An Approach to Visually Relate Annotations with GPS-tracks in the Space-Time-Cube

BIINGBING SONG

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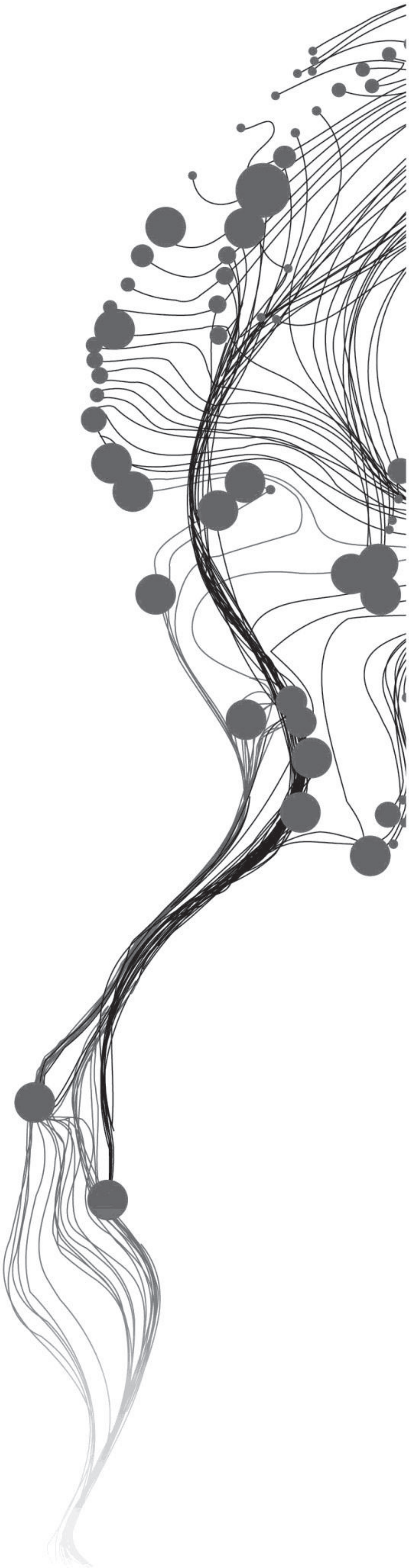
SUPERVISORS:

Prof.Dr. M.J. Kraak

Dr. C.P.J.M. van Elzakker



An Approach to Visually Relate Annotations with GPS-tracks in the Space-Time-Cube

BINGBING SONG

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SUPERVISORS:

Prof.Dr. M.J. Kraak

Dr. C.P.J.M. van Elzakker

THESIS ASSESSMENT BOARD:

Chair: Prof.Dr.Ir. M.G. Vosselman

External Examiner: Dr. I. Delikostidis

Advisor: I. Kveladze

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ABSTRACT

The Annotated-Space-Time-Paths (A-STPs) able to represent more attribute information than the conventional STPs. However, there is a high risk of visual clutter.

In this study, multiple views are used to visualize the A-STP and visual clutter problem of the A-STP is discussed. Visual clutter can be introduced by three situations, multi-scale, multiple trajectories and high-density annotations. Solutions for each of the three situations are provided, discussed and evaluated.

The theory of time geography and Space-Time-Cube (STC) is illustrated first. It emphasizes that time as well as location is a significant component of geographic object and STC is suitable to display the A-STP. Some use cases are discussed and some of their concepts can be applied in this research. Then the annotation and STP are analyzed. They are both geographic objects and their combination is A-STP. Their characters are analyzed. The "Triad framework" is used to link annotation and STP. To visualize the A-STP, visual variables are analyzed both in 2D space and in 3D space and their applications on annotation and STP are discussed. Based on the above aspects, a conceptual framework is created. At the overview level, the visual clutter introduced by high-density annotations can be solved by aggregation. Visual clutter introduced by multi-scale and multiple trajectories are solved at zoom/filter visual level. Finally, a usability evaluation is made to explore different solutions for annotation aggregation at the overview level. Advantages and disadvantages of each solution were stated by participants.

Key Words: STP, annotation, A-STP, visual variables, visual clutter, multi-scale, multiple trajectories, annotation aggregation

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1. INTRODUCTION

1.1. Motivation and problem statement

Background

The evolution of human beings is related to the process of people exploring our planet. Geographic information, as the results of exploration and as assistance to explore further, is increasingly important and close to people's everyday life. The map is one of the main products of the geographic data handling process. According to Kraak & Ormeling (2009), maps help people better understand the geospatial relationships and patterns. Due to the new techniques of data acquisition, the amount of data has increased. This helps to produce more map products but at the same time makes data organization and analysis more complex. Geographic visualization, which is a powerful data exploration technique, exploiting the ability of current computing technology to dynamically analyze and display large amounts of information (Edsall et al., 2000), is an effective way to solve this problem. Many different visual representations like animation map and Space-Time-Cube (STC) are increasingly important and widely used.

Nowadays, the geographic visualization serves not only experts but more and more the public as well. "Our dynamic geo-community currently witnesses a trend which demonstrates an increased need for personal geo-data", stated by Kraak (2003). In addition, Goodchild (2007) said that the public is encouraged to make their own maps. This trend is ascribed to the development in two main aspects, data acquisition and data sharing.

Data Acquisition

If the public wants to share personal geo-data, they usually share information about where they have been (the travelling trajectories) and what activities they have done (photographs, stories etc.). Maps and GPS devices are the most popular ways to collect the trajectories. The GPS devices are easy to take, or equipped on vehicles. They are also often part of smart phones or cameras. This research focuses on GPS data. This data consists of three components, x, y (they together record the location) and time.

Besides the geospatial data people want to share, they also want to publish additional data of the activities. This type of data could be considered as annotations of the trajectories Annotations can be products like photos, videos, voice, notes etc. They are a common and consistent method to add extra information (Kim et al., 2009b). One characteristic of annotations is that a time component is always included.

According to Peuquet (1984), geo-data can be described by three components: location (where), attribute (what) and time (when). Both GPS data and annotations have these three components. For GPS data, the location and time information are recorded directly, and the attribute information might refer to the person who 'walked' the trajectory. The recording of the annotations gives the where and when and its content can be seen as the attribute (what).

Data Sharing

To share their data, the public need to publish it. To visualize the GPS tracks with annotations, different visual representations are available. Google Earth, for example, provides them a platform to share personal data, both annotations and GPS tracks. Annotations are symbolized based on categories and attached on the 2-D map; GPS tracks are also shown on it and the time is represented by animation. But the annotations and

GPS tracks are separately represented; annotations produced during the trajectories cannot be linked to them. Furthermore, there may be visual problems because of the annotation density (Harrower & Fabrikant, 2008). Additionally, because of the human perceptual limitations, the trajectory animation is more suitable for showing movement tendency than for exploration.

Are there suitable representation options? According to Hägerstrand's (1970) time geography, the location and time are inseparable. And he used the Space Time Cube (STC) to represent this combination. This also is suitable for GPS data, for which location and time are two indispensable components (x and y axes represent space and the z axis represents time). So, STC could be chosen as the visualization environment of GPS tracks. The annotation could also be position in the STC. When the annotations are linked to the trajectories in STC, it will give viewers both the geo-data and non-geo-data and enable them to explore the data.

Problem Statement

Based on the above statements, it seems that when using the STC to show annotations in combination with GPS tracks it gives the users and integrated view. However, there are some problems to address.

The first problem is how to relate annotations to GPS tracks in STC visually. From the discussion above it can be learned that both GPS tracks and annotations have three components, location, time and attribute. Because annotations were recorded during the travelling track, the location and time annotations produced overlap that of the trajectory, and thus annotations and GPS tracks can be combined based on this fact.

Even if the annotations could be related to trajectories, there might be visual clutters in some situations. In case of multi-scale trajectory, due to different data densities, the space and time ranges and annotation amount might be greatly unmatched. Not only short time ranges might correspond to long distance and vice versa, but also large amount of annotations correspond to contracted space in STC and vice versa. This leads to problems when to exploring and analyzing the data.

Besides multi-scale problem for one GPS track, there is additional problem introduced when more than one trajectory exists in the STC. They could twist one another in similar time ranges and geographic extents, or they could be separated by either of the above factors. For the former case, it needs to be solved that which annotation belongs to which trajectory. For the latter one, comparing different trajectories should be taken into account.

1.2. Research identification

The main research objective is to develop a method to visually relate annotations and GPS tracks in a STC and provide solutions of visual clutter problem.

1.2.1. Research objectives

The objectives of this research are:

1. To propose the solutions of visual clutter introduced by multi-scale, multiple trajectories and high-density annotations by applying symbology and the "Visual Information-Seeking Mantra".
2. Evaluate solutions of visual clutter to test their advantages and disadvantages

1.2.2. Research questions

The research questions of this research are:

1. Why is the STC used to represent annotations and GPS tracks?
2. What kinds of annotations exist and what are the characteristics of them?
3. How can the annotations and trajectories be linked?
4. How should the different trajectories and annotations be symbolized?
5. What is the visual clutter problem and which situations is it introduced in?
6. How can the visual clutter be resolved?
7. Can the STC handle the exploration of the trajectories with annotations or should other solution such as linked views be introduced? If yes, how do they interact?
8. Implement the solutions based on the designed concepts?
9. What kinds of usability methods are used to evaluate the prototype and what are the results?

