.e., discrete change, stepwise change and continuous change (Figure 5). Three time-varying patterns structuralize temporal data, certainly including spatio-temporal data.

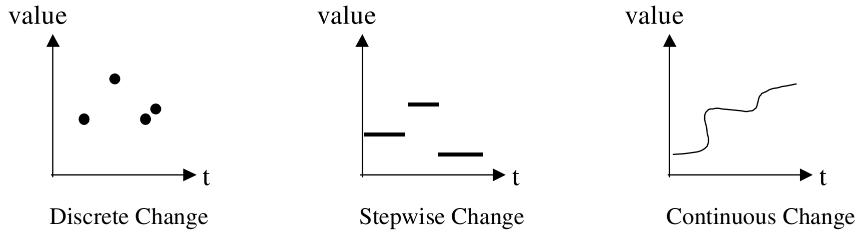

Figure 5. Primary temporal changes

4 CONCLUSIONS

Motivated by previous work, in this paper, we focus on studies of spatio-temporal semantics modeling in spatio-temporal databases. Following the time semantics of event-sequence, we attempt to explore various events involved in spatio-temporal databases. Specifically, we define spatial changes at three levels, scene change, object change and property change. At the level of property change, a set of primary spatial property changes (location change, distance change, direction change, size change, shape change), together with geometrical dimensionality changes (point change, line change, area change), are innovatively proposed. At the level of object change, we present six kinds of object changes in terms of mapping relationships between source objects and result objects. At the level of scene change, a few of the whole changes of scene and distribution type changes are given. Advanced various spatial changes (or spatial events), as a central part of spatio-temporal semantic modeling, are expected to bring closer theory and applications of spatio-temporal databases.

However, our work is still very initial. Further studies are needed to do in next days. The first following thing is to seek cognitive evidences for proposed spatial changes towards a complete taxonomy of changes. The second is to add spatial relationship change to our change classification. After all, as proved experimentally by J. Piaget and B.Inhelder (1956), topological relationship is a kind of fundamental spatial knowledge as well as geometrical metrical knowledge. The third is to formalize changes qualitatively or quantitatively for a theory of spatio-temporal semantics model. The last one is how to implement spatio-temporal semantics with data structures (explicit semantic modeling) and data operations (implicit semantic modeling) for a physical spatio-temporal database system.

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