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# Event-based semantic visualization of trajectory data in urban city with a space-time cube

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*Abstract:* - Visualizing the implicit information of trajectory data is very important for analyzing human activities and is of great value in the decision making process. The objective of our research is to provide a semantic visualization method for trajectory data and the result of analysis. To format the trajectory data, we propose an object-oriented abstract data type (ADT). An event, which represents the human activities in our ADT, is a critical element for analysis enhanced with two special attributes: a semantic-based relationship to extract implicit information; and semantic-based levels of details (LOD) as a standard for the processing of raw data. The proposed visualization concept has been implemented in a prototype system with a space-time cube. Further information is achieved by internal queries making use of semantic attributes and is shown in an advanced user defined space-time cube, which displays richer information. The results of the experimental prototype system suggest that the proposed visualization method is feasible and flexible.

*Key-Words:* - visualization, trajectory, semantic, spatial temporal, topological, event, time-space cube

## 1 Introduction

With the popularization of GPS devices, a flow of location data, known as trajectories, rushed into our life but is only available as sample points which cannot be used without processing. Many works have been making use of trajectory data, mainly for modeling, storing, mining, and visualization, but mostly focusing only on geometric properties, ignoring semantic attributes. Thus, even after those complex processings, the implicit information is still hard to read and understand from the user's point of view. Therefore, it is necessary to find an effective tool to translate the numerical values into a social language. Actually, since a trajectory is a record of human activities, it naturally contains a contextual social knowledge and can be described using semantics. Using semantics, the queries performed on these data are well understood by normal users.

The main contribution of this paper is to propose a visualization method of trajectories based on the time-space cube and semantics. This method is able to display the results of complex spatio-temporal queries and could therefore give the users a better understanding of these results. The rest of this paper is organized as follows: Section 2 is a review of the related works. Section 3 gives our identification of a semantic-based topological trajectory data. To verify the feasibility of our method, we present a use case: query, analysis and plan weekend life by an event-based visualization system in section 4. Section 5 concludes and shows further research directions.

## 2 Previous Work

*A trajectory* is the user defined record of the evolution of the position (perceived as a point) of an object that is moving in space during a given time interval in order to achieve a given goal, which is a segment of the spatio-temporal path covered by a moving object [3]. *Semantics* is a critical concept which has several explanations according to different subjects. In this paper, semantics has two meanings: the semantic attribution of the city, and the meaning of human activity, for which, semantics are used to describe and explain their movements and in return, new knowledge will be generated.

To transform the raw trajectory data into an object-oriented description, Spaccapietra and al. [3] proposed a stop and move description, which is a formal definition for modeling the trajectory data. This basic idea of stop and move has then been widely used or expanded depending on applications, such as in [2], Stops are patterns for frequent points in some regions. In [8], stops are used to regulate the interval in one place; [6] added more restrictions to stops and moves from the geographic perspective; in [1], semantics is added to link stops to important places, the same basic idea is also used in our paper.

For visualization, the main methods can be classified in two categories: 3D time-space cube and 2D baseline. [5] can be referenced as an important index because it contains empirical and statistic based experiments to compare those two methods. The results show that the 3D time-space cube has a strong ability to provide integrated

information, a comprehensive control of the whole case and a better capacity for increased data sets. In the early 70s Hägerstrand [12] developed a graphic view with time as an additional spatial dimension, and this constituted the original time-space cube. He suggested a three-dimensional diagram, the so-called space-time cube, to show life histories of people and how people interacted in space and time. Kraak [13] demonstrated the time-space cube in an extended interactive and dynamic visualization environment, with options to move slider planes along each of the axes and highlight a period in time or location in space. [14] built the GeoTime visualization concept used to improve perception of movements, events and relationships as they change over time within a spatial context. In order to enhance the interactive manipulation and to reflect the detection of spatio-temporal clusters of events, based on the original space-time cube, [4] presented an advanced version with operations for changing the viewing perspective, temporal focusing, and dynamic linking with a map corresponding symbols. For more details, we refer to [11], which offers a survey of technologies and tools related to data exploration.