1.2.3. Innovation aimed at

There are many researches on visualization of space-time data in STC. Some of them are about adding attributes to these data (like the research of He(2009)). This research extents her work on three aspects. First, annotations are graphically represented as symbols or icons. But this leads to interaction problems when rotating the STC, and when the amount of annotations is large, it will be too massive to visualize. Second, the situation of multi-scale problem is considered. Third, when there is more than one trajectory in the STC, that which annotation belongs to which trajectory becomes a problem and needs to be solved.

1.2.4. Related work

Since Hägerstrand (1970) promoted the time-geography, the time and space were seen as inseparable and the STC was introduced. However, maybe because the interactive viewing environment cannot be easily found, only recently there is increased interest in the STC, which is stimulated by new data sources including GPS (Kraak & Koussoulakou, 2005). Many researches are done on the STC. Some researches focus on the cube itself (Kraak & Koussoulakou, 2005)). Some researches witness analysis on tracks in it. For example, Demsar and Virrantaus (2010) used space-time density to find movement patterns; Vanhulsel, et al. (2011) researched dissimilarity between space-time paths. Additionally, based on the Peuquet' theory (1984), the attribute is also an important component to geo-spatial object or event, but attributes represented by trajectories in STC are limited. Therefore, there are many researches about adding diverse and detailed attribute information to tracks in STC. For example, Kwan and Ding (2008) added attribute data to spatial-temporal life path by analyzing, extracting narrative texts and representing them based on time-geography; Li (2005) designed PCP-Time-Cube and Multivariable-Time-Cube and linked them to STC which also aims on combining attribute and space-time objects; Kapler and Wright (2004) developed a method to visualize and work with spatial, temporal data in a single, interactive 3-D view. What's more, Nannan He (2009) created the Annotated-Space-Time-Path, which attaches annotations to space-time trajectories, and used STC as its visualization environment. In Nannan He's research, she linked annotations to space-time-path based on coordinates and time-stamps; the annotations are attached symbols or icons to the tracks and details of them can be viewed in other windows. For exploration, Shneiderman's "Visual Information-Seeking Mantra" (1996), "Overview first, zoom and filter, then details-on-demand", was used in her research.

1.3. Methodology

The research will be composed by seven phases (see Figure 1.1):

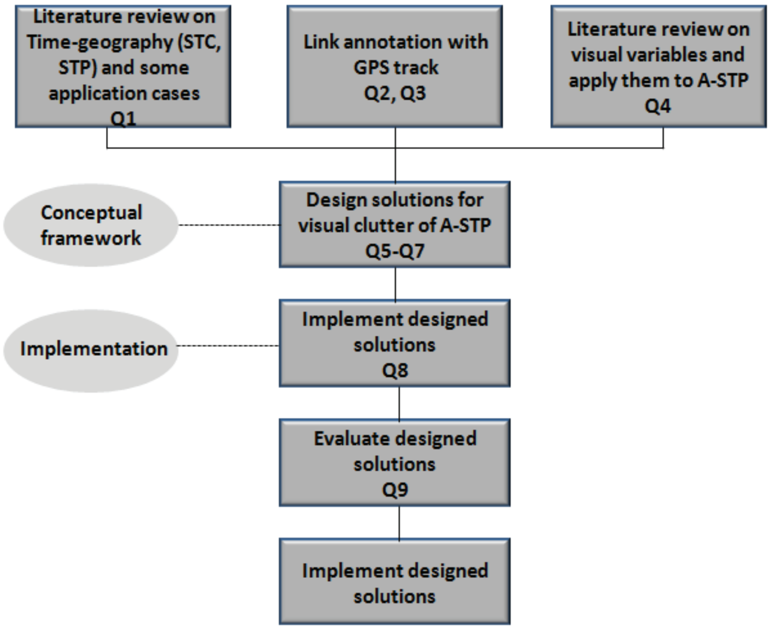


Figure 1. 1 – Main research phases

1. Literature review will be the main approach to study time-geography. The content includes:
    - Concepts of time-geography
    - STP, STC and visualization environment of the STC
    - Some application cases of time-geography
2. Annotation and GPS track will be analyzed. They will be linked based on the "Triad framework".
3. The six visual variables will be reviewed and applied to annotation and trajectories.
4. Solutions of visual clutter problem will be designed.
5. The designed solutions will be implemented.
6. The designed solutions will be evaluated.
7. Finally, analyze the results, derive conclusions and advance recommendations.

1.4. Summary

In the first chapter, the motivation of the research, research problem, objectives and methodology are discussed. The remaining part of the thesis will include 7 chapters:

Chapter 2 will review literature about the concept of time-geography, STC and some application cases of time-geography.

Chapter 3 will illustrate characteristics of annotation and GPS tracks. The "Triad Framework" will be used to link them and create the Annotated-Space-Time-Path. Multiple views will be used as its visualization environment.

Chapter 4 will review literature about the visual variables in both 2D and 3D; then they will be applied to annotation and Space-Time-Path.

Chapter 5 will discuss the visual clutter problem and the solutions will be conceptually designed.

In Chapter 6, the multiple views which are discussed in Chapter 3 and the solutions, which are designed in Chapter 5, of visual clutter will be implemented.

Chapter 7 will execute an evaluation session to test the disadvantages and advantages of different solutions of visual clutter.

The conclusion and future work follows in Chapter 8.

2. TIME GEOGRAPHY AND THE STC

2.1. Introduction

Before 1970, place-based representations and methods were developed in an era when data were scare, computational platform was not developed and questions simpler (Miller, 2003). It ignored the basic spatio-temporal context of human activity.

In 1970, Hägerstrand introduced the concept of the time-geography. The time-geography illustrated that time is such a factor as important as the spatial factor in the analysis of movement of objects. Both the time and spatial factors should be taken into account together, rather than be considered separately.

The time geography is capable of exploring the changes from a people-based perspective (Hägerstrand, 1970; Miller, 2003). The Space-Time-Cube (STC), the most prominent product of time geography, is the graphical representation of time geography. It provides an effective visualization environment to the spatio-temporal data. This visualization tool reproduces the real activities and makes it ready for further exploration.

In this chapter, concepts of time-geography are illustrated first. They are followed by section of the STC, which includes description of the Space-Time-Path (STP) and the suitable visualization environment of the STC (multiple trajectories). In the next section, Kwan's studies and GeoTime are discussed as examples of the applications of the time geography.

2.2. Time Geography

2.2.1. Movement

Hägerstrand's time-geography theory is one of the earliest spatial integrated perspectives for human activity analysis in space-time and also inspired generations of social scientists in the description and analysis of activities in space-time (Kwan, 2000).

According to the concept of the time-geography, movement is a universal behaviour of human beings. Patterns extracted from micro-situations cannot be applied to general cases. Hägerstrand (1970) stated that "It may well be that when a region is given a certain areal size, … it does not matter very much what forms micro-arrangements have happened to take. Such possible insensitivity would, in itself be a problem for analysis". Therefore, the patterns and the tendency of those models cannot and should not be applied to other situations. Movement, on the opposite, is a behavior shared by all of objects, which have the ability to move or even not (static can also be seen as a kind of movement). It is suitable to be analyzed for general purpose and is the basic behavior for analysis of other behavior.

When analyze the movement behaviour, temporal dimension as well as spatial dimension must be considered. Time to dynamic space is similar to an engine to a moving car (Thrift, 1977). Although taking into account of the temporal dimension increases the costs of analysis, ignoring them would eliminate the change and would not allow the analysis of movement. Therefore, combining time and space is required. Not only does the time geography reveal the significance of the temporal dimension and spatial dimension, but also the interaction between them and their joint effect (Kwan & Lee, 2004; Kwan, 2000).

2.2.2. Characteristics of Time

Although time is as important as space, it has its own features and are not similar to space or anything else. Time has the three characteristics, as stated as follows.

The first characteristic is that time "does not admit escape for the individual" (Hägerstrand, 1970). It is one way in forward direction only. The moment past can never go back and pass again. Therefore, you will never observe the overlap of two different moments. Time is also ordered and continuous. One o'clock is always before two o'clock and two o'clock before three o'clock. No one could experience three o'clock before two o'clock. Furthermore, individuals have to pass every moment, no matter whether they move or not. The time just goes in its own pace and wouldn't change for anything.

The second characteristic of time is the limitation. Time is a kind of limited resource. There are only twenty four hours in a day. It needs to allocate to different activities. On every moment, one could only participate in one of the activities at one location. Once an individual takes part in one activity, the period of time is spent on this activity before switching to other activities. It is the participator who decides which activity to take part in for some time period; but other activities have to be abandoned during the time period.

The third one is that time, which is different from money, is un-storable. Time will never freeze, speed up, or slow down, but just goes constantly. Because time cannot escape and jump, it has to be allocated to different activities, one after another. At every time point one must participate in some activity and occupy some spatial position; s/he cannot disappear and after a while appear again as long as he is alive.

2.2.3. Three Constraint Categories on Space-Time

Both space and time are necessary causes of movement. They together can be observed as the environment within which movement processes. Life path, according to Hägerstrand (1970), traces the moving track of an individual starting at the point of birth and ending at the point of death in the space-time environment. It records the information of the individual that when and where s/he is. Because both space and time have limits for individual, plus other limits, the external ones like social and cultural reasons and the internal ones like intension, decision, or past experiences, the life path can hardly be random (Hägerstrand, 1970; Pred, 1984). There are multiple constraints on the life path. In general, they can be generally grouped as three categories, the "capability constraint", the "coupling constraint" and the "authority constraint" (Hägerstrand, 1970). They will be illustrated:

➢ **Capability Constraint**

The type of constraints is the limit because of "biological construction and/or the tools he can command". It includes limits because of predominant time and reachable distance, limits of the "range of voice" or distance of information transformation, and limits as the boundary around the "home base".

➢ **Coupling Constraint**

The type of constraint handles group of individuals when they share the same activities, the same location and the same time period. When it happens, parts of life paths of individuals who participate in this activity will be grouped together and consist of a "bundle". Predetermined time-table is thought to be the reason of it. The "bundle" submits not only the capability constraints of every life path within it, but constraints the group shares.

➢ **Authority Constraint**

The type of constraint refers to the time-space related authority. There are, in reality, lots of domains not admitting free to enter without payment, invitation or competition. This kind of authority again effects life path of individual.

2.3. Space-Time-Cube

2.3.1. Definition of the Space-Time-Cube

Space-Time-Cube (STC) is a part of the time-geography and displays it graphically. It is considered as the most prominent element in Hägerstrand's approach (Kraak & Koussoulakou, 2005). There are three dimensions in the STC model, namely X, Y and T. The X and Y dimensions, which are used to define a plane, represent geographical coordinates, just like a 2D map. The T dimension displays the time (Hägerstrand, 1970). A base map is usually attached to the 2-D plain and marks the precise location of individual(s).

2.3.2. Space-Time-Path

The life path describes the trajectory of an individual in space-time. When put it into the STC model, it is termed as the Space-Time-Path. It is an unbroken trajectory which never goes backward, since time can neither be escaped nor jumped, nor reversed back. The footprint of Space-Time-Path on a 2-D plan (e.g. a basemap) traces the object's movement in space. It could be observed as to project it on the map (Kraak & Koussoulakou, 2005). The footprint on the third dimension, namely the T-dimension, on the other hand records the time on which the object is at some certain location. Through simple analysis, information like how long it takes to go through some distance and the travelling speed of the objects could be figured out. The more is the Space-Time-Path close to be horizontal, the faster does the object travel. A vertical line, which means there is no movement and the object retains at a particular location for a while, is termed as "station" (See Figure 2.1).

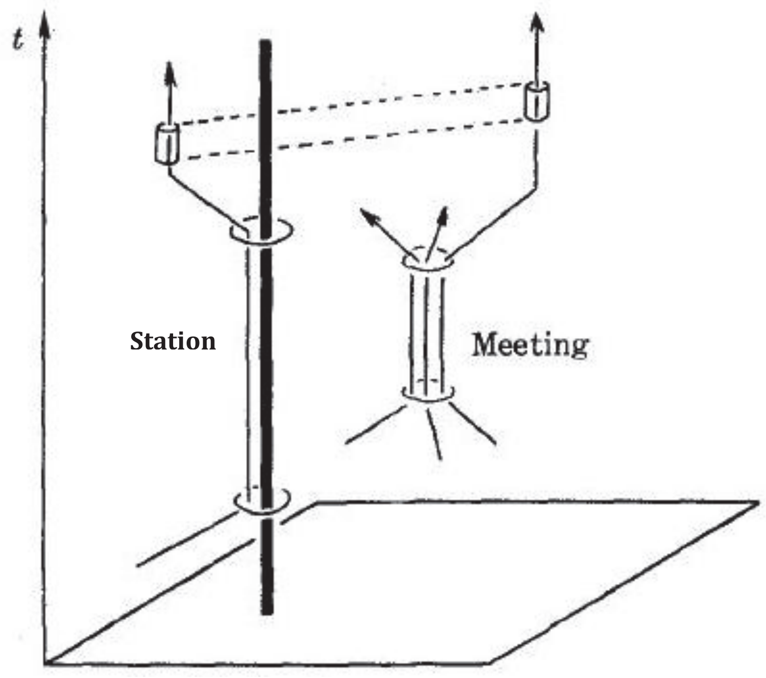


Figure 2. 1- Station (Left) and Bundle (Right) (source: Hägerstrand (1970))

The three types of constraints present the shape the life path of individual in the space-time. They also can be graphically displayed in the STC model.

For instance, the "capability constraints" illustrate that an individual cannot go as far as he wants without limit. In the STC duration of a particular time interval, there is a definite boundary line, which is the furthest distance he can arrive if he has to return to the starting location (Hägerstrand, 1970; Kraak & Koussoulakou, 2005). This boundary is Space-Time-Prism (See Figure 2.2). In the same time interval, the faster is the transportation, the larger is the Space-Time-Prism. It illustrates that the space-time offers opportunities, but also restricts choice behaviour (Miller, 2003).

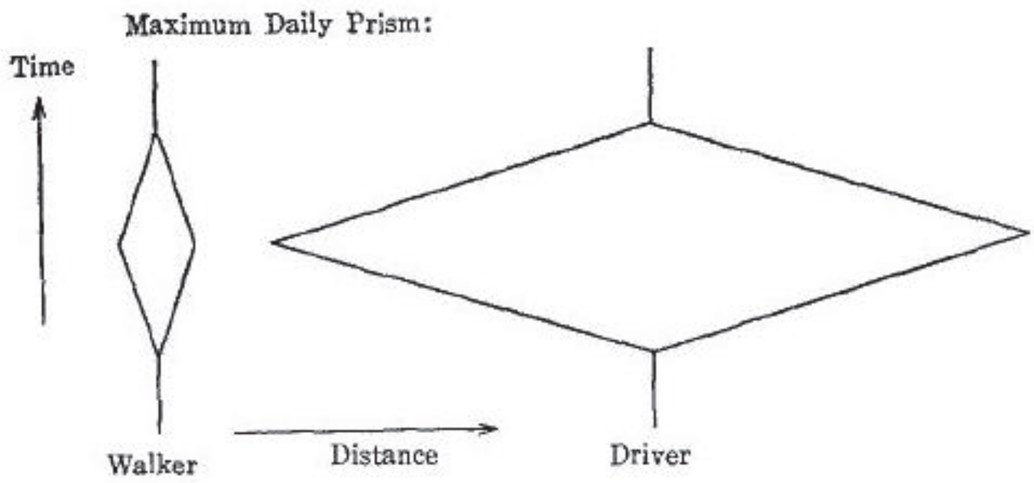


Figure 2. 2 - Space-Time-Prism (source: Hägerstrand (1970))

The "coupling constraints" are those when group of individuals participate in the same activity, there life paths are similar and grouped to a bundle during particular time interval. In the STC model, it represents as grouped Space-Time-Paths shaped the same in particular path periods. The bundle usually happens at stations where people are staying still. For example, group of people have a meeting in one office for an hour (refer to Figure 2.1).

The "authority constraints" display as the rule volumes, in which only particular individuals could enter. In the STC model, these domains appear as cylinders and the insides of which are only accessible to particular individuals (Hägerstrand, 1970).

2.3.3. Visualization Environment for the Space-Time-Cube

Although the STC was created by Hägerstrand at the end of sixties of last century and let to an impressive stream of theoretical and analytical studies in that decade, the interest faded gradually after that. This is because there were scare available data which are in low quality and analyzing technologies as well as storing and managing platforms are weak. There were limited manual operation approaches to create the graphics and the user could only experience the single view (Kraak, 1988). Every alternative view on the cube required another drawing exercise.

The fast development of IT technologies, including the development of software, hardware, networking and database, provide the opportunities to explore the STC model and its content automatically from a database, and thus increase the cube's application. What's more, a rich new data source because of mobile phones or global positioning device solves the problem of lacking abundant data and methods and techniques (Kraak & Koussoulakou, 2005).

Similar to mapping application, which is observable as an interface to geospatial data and conveys information or even knowledge, the STC can also be one to improve our insights and understandings in geospatial-temporal data (Kraak, 1988). Three aspects can make it better for exploration and understanding:

- Interaction – It enables viewers communicating with the STC. It provides the users different viewing perspectives on the STC and thus gives different impression to them.
- Dynamics – It is introduced by time element and emphasizes on changing.
- Alternative views, or multiple views – Of which each view focuses one aspect; the same content impresses viewers from different directions. "An alternative perspective on the data will sparkle the mind with new ideas", according to Kraak (1988). It significantly makes it better for exploration and understanding.

Take Figure 2.3 as an example. When zoom in part of the object path, the working-view gives its content (with enabling interaction of course). The 2D-view provides the footprint of the object and highlights the zooming part. The 3d-view reveals the relation between zooming part and the whole path. The attribute-view provides attributes of the object. Although these alternative views might not be complete to convey enough information to the users and views like "time line" may be essential in some situations, different views emphasize different aspects of the same content and give the users detailed information as well as general impression.