### 3 Semantic Abstract Data Type for Trajectory

In this paper, we focus on the semantic visualization work supposing that the original data can be clustered into our defined Abstract Data Type (ADT). We used the classical concept stops and moves to abstract the trajectory data, but compared to previous work, we link each stop to an event, focusing more on events information, which has a significant meaning for the analysis of human activities. Two important attributes have been added to enrich the semantics and classify the trajectory data by event: semantic relationship and LOD. The benefits are shown later in the visualization part.

#### 3.1 Abstract data type

The effectiveness of visualization depends on the format of input data. It is better to have a clear definition of the trajectory elements. For each trajectory, there are four main parts: person, temporal, spatial, and events which can be respectively linked to who, when, where and what. Among those, the event (what) will be the critical element, responding to semantics, mainly used in our analysis.

In particular, the spatial-temporal parts are represented as moves and stops (turning points). The moves represent a location transformation, and the stops, known as events in this paper, link to important activities such as staying in some places. We ignored activities with an obvious location transformation, such as a bike race, and where the moves could also link to an event, and we chose some

typical urban city life as research objects. The trajectory elements are summarized as follow:

- *Person* as “who”, is the main subject which performs activities in the social world.
- *Stops* as “when +where” are important state change points, which should be obligatorily linked to events
- *Moves* are important state change in both of the temporal and spatial, linking stops.
- *Places* represent the semantic urban areas.
- *Events* as “what” can be recognized as social activities, distinguishing three components in such data: space (where), time (when) and thematic (what), which will be mainly used for later visualization and analysis.

As we introduced before, the trajectory is constructed by the elements above. Each of them can be used as input conditions to query out trajectories, or be queried out by the relationship to the other elements. Complex conditions will also be accepted. In the sequel, we present a few examples of our methods (only by their names) shown in Fig. 1:

Basic methods for querying trajectory data:

- `searchTbyPeople(trajectory)` – use people id “who” to query out the corresponding trajectory
- `searchEbyP_PType(event)` – list out events belonging to certain people happening on certain kind of place.

Special methods are provided for later analysis and visualization, making full use of the two attributes of “events”:

- (1) A semantic-based relationship is defined to find out the implicit relationship between the trajectory and a city area or between trajectories, and can even discover social relationships between people as shown in the later use case. Important methods are:
  - `searchMeet(event)` – to find group activities, i.e. when people stay in the same place at same time.
  - `searchAcross(event)` – to find the event that happened in the same place.
- (2) A semantic-based LOD of trajectory data, which is different from the methods focused on the numerical value, presents a new standard for the filtering of sample points according to different applications, and at the same time, acts as an exact definition of the data used in our visualization system. Examples are:
  - `searchTinLOD(trajectory)` – switch to another level. Each trajectory has three versions, distinguished by data quantity, which can be set to different values depending on the application.
  - `searchEinLOD(event)` – get the events in different LOD.