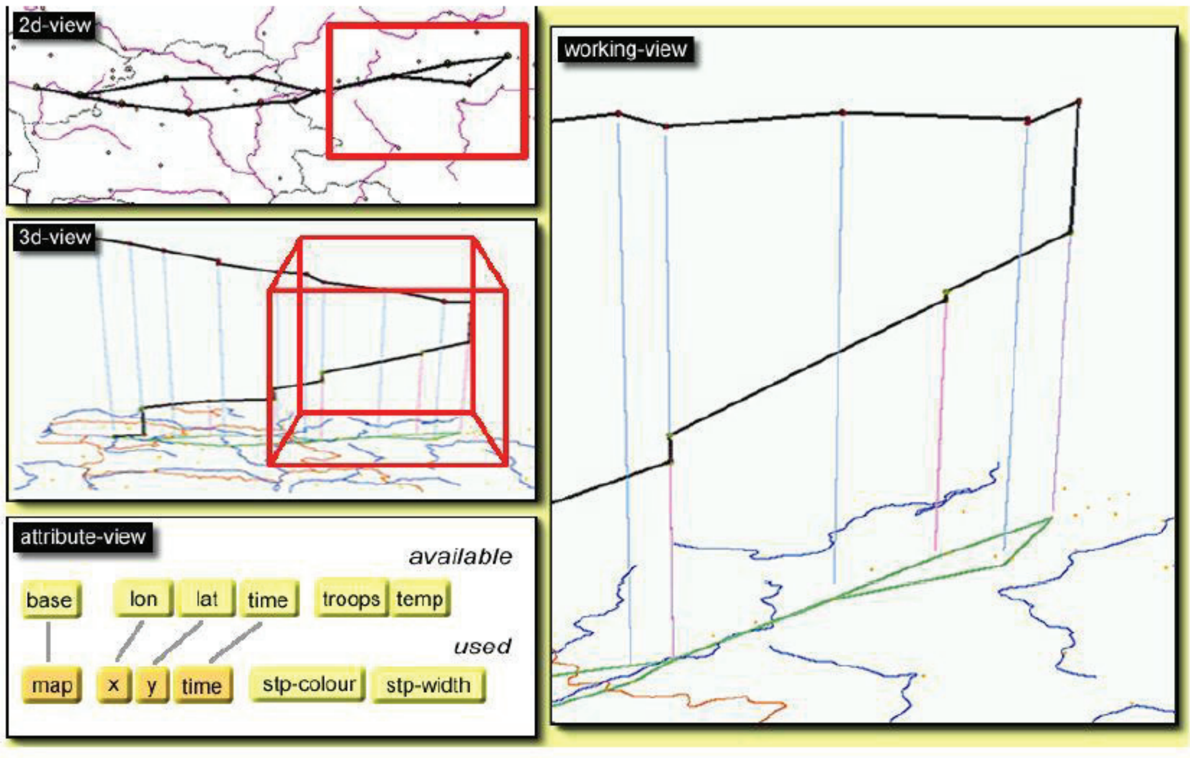


Figure 2. 3– An example for multi-view (source: Kraak & Koussoulakou, (2005))

2.4. Some Applications of Time-geography

2.4.1. Kwan's Case

The time geography was successfully applied as a visualization tool by Kwan (Kwan & Ding, 2008; Kwan & Lee, 2004; Kwan, 2000) to the analysis of human activity pattern. It overcomes the difficulties of traditional activity pattern analysis methods (Kwan, 2000), which include that unreal geographical locations are handled, the space and time included are not continuous, and complex and large data sets are not suitable to processed.

The time geography reveals complex interaction between the spatial and temporal dimensions, and provides activities a space-time environment of many interating dimensions, including timing, duration, activity sequence, and so on. Therefore, time geography enables simultaneous analysis of activities. Not only can the patterns implied in separated dimensions be revealed, but also the ones caused by interation of multiple dimensions are represented.

Because the focus of Kwan's study is on activity pattern, only activity-related information is kept. The information includes when the activity happened, where it happened, how long it takes to finished. In the STC model, the starting point records when and where the activity happened. A vertical line started from this point shows the activity. Its length represents its time period, and itscolor illustrates the categories. Therefore, all activities were assumed as stations. Their realistic movements during each activity and among different activities are ignored to simplify the model. When all the useful data are handled like this and shown in the STC model as many short vertical lines (each of them standing for one activity), explorations is applied on it. Two of them (Kwan & Lee, 2004; Kwan, 2000) are listed below:

- Activity density patterns in geograhic space
- Space-time activity density surface

After connecting ends of activity short lines, the faked space-time paths are established. As followed the standardized space-time paths are created to analyze the activity patterns. With the help of GPS, the real space-time paths can be tracked to reveal the transportaions as comparing with the highways and arterials map.

Geo-Narrative of Kwan & Ding (2008) applied the approach that is somehow similar to the A-STP model. It applied the time geography to analyze the human activity pattern again but used data extracted from the narrative. The narrative is a kind of qualitative data and it is the "stories" that records human's activity events. It can be defined as annotations, additional informaion of trajectories. The related information for activity analysis is extracted from the narrative with the assistance of computer-aided program. The difference between this research and the A-STP model is that this study still focus on analysis of activity patterns while the A-STP model focuses on visualizing the annotations as well as the trajectories.

2.4.2. GeoTime

GeoTime is defined as Geospatial analysis software that allows the realtime analysis of where people are in realtime with data aggregated from satellites, mobile phones, social networking websites, internet logs and financial transactions (Andrienko et al., 2004).

GeoTime is developed to improve understanding of movements, events and relationships based on concept of analyzing activities in space-time environment (Kim et al., 2009a).

Being different from Kwan's studies, the events are simplified as points rather than perpendicular lines. Besides spatial and temporal information is emphasized, the sequences of events at some particular locations are mainly concerned. A 2D ground plane represents the spatial information and Z-axis represents time.

This looks to be similar to the STC model, but in the time dimension, time points appear only when events happen, called instant of focus according to Kapler & Wright (2004), are highlighted. The 3D timeline is introduced to illustrate the sequence. Each unique location of interest has one timeline perpendicucular to the ground plane and all events happened here are ordered in sequence. When link all events based on time order, the "faked" space-time path shows the movement.

As described previously, Kwan visualized the spatio-temporal data and analyzed it by applying some kind of computation. GeoTime, on the other hand, focuses on handling data automatically (MacInnes et al., 2010) and visualizing data as human friendly (Brath, 2010; Brath et al., 2005). It enables interaction and animation to explore data, uses zoom for spatial and temporal navigation, and builds multi-dimensional representation (Kapler et al., 2005; Kapler & Wright, 2004; Nahum, 1997; Wright, 1997). Further, the information in stories in GeoTime are extracted and used for analysis (Eccles et al., 2007); this is similar to part of Kwan's study (Kwan & Ding, 2008).

2.5. Summary

This chapter presents the literature review on time geography and the STC. The core concept is that time and space are undivided. Specific key issues that relate to time geography are discussed. They include movement which is a universal behaviour, characteristics of time, three constrains of space-time, STP and multiple views, which is a suitable visualization environment for the STC. Then two application cases, Kwan's case and GeoTime are discussed.

In next chapter, annotations and GPS tracks will be analyzed. They will be linked according to the "Triad framework" and becomes Annotated-Space-Time-Path.

3. ANNOTATION AND GPS-TRACK

3.1. Introduction

GPS tracks and annotations are discussed in this chapter. Their combination is called the Annotated-Space-Time-Path. The "Triad framework" is used to combine them and Shneiderman's "Visual Information-Seeking Mantra" is used to explore it.

3.2. GPS track

Global Positioning System (GPS) is a satellite-based navigation system. It was developed by US Department of Defence in 1973 and became fully operational in 1994. This worldwide satellite based radio navigation system is formed by a constellation of 24 to 31 satellites as well as ground based stations. Four to twelve satellites are visible to any place on the earth at any time, which is able to provide users the instantaneous 3D position information accurate to several meters. The sampling period of GPS (time between samples) that can be set by users ranges from few to dozens of seconds. Another advantage of GPS is that it is used widely. GPS has been installed in different kinds of carriers, like cars, ships, aero planes, mobile phones and even cameras and it has been applied in many fields, including survey, navigation, and so on. Although it was at first developed for military, it is now available to civilian all over the world. Anyone, including the public, with a GPS receiver, the device for receiving GPS signals, is freely accessible the GPS data. A GPS receiver is getting increasingly developed, cheap and handy (Sickle, 2001; Wright, 1997).

The GPS data are composed by location and time. Unlike the conventional geospatial data acquisition tools, GPS adds time as an essential component which inherits the time geography that time is as significant as space. The 3D data, X, Y, T, coincidently are able to be represented and analyzed in the STC model directly.

Now, GPS are extensively equipped in automobiles, telephones, or even watches and cameras for navigation. Besides this, at the same time, the huge amount of spatio-temporal data records can be stored and are able to be used for movement analysis. So this new data source is able to provide abundant data than ever before and stimulates the development of time geography (Kraak & Koussoulakou, 2005). Nowadays, there are different kinds of software which enables displaying GPS data in either 2D or 3D automatically. The dense dot set of GPS data are linked by short lines one by one and established GPS tracks. When displaying in the STC model, the GPS tracks are transformed to the STPs.