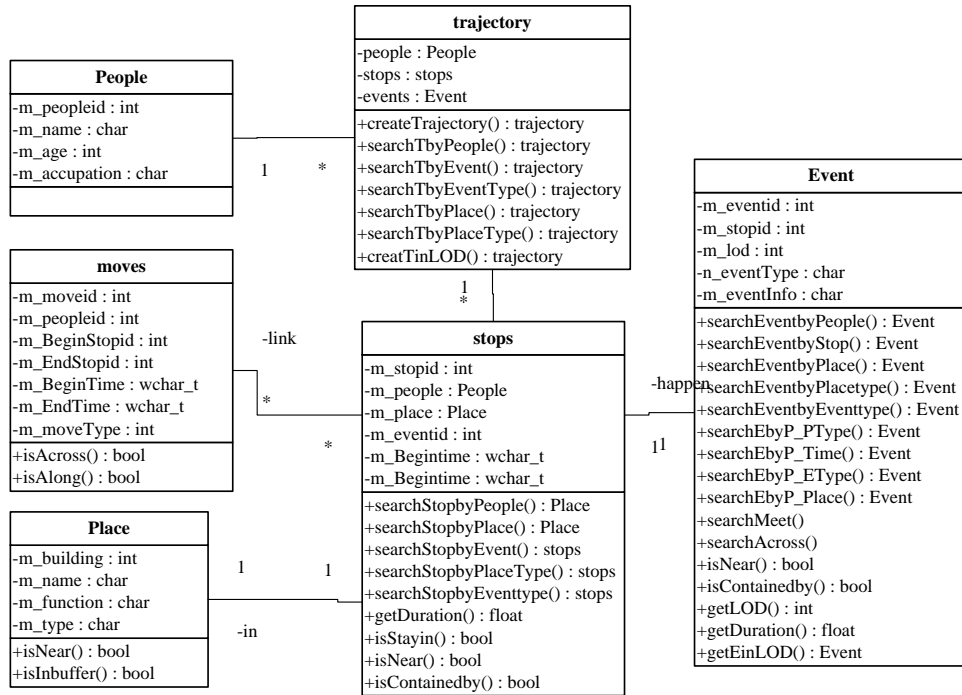


Fig. 1 object relationship

### 3.2 Semantic relationship with events

Discovering the implicit meaning of events plays an important role in studying trajectory data. From the aspect of linguistics, an event is always described as somebody is doing something at a certain time in a certain place. This syntax rule can be summarized to a “what = who + when + where” formula, which will be used in the visualization system. Therefore, an event can be decomposed into three parts to generate different topological relationships.

#### (1) “Where”- Spatial topological relationship

The GIS science provide a clear definition of a spatial topological relationship, which explains the “where” factor. When visualizing, spatial data (points, lines and surfaces) are always used as basic geometric data type, representing ground features. Many topological relationships between A and B can be specified using the nine intersections model [17]. If we define the relative spatial positions as intersections between interior, boundaries, exterior of A, B, they can be arranged as a 3 by 3 matrix. The result can then be *disjoint*, *contains*, *inside*, *equal*, *meet*, *cover*, *covered by*, and *overlap*.

#### (2) “When”- Temporal synchronization relationship

Allen relations [18] define thirteen base relations to capture the possible relations between two intervals, which can be used as an efficient standard for our temporal topological relationship between trajectories. They are classified as: *before*, *meet*, *overlap*, *start*, *during*, *finish*, *equal*. As we mentioned before, the most important

parts of a trajectory are the events, which can be considered as intervals, or a period from the aspect of time dimension “when”. With this approach, we can figure out the time sequence of the activities, and find out the best way to model city life.

#### (3) “Who”- Social relationship

Social relationships between people can also be analyzed based on the idea of topological relationship in space and time. But aside from these joint points in space or same instants in time, the objects used to link two people together are events, as shown in Fig. 2 Social relationship. This means that social topological relationships could be a derivative result of the integration of space and time.

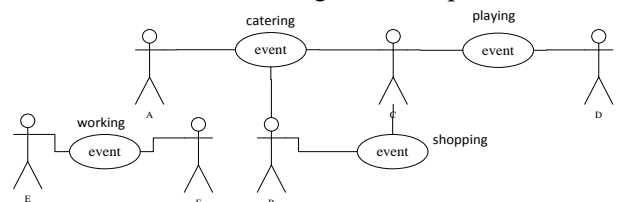


Fig. 2 Social relationship

By integrating the three perspectives, topological relationships can be divided into two categories: the first one is between trajectory and urban area, which is a pure spatial data relationship, used to meet the general query; the second one is between trajectory and trajectory, which is used for a comprehensive analysis of the social meaning of the events. Important relationships are listed in Table 1 and Table 2.

(1) trajectory & city area (refer to the method in place, stop, and move)


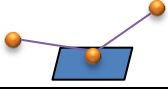
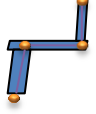
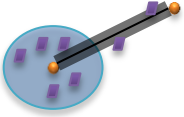
Relationship	Object description	Example	Representation
staying	A stop located at a place (represented as a vertical line).	Tom and Jerry have dinner at a restaurant.	
Cross	A trajectory passed by a place during position transfer.	Tom goes to school from his home, passing by the square.	
Along	A move is along traffic area.	Tom goes to the post office through Peking Road.	
Near	A number of urban areas are located in the buffer area of the trajectory. The buffer size could be defined by users.	Tom chooses this road because it is convenient to buy something in the grocery near there.	

Table 1 Relationship: trajectory and place

(2) trajectory & trajectory (refer to the method in stop, and event)

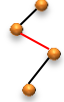


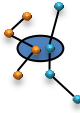
Relationship	Object description	Example	Representation
contains	All the moves can be extracted as a single small trajectory, contained in the complete one.	Jerry has spent a few hours in the park yesterday.	
Meet	There is at least one common stop, which means two people passed by the same place at the same time.	Tom and Jerry appeared at a place at the same time.	
Across	A special meet, which means two people passed by the same place but not at the same time.	Tom and Jerry have been to the same places during the day but not at the same time.	
Near	Some stops appeared at the same time in the same region. (for this one, the definition of the "region" corresponded to different LOD)	Tom and Jerry had BBQ in the same park but in different region of the park.	

Table 2 Relationship: trajectory and trajectory

Since the implicit meaning of the trajectory is people's activities, the topological relationship between trajectories can also be recognized as a method to explain the relationship between people activities. Of course, the social relationship can be generated from that.

### 3.3 Semantic Level of details of events

The raw location data is always available as sample points, it cannot be used directly for analysis, and only the filtered *turning points* have a significant meaning to the trajectory. However, the turning points, here the events, are not a clear concept, for different purpose. In [10], Pfoser and colleagues presented a set of attributes for the moving objects with the attributes speed, agility and direction, for that, turning a corner, speeding up are events; and from the perspective of geovisualization like [13], all the sample points are recorded. Clustering seems a good approach to get these turning points, but currently,

most of those technologies are based on numerical values, ignoring the semantics. [8] presented a spatio-temporal clustering method based on speed and [16] with time. In this paper, we propose semantic-based LODs, based on the meaning of the activity and the application it belongs to, which will critically decide the data quantity of trajectory as shown in Fig. 3.

#### LOD 0: Event-based LOD.

In this level, the moves and stops are generalized based on events. We focus on the places where people stay, ignoring the outside travelling details. Our objective at this level is to provide a general impression of the whole trajectory, focusing on the human activities. Some of the questions can be answered like:

- How many places of interests did they visit? And where are those places?

### LOD 1: Traffic-based LOD.

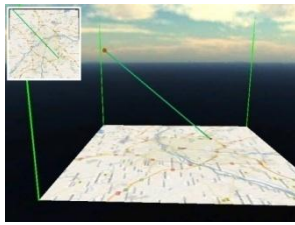
In this level, we care more about the travelling details; more city constructions will be included. Compare to LOD 0, the most important difference is the traffic region, such as the bus stops, roads, the bridges, the ship channel, and etc. Questions can be as follows:

- Why did Tom choose this way to the park? Which stop has the highest flow of people?

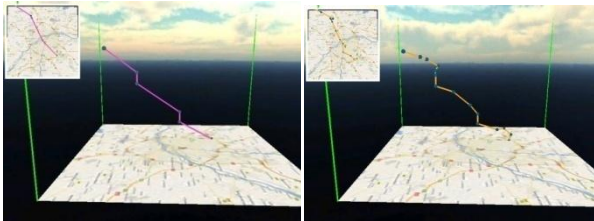
### LOD 2: Location-based LOD.

In this level, many more points will be taken into account, most of which have no relationship with the city areas. With those detailed location data, we can zoom out the situation in one region and take more factors like weather, society and etc. into consideration. The question could be:

- What happened on this road during that period when the highest flow occurred?
- How about the influence of the rain and wind to the walking speed of pedestrians?



(a) LOD0



(b) LOD1

(c) LOD2

Fig. 3 trajectory data in different semantic-based LOD

For different LODs, the quantity of data is different, the higher LOD, the more precise, but the less semantics. LODs also have an influence on the topological relationship we defined in next chapter. Though regulation is feasible, the results of judgment might be totally different because of the data.