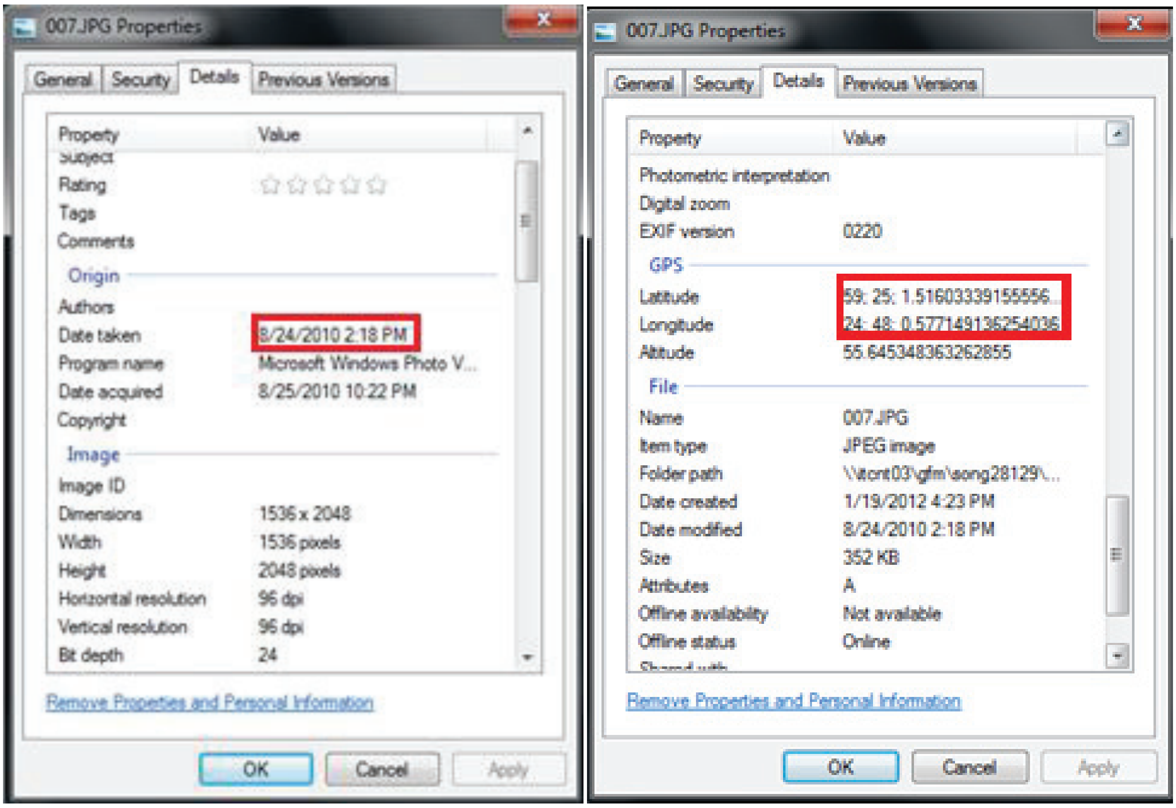
3.3. Annotations

Annotations, or user-generated annotations (He, 2009), include all the materials that are generated during the movement by travellers and are relative to the STPs. Annotations here refer to those generated during the travelling. If the STP is thought to be the recording of the movement track, the annotations are the additional information which helps to impress the important events or locations. The photos, videos, notes and sound recordings included in annotations enrich diverse and abundant spatio-temporal relatively information to the STPs.

There are mainly four types of annotations. They are photo, video, notes, and sound recordings. In this chapter, these four types of annotation are to be discussed.

3.3.1. Photo-Type Annotation

Digital cameras are popularly used and increasingly developed. The digital pictures (main products of digital cameras) are the most common type of annotations for travellers. A digital photo can be characterized by an attribute of time when to take the photo (see Figure 3.1a). As GPS becomes more and more popular, digital cameras start to record geographic coordinates (see Figure 3.1b). The content of a photo contains a lot of attribute information. In many circumstances a picture is worth of a thousand words. Details related to diverse aspects can be extracted from one picture. The distribution of pictures itself might illustrate some kind of interesting pattern.



(a) (b)

Figure 3. 1 - Time attribute (a) and location attributes (b) of digital photo

3.3.2. Video-Type Annotation

Video recorders can make and store videos, which may also be implemented using digital cameras or some fancy mobile phones. Therefore, video is used as another common type of annotations. Its function is similar to that of digital photos in some aspects. It can also have attributes of time and geographic coordinates. Besides, a recorded video can have sounds with the pictures. This means a video can record much more information than digital photos.

The time of a video is actually not a time point. Like digital photos, its time is measured as a time period, from starting recording to end recording. Since the time periods of a video are usually too short to compare with the whole travelling process, a video thus has the continuous annotation effect.

3.3.3. Sound-Type Annotation

Unlike video- and picture-types of annotation, sound-type annotation presents sounds only. The device required for sounds is much simpler than videos and also much easier to operate. They share some similarities with videos also. Sounds record what has happened during period of time. When using it, the time attribute refers against the starting time point. Location information may be hidden in content, and the accurate coordinates, latitudes and longitudes, do not record directly.

3.3.4. Note-Type Annotation

Taking note is not a novel way to record information. The development of digital products stimulates people to take note with advanced tools (such as laptops, cell phones, etc.) to enable the digital formats of notes. Being identical to other digital documents, digital notes record time as a necessary attribute. There is no, or only few, pictures or sounds in notes but are mainly words and symbols. It takes some time to complete one piece of note, but the time to finish it is recorded and treated as the time point for the note.

The development of digitalization leads to diverse kinds of digital products, photos, videos, sounds and notes. All these products can be made during travelling and be annotations of the tracks. Some of them (but not all of them) may contain location information (e.g. geographical coordinates including longitudes and latitudes). However, all the digital products contain time. This key point is significant in the following sections.

3.4. Linkage of Annotations to GPS Tracks

3.4.1. Triad Framework of Geo-Related Object

Mennis et al. (2000) described an approach of geographic representation, which integrated the principle of human cognition. They stated that human beings to cognize the world by grouping knowledge into categories. The categories are arranged in hierarchies and in different generalization details. However, whichever level an object is in knowledge domain, it always has three information components, space-based (where), time-based (when), attribute-based (what) (Mennis, et al., 2000; Peuquet, 1994). The "what component" includes all non-spatiotemporal information of an object. This is termed as the "Triad Framework".

The three components are interdependent and related. Time is detected by the change of location and/or attribute; and time and location cannot be separated. Location and attribute are interdependent for vision (Hägerstrand, 1970; Mennis, et al., 2000).

Any of the three aspects of the "Triad Framework" can be generalized in different detail hierarchies and represented in varying levels of completeness (Peuquet, 1984). The Shneiderman's(1996) "Information-Seeking Mantra", a good approach to visualize objects at different levels (overview, zoom/filter and details-on-demand).

3.4.2. Annotated-Space-Time-Path

In the previous researches, annotation and the STP were considered as two relatively independent objects. The STP records detailed space and time information of the whole travelling track. In theory, every point during the movement is recorded by the track, including both time and location. However, because of its limited ability to represent attribute information, the STP cannot be used to represent complex attributes or significant events that happen during travelling. The annotation discussed in this study includes only user-generated digital documents during the travelling process. It is a type of additional information to the STP.

The A-STP is the enhanced STP with the integration of annotation. For A-STP, annotations help record events of some particular locations at particular time, and they characterize the tracks they belong. In the scenario of having two STP that overlap with each other, the annotations generated will be different. Besides the content of annotations, the information of time and location is included. As a result, possible conflicts in the overlapping can be avoided.

3.4.3. Visualization Environment of A-STP – Multiple Views

Before handling the visual clutter problem, the displaying environment is illustrated. To make the exploration of the annotated-STP, a coordinated Multi-view environment is used. Because both of the annotation and STP objects contain the information of location, time and attributes, Multi-view helps to focus on either one of them simultaneously.

The main interface displays the STC and the Annotated-STP objects. It enables the cube to tilt or rotate. A viewer can visualize the cube or the Annotated-STP objects from any viewpoint. The panoramic window, which is a kind of 3D-view window, can be used to show the STC. Zooming in the main window to a part of Annotated-STP objects, a viewer can easily get lost about to which part of the whole path the present displaying path period belongs to. So this panoramic window always displays the whole paths and highlights the present displaying path period in the main window with a sub-cube (see Figure 3.2). A map window is also added. It is actually the geographic 2D plane with the footprint of paths and annotations. The map changes as the STC changes. It emphasizes the location information of the Annotated-STP objects, including both paths and annotations, and overlooks their time information.

Another view window, which is called the timeline, focuses only on time information of the Annotated-STP objects. It is also interactive with the main window and shows its present time period. Annotations are ordered by time and represented in the timeline. Additionally, an annotation content interface is necessary to display detailed content of any annotation when needed. These five windows all have their own emphases on different aspects, while they work together and interactively and give viewers as complete information of the Annotated-STP objects. A selected object will be highlighted not only in the current interface, but also in others. For example, a selected path in main interface will be highlighted in map interface and in panoramic interface. A selected annotation in the main interface will also be highlighted in map interface and timeline interface, and its content be displayed in annotation content interface.

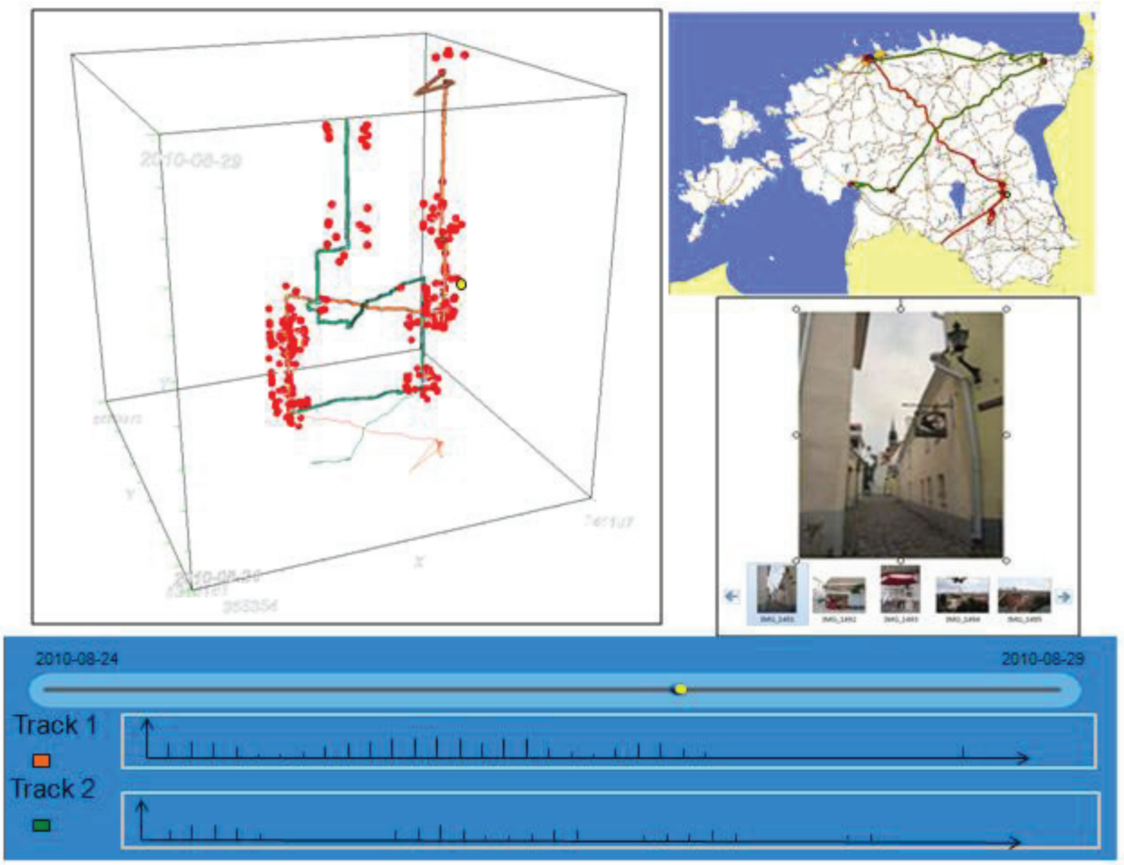


Figure 3. 2 - Examples of Multiple Views

3.4.4. Triad Framework of the STP

The STP model records movement of objects. Although time and space information is obvious shown in the STC model, diverse attribute information exists for every moment of the movement. User questions can be solved using either one of the three approaches (Peuquet, 1994):

- **where + when → what** - Which objects are or what happens at a given location or (or a set of locations) at a given time (or a set of times)?
- **when + what → where** - Where are the given objects or events at a given time or a set of times?
- **where + what → when** - When do the given objects arrive at given location of a set of locations?

As a geographic object, the STP model contains the three components: where, when and what. However, as records of movement track, the STP model is lack of attribute information. As we know, GPS mainly records spatial and temporal information. Any attribute information of a track (e.g., who makes the track, what kind of transportation device is used in the track, what happens during the movement, etc.) depends on recording by hand and can hardly be complete.

3.4.5. the Triad Framework of the Annotation

Annotation is also a kind of geographic object. When use "Triad framework" to analyze it, there are three components of it, space (where did the annotation make), time (when did the annotation make) and what (what's the type of the annotation and what's the content of the annotation). There are three basic kinds of user questions (Peuquet, 1994):

- when + where → what: Which annotations or what content of them are at a given location or set of locations at a given time or set of times.
- when + what → where: Where the annotations with particular types and content are made at a given time or set of times.
- where + what → when: When the annotations with particular types and content are made at a given location or set of locations.

As discussed previously, the time of a set of annotations is a time point plus the locations of the points of the annotations. Annotations in the STC are represented as point objects. The STP focuses on movement of objects, whilst the annotation records what happen (events) at the particular time and location as its content.

3.4.6. Link Annotation with the STP

Due to the limitation of the STP model in recording attributes, it is almost impossible to display what happened for an object's movement trajectory. However, for a traveller, the events happened during the travelling are much more important than accurate description of moving track. Annotations, with powerful ability to record diverse attribute-based information, can be used to complement the STP model's deficiency by their links to the STP model.

Supposed someone makes an annotation as a geographic object with both location and time specified (namely three aspects of information, space-based, time-based and attribute-based are available). As illustrated in Figure 3.4, integrating the information in a STP object with the information in an annotation object together will provide provides a better picture for user to in his/her analysis. This integration can be achieved by the linkage between both annotation and the STP objects through two of the three parameters (location, time and attribute).

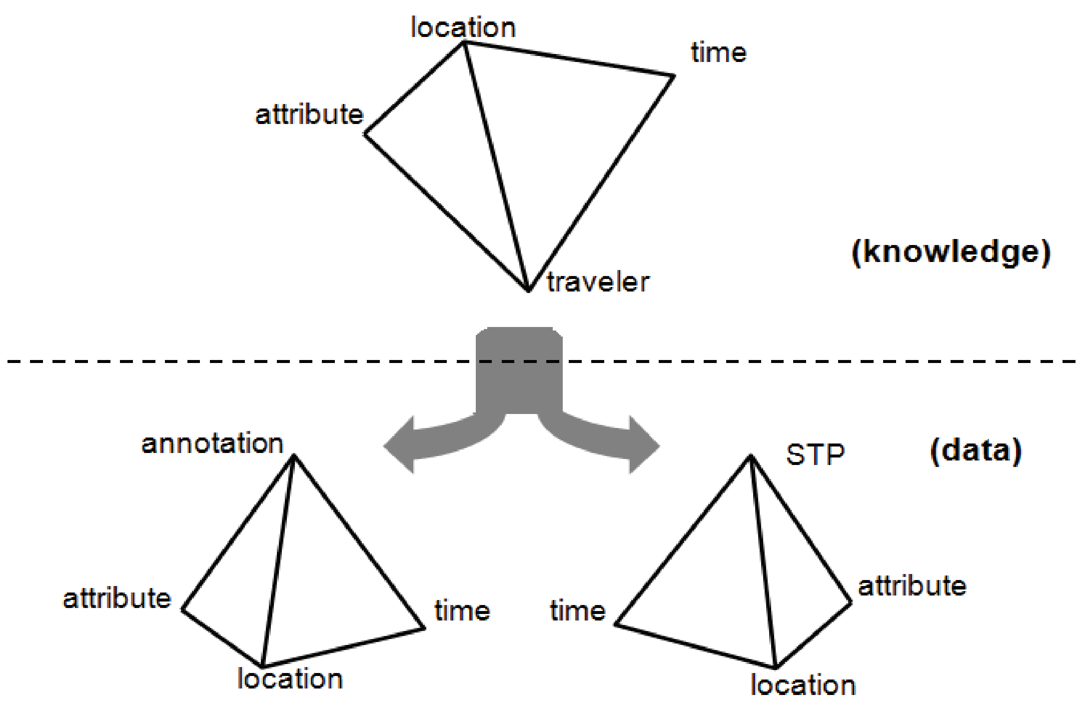


Figure 3. 3 - Traveller situation with the presentation of annotation and the STP model

Both annotation and STP have three components, location, time and attribute, but neither of the three can link annotation and STP alone. Attributes of annotations are complex and hard to be extracted; while there are only limited attributes for STP. It's difficult to analyze them and link them together. One object can pass one location several time and different objects can also pass one same location, so location alone should not be used to link annotation and STP. Time is one component of any A-STP. Each time point is unique for one single path. But different paths may all content some time period and thus time alone cannot link annotation and STP.

Two of the three aspects, time, location and attribute can be used to link annotation and STP. If both location and time are used, "where + when", it is a fixed spatio-temporal point in STC, so annotation and STP can be linked based on them. Attributes of objects are complex and diverse. It is not like location and time which are recorded as coordinates and time moment. There are too many types of information and too many means to represent attributes; thus only few of them can be used to link annotation and STP. Identity is a kind of attribute which is unique for every object and easy to be exacted. It can be applied to the linkage of objects. If time and identity are used to link annotation and STP, "time + identity", it is a unique point at the interested A-STP, because any object can only be at one location at one given moment. Therefore "time + identity" can be used to link annotation and STP. But the "location + identity" cannot be used to link annotation and STP; it is not unique, because one person can pass one location several times.

Linkage by 'Where' and 'When'

This is an easy way to link annotation and STP in the STC. The annotation with precise geographical coordinates and time moment is a point in STC and must overlap with the STP during which it is made. Thus this annotation is linked to the STP and helps add much attribute information to it (see Figure 3.4).