## 4 Experiment: case study

In order to illustrate the capabilities and feasibility of our visualization concept, a useable prototype has been developed. In this paper, a use case about weekend activities in urban city is studied. The trajectory is formatted in our defined ADT in LOD0, since more semantic information is event-based. A series of queries is performed making use of the semantic information and of the advanced topological relationships.

### 4.1 Simple query

The space-time cube has been implemented as view tools in this paper. For each query, the users select people from a drop-down list, and use time slider to input the time and to move a temporary map along the time axis. Multiple interactions are allowed with dragging and rotating. An additional small view is locked in the vertical direction to provide orthography. The result of the query makes use of the “who, when, where, what” grammar to be formatted into a complete sentence, which is easy reading for normal users. A query is shown in Fig. 4. Other base queries with more conditions have also been realized.

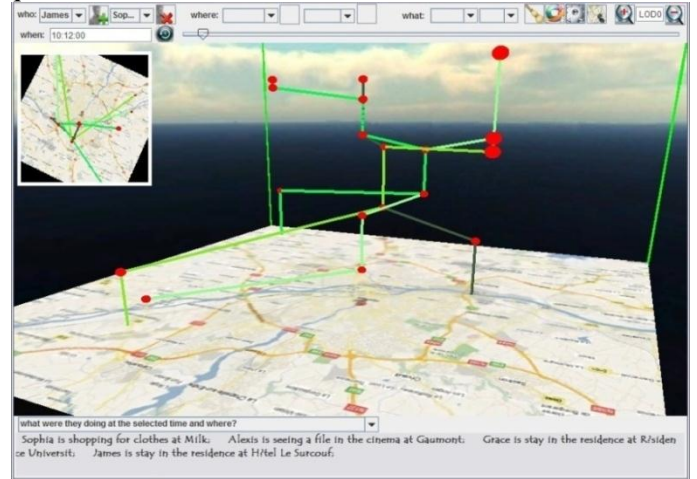


Fig. 4 simple query about four peoples activities in certain time

### 4.2 Query extension

Further queries have been developed based on topological relationships. The events in the database are stored with unique id, linking the places and persons as jointed points. For instance, a group event means there is a “meet” relationship among the trajectories. The events on one place can also be queried, they have an “across” relationship. Therefore, the social relationship of people and their interests of the activities and places can be found out. Here, two analysis functions have been implemented: place search and user defined cube.

#### 4.2.1 Place search

As illustrated in Fig. 5, the expanding search function provided suggestions about the location of the users. Four queries are performed making use of the semantics and relationships between trajectories and area as we defined:

1. searchTbyPlaceType() – to select the place with the given function;
2. searchMeet() – to find out group events as shown in the left picture;
3. searchEventbyEventtype() – to find out the events having the desired subject.
4. isNear() – to find out places in buffer area as shown in the right picture.



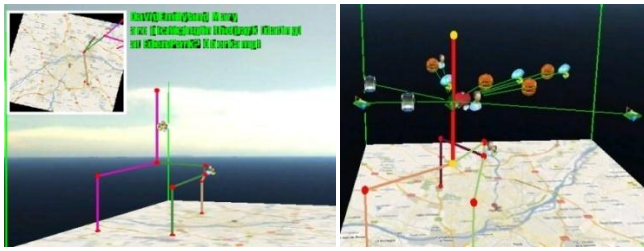


Fig. 5 place search: a picnic place

#### 4.2.2 User defined time-space cube

Normally, a space-time cube is designed with x, y axis to give the geographical position and with a time axis to show the temporal attribution. We also performed this

common space-time cube in our main interface. But actually, the cube can be expanded with more dimensions. If the meaning of x,y,z axis can be modified and optionally redefined, more information can be contained and the analysis result can be shown in the graphic user interface. In Table 3, a set of data is shown in five extended time cubes; each result shown in the cube is achieved by internal complex queries. All the results are computed by the methods of the «Event» class introduced in 3.1.

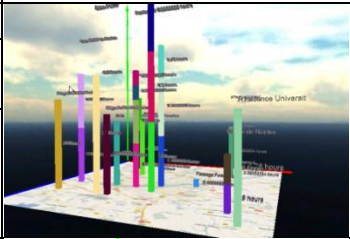
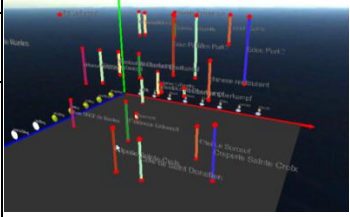
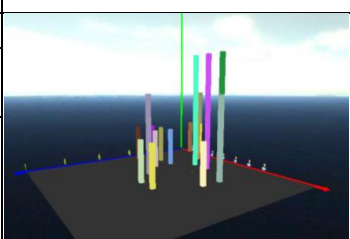
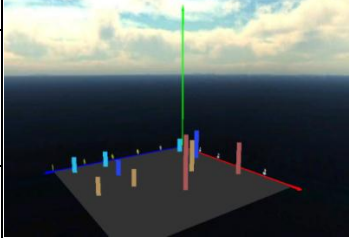
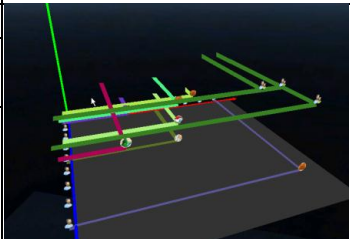
X	Y	Z	View
<b>Example Question :</b>			
<b>Explanation:</b>			
<b>Where</b> ( location x, y on the map)	<b>How long</b> (Time_consuming)		
Which place do people prefer to stay in? and how many people had been there? ( searchEventbyPlacetype(String placetype) )			
All the place meeting the condition will be shown, the events that happened on the selected placed are queried out. Different colors represent different stops and show how many people been there.			
<b>What</b> (EventType)	<b>Who</b> (people)	<b>When</b> (Time)	
What kind of activities are popular during the weekend and when? (searchEbyP_Etype(String eventtype))			
the events belonging to one person are in the same color. Events having happened around the same period have the same height. For example: we can find that most of the peoper prefers to have lunch from 12:30 to 14:00. Same subject of the activies have same y. So most of them prefers eating and shopping.			
<b>What</b> (EventType)	<b>Who</b> (people)	<b>How long</b> (Time_consuming)	
How long do people spend on these popular activities? (searchEbyP_Etype(String eventtype, double duration);			
Compared to the last one, it is a much easier question, the height of the box shows the time people spent on one kind of things. And it looks that there are three people who spent a really long time on shopping.			
<b>Where</b> (Place)	<b>Who</b> (people)	<b>When</b> (Time)	
Which kind place do people prefer to go? What are the subjects of peoples' activities in this kind of place? (searchEbyP_Etype(String placetype))			
The information in this cube is quite like that the third one. Only diffence is that, y-axis is not the events but the function of places.			
<b>Who</b> (people)	<b>Who</b> (people)	<b>When</b> (Time)	
What are the relationships among these people? (searchMeet(ArrayList<people> p))			
Each two people who have a contact or common event will have an intersecion points. Sometime as shown in the picture, the dark blue have two insecion points which means, same events with more than two people.			

Table 3 five typical user-defined space-time cube

The prototype of the visualization system demonstrated that our visualization concept can be implemented into a visualization system, and is effective to query out and render some implicit information.

## 5 Conclusion

In this paper, we proposed an ADT and a semantic-based LOD to format the trajectory data, and some new topological relationships for later analysis. By comparing the two main visualization methods, we choose a space-time cube as view interface, an advanced user-defined time cube is proposed in order to contain more information and expand the dimensions. An experiment proved that our tools provide direct view of trajectories and analysis result for users; the information retrieval can be achieved without a direct database interaction which means a higher usability. However, more experiments should be done with different LOD, providing different analysis with LOD1 and LOD2. Dynamically generated methods for trajectory LOD should be added at the same time.

Further research works will look towards the development of a more complete visualization system with higher interactive operations for decision-making. The analysis function should integrate more data mining algorithms as well as GIS spatial analysis methods to make full use of the geographic data. The spatio-temporal data and semantic information is an effective new breach for us to explain human activities.

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