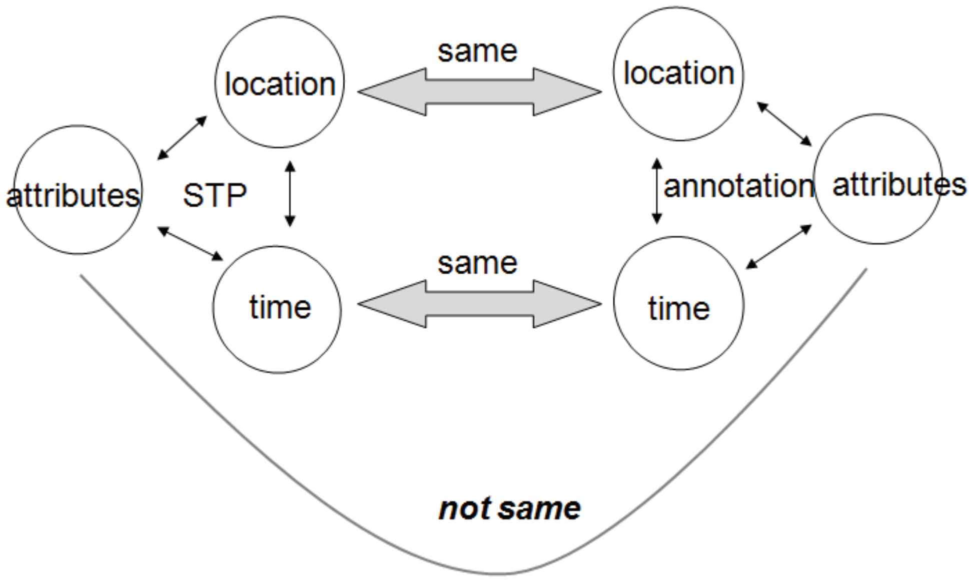


Figure 3. 4 - Linkage of the STP model and annotation by location and time

Linkage by 'What' and 'When'

This solution is to use "time + identity" to find the geographic coordinates from the STP whose identity is the same. Identity is an attribute which is necessary for both annotation and STP and is available to link them (See Figure 3.5).

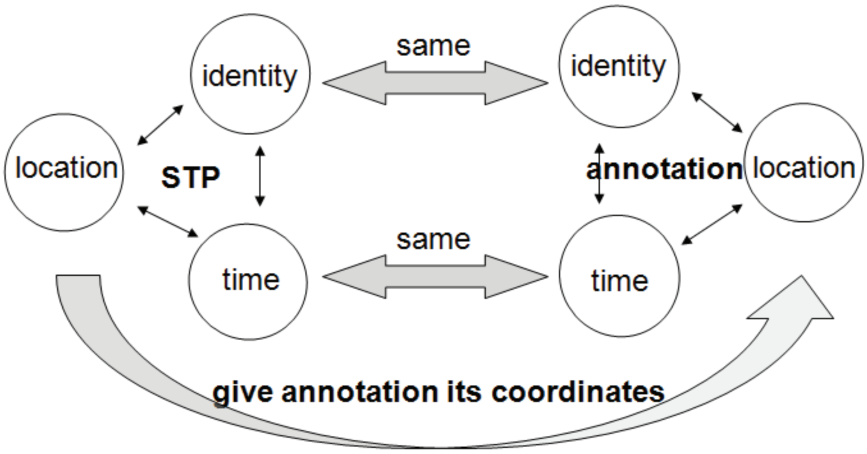


Figure 3. 5 - Getting location from the STP object

3.5. Summary

This chapter covers the basis of GPS tracking and its characteristics are illustrated. Annotations are also discussed. There are four types of annotations, such as photo, video, notes and sound recordings.

The emphasis of this chapter is introducing and discussing how to link annotation objects to the STP objects. The combination of them is termed as the A-STP. Specifically the "Triad Framework" is applied for the combination for both annotation and STP are geographic objects.

In next chapter, visual variables will be discussed and analyzed in both 2D and 3D space. Apply them to annotation and STP is mainly emphasized.

4. GRAPHICAL REPRESENTATION OF ANNOTATION AND THE STP MODEL

4.1. Introduction

Visual variables and their measure scales are analyzed in this chapter, which is followed by discussion of their situations in 3D. The applications of each visual variable to annotation and STP are mainly illustrated.

4.2. Visual Variables

4.2.1. Measurement Scale

To distinguish different data type, the measurement scale is introduced. It includes absolute numbers, ordered sequence, general comparison and quality distinguishing. The measurement scale is limited by the data acquired and oriented by cartographic requirements and intension. There are four different scale types(Kraak & Ormeling, 2009), such as

- Nominal – It refers to distinctions in nature or quality. For objects in this scale, there is no sequential or hierarchy relations among them. For example, different land-uses, like forest, water and urban areas, are usually represented by nominal symbols.
- Ordinal – By its name, this type implied order or sequence. High, medium and low is typically used to describe the ordinal distribution of some phenomenon. It conveys a general comparison of importance or amount, but the boundary among this comparison is not clear and thus cannot be measured by numbers.
- Interval – This type of scale provides concrete numbers and numerical scale. This type can convey more detailed information than the nominal and ordinal types.
- Ratio – Like the Interval type, this type also provides concrete numbers and numerical scale.

The difference between the Interval type and Radio type is the setup of absolute zero. The Radio type does have absolute zero, but the Interval type does not. For example, the temperature is a kind of interval data. The value of 2°C is two degrees less than 4°C, but we cannot say that 4°C is two times higher than 2°C. Ratio type data, on the other hand, has this ratio relation and the numbers at this level and can be divided or multiplied.

4.2.2. Visual Variables

Visual variables are summarized from the various basic differences in the graphic character of the symbols (Kraak & Ormeling, 2009). They each have their own level of organization, which could be associative, selective, ordered or quantitative perception (Bertin, 1983). The measurement scales of data are generally related to the organization levels of the graphic variables. The particular measurement scale could only be perceptible when the level of organization of the used graphic variable is at least equal to it. In other words, it is the organization level of graphic variable that decides the measurement level whether it could reveal or not. "An order will not be perceptible if the variable is not ordered; a ratio will not be perceptible if the variable is not quantitative"(Bertin, 1983) . The associative level relates to the qualitative scale, and objects are distinguished in quality. The selective level is similar to the associative level, but the only difference is that some class is emphasized visually and seems closer to the views without leading to ordinal or ratio impression. The ordered perception and quantitative perception refer to the ordinal scale and numerical scale in measurement level respectively.

Visual Variables

There are six visual variables presented by Bertin (1983) for 2D maps. They are size, shape, color, value, orientation and texture. MacEachren (1994) created different types of visual variable based on these original six ones. They are size, shape, color value, color hue, color saturation, texture, arrangement, orientation and focus. They are more complete than the original six variables. Color saturation is the purity of a hue, in color context only. It is similar to color value to present a visual order. But it is usually used together with color value or hue to enhance the perception. Arrangement is a variable about pattern, which is similar to texture. It's about the relative position of symbol elements and is most suitable for area symbols. Focus is a variable make use of sharp and fuzzy to convey the concept of certainty and uncertainty.

Description of the Graphic Variables

MacEachren's nine-variable model is the expansion of Bertin's six-variable model. The basic principles of the two models are essentially the same. In this section, only Bertin's six variables will be discussed.

- Size

A graphic variable size is usually applied to represent quantity difference, for both data of the same species and data of different species. It is suitable to represent order and even number, because size is easily differentiated by human perception (MacEachren, 1994).

Size is the only graphic variable, which can be measured accurately and conveyed with absolute number. In practice, size is more often used for ratio scale and changes in only one dimension for interval scale. The larger is the size of a symbol, the more easily is it perceived by viewers. It seems the large symbol is closer to viewers.

- Value

Value is also a graphic variable, which can convey amount difference. It can mainly distinguish amount difference in the same species. Value is suitable to express order rather than absolute number because human eyes are not as sensitive enough to the color lightness as to the size (MacEachren, 1994). Adjacent values can hardly be distinguished, so data are often classified to several obvious levels and then value is used to show the order of them.

- Texture

"Texture variable is the sensation resulting from a series of photographic reductions of a pattern of marks" (Bertin, 1983). In other words, it refers to symbols of different frequency pattern but in the same value (see Figure 4.1).

Texture is also a variable suitable for conveying order, with a sequence from fine to coarse. Usually, the coarser is a texture, the closer does it seem to the viewer (MacEachren, 1994). It can be used to separate different information detail levels visually.

Figure 4. 1 - Texture difference

- Color Hue

A color hue variable refers to the perceptible difference on color like the difference among red, green and yellow. Although the different wave lengths of different colors can be ordered, human won't tell this order when viewing the colors. Therefore, color hue is such a type of a variable as cannot represent order, but it can only tell qualitative differences. However, this fact exists only when other graphic variables have no effects.

A color contains the three dominate properties: color hue, value and saturation. These properties can hardly be analyzed distinctively. Therefore, when choosing different colors for objects, attention should be paid to avoid misleading viewers with the potential order or sequence caused by color value.

Taking Figure 4.2 as an example, the left picture misleads viewer with the "East-West" image, but actually it should be the "North-South" image (Bertin, 1983). Besides, some colors are naturally more obvious to viewers than others because of psychological reasons. For instance, people will focus on red easier than on blue. Attention should be paid when choosing colors for associative or selective perception.

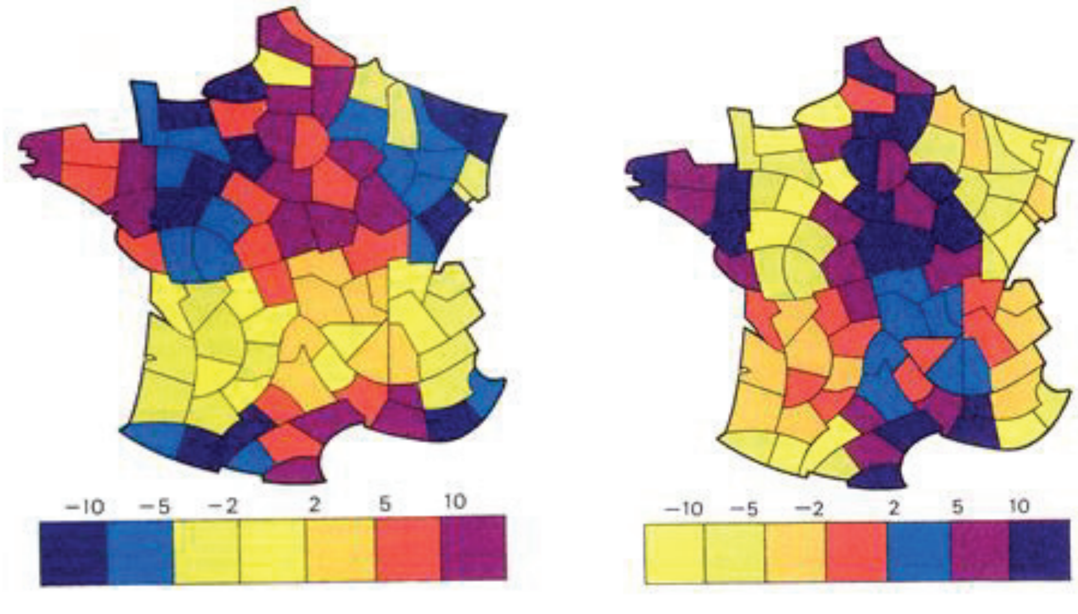


Figure 4. 2 - Value effect to the color hue (source: Bertin, 1983)

- Orientation

Orientation has the ability to differentiate presented objects without implying order or emphasizing one category over another (MacEachren, 1994). It usually serves for nominal differences. But one of the limits for orientation is that there shouldn't be many types of symbols with different orientations. Although orientation difference is obvious to human eyes, it will be messy and may cause some frustration when too many classes present. In normal practices, it is better to restrict only four orientations for point and two for line (Bertin, 1983).

- Shape

Shape is another variable for nominal difference. No levels will be ranked by different shapes. However, human eyes are more easily attracted by mimetic shapes than geometric ones (Bertin, 1983). The mimetic symbols and geometric ones are two kinds of symbols. They are distinguished and should not be used in parallel. People will classify mimetic symbols as one group and geometric ones as another.

Combination of the Visual Variables

Different graphic variables can be used as a combination set. The combination of them could be either redundant or meaningful. In the redundant combination, several variables represent only one phenomenon (Bertin, 1983). This type of combination increases the expected differences and stresses.

Meaningful combination refers to several variables each for one phenomenon are combined together to represent several phenomena simultaneously.

4.3. Visual Variables in 3D Space

4.3.1. Two 3D Graphic Variables

Besides the six graphic variables that are used in 2D visualization, two additional graphic variables, shading and depth perception, are used in 3D visualization. Since the studied visual environment is the STC that is a 3D space, the two additional 3D graphic variables are discussed in this chapter.

The introduction of 3D space is of course with the advantages in some aspects, especially in displaying 3D in several sub-fields of cartography (MacInnes, et al., 2010). Like the STC, 3D objects are very necessary to statically represent movement or change of objects. However, in the same time, some problems are generated by 3D perception for the six conventional visual variables. When displaying the 3D space on a 2D screen, it is the shading and depth perception to impress viewer's eyes. Besides, the STC is an interactive 3D space. It allows rotating, zooming in/out, etc. All these features may cause some conflicts with effects of the six visual variables.

4.3.2. Shading

Shading models the existence of the Sun or other light sources in reality. When applying different values to the same object, some parts are light but some parts are dark. Thus, it seems that the object exists in the 3D space. Because shading is represented by the use of value, it may cause some confusion if its value is applied for other intensions.

Because shading always applies dark value, light value can be used to emphasize objects. The problem is that under the light background the light value may be too weak to be ignored. Therefore, a dark background may help viewers focus on expected objects.

4.3.3. Depth Perception

Because of the depth perception, the objects may be distorted. The object far away from viewers seems much smaller than its real size. Two horizontal lines seem to intersect at a point if they are observed far away. Therefore, when size is used to represent quantity difference, the results may be not so reliable.

The depth perception is an inevitable problem. Because the STC is accepted as an interactive 3D space and viewers are allowed to view from any perspectives, people may get the right impression and effect of depth perception is greatly reduced.

4.3.4. Interactive 3D Space

Because the viewers may want to see the 3D Space-Time-Cube from different perspectives, the cube allows interactive operations, including rotating and zooming in/out. The rotating causes problem in orientation. The "left-right" distribution may be "up-down" when from other perspective.

4.4. Applications of Visual Variables to Annotation and the STP

There are three types of signification, point, line and area in a 2D plane. In a 3D space, there are four types of significant, namely with volume as the additional variable besides the three in a 2D plan. Since the objects in this study are annotation and the STP model, they are point and line objects respectively.

4.4.1. Applications of Visual Variables to Annotation

Conceptually, a point in a 3D space occupies no space and its centre represents its location. This is similar with in a 2D plane. However, practically, a point symbol does take some space. Different options are available for point symbols (either 3D or 2D symbols).

- Size Variable

If size is applied to represent quantity difference, either 3D or 2D symbols should be chosen. If a type of 3D symbol is used and the volume represents amount, the symbol expanding may be not so obvious for viewers to view them on a 2D screen. If a type of 3D symbol is used and only two dimensions are used to represent the amount, it may be problematic from some particular perspectives. If a type of 2D symbol is chosen to convey amount, it's similar to the 2D situation. However, the problem may be from some perspective. Especially when paralleled with either of the two dimensions, the symbols disappear. Because using 2D symbols is easy to control, 2D symbols are extensively used for annotation.

- Shape Variable

Shape is an excellent variable to quantitatively represent different annotations. Symbols can be classified by shape as tow groups: geometric symbols or mimetic symbols.

The main advantage of geometric symbols is that geometric symbols are usually simple in shape, and therefore they can be perceived and distinguished by viewers easily.

The main advantage of mimetic symbols is, on the other, that the symbol's shapes can imply the objects they stand for. As a consequence, viewers can immediately understand the meaning of the symbols without assistance of the legend.

In this study, four types of annotations (namely photos, videos, recorded sounds and notes) are discussed. These annotations are represented by four mimetic symbols. Because annotation aggregation is applied, one mimetic symbol, which is like a folder, is used to stand for all of the annotations ignoring their classification.

If no aggregation, one annotation is represented by one geometric symbol (e.g. a circular or a square-shaped symbol).

- Color Variable

Color is another good option to distinguish annotation type. The classification will be more obvious if color and shape are used together.

The other three visual variables, namely value, orientation and texture, are not so suitable for annotation. An annotation is a point object, and it is not sensitive enough to viewers if value is used to show the quantity. Texture, the frequency pattern, is a variable for representing order, but its complex pattern may cause confusion for the viewers. Orientation is usually for distinguishing different types of objects. However, rotating the STC will cause other viewing problem. Therefore, the usage of orientation for either annotation or the STO objects is very limited.

4.4.2. Applications of Visual Variables in the STP Model

Theoretically, a line, like a point, in a 3D space does not occupy space, and its central axis stands for its exact location. It may be extendable to any direction in a 3D space. In the STC, the STP is represented by line symbols. Because the STP records moving track, its extent is fixed, but its radius direction may vary.

- Size Variable

Size of line symbols refers to the profile. If the profile is not a circle (tubular line) it cannot be expanded in its thickness, and there are fewer options to convey its attributes.

The profile of a trajectory may be in 2D. But viewing from different perspectives may mislead viewers unless the path is dynamic and always shows views on the same side. Its effect is similar to the effect of a tube (but a tube is easier to be realized due to its non-dynamic feature). Therefore, the size in the STP model means the width of the STP object only. It can be used to represent order or number attributes of the path.

- Shape Variable

Because the path is fixed in shape, discussion should be made on its profile shape.

Circle is a very good example of the profile shape. From any perspective, a tubular profile is visualized as the same in its cross section that is circle, a simple geometric shape. It won't make the tube surface complex or mislead viewers. Therefore, only circle is used for STP profile.

- Value Variable

Value, which cannot be used for point symbol annotation, can be applied to line symbol object. It usually represents order. Similar with the applications in 2D mapping, viewers are not sensitive with value. Therefore, only limited classes or levels of value variables are available to distinguish the difference between objects to be presented.

- Color Variable

Color hue is a good option for path to represent quality difference. It is obvious for viewers when there are perceived distinctions among paths. It should be realized that color is one of annotation's properties. When annotation is used, the annotation's color should also be chosen.

- Orientation and Texture Variables

Orientation and texture are not suitable to use for the STP objects. Orientation may cause confusion when rotating a STC object. The complex patterns of orientation variable would make the path messy and hard to be visualized.

Texture shares the messy path problem, so it won't be used in this study either.

Besides the six conventional visual variables, additional variables (such as 2D symbol, plane direction, and 3D symbol, volume) are available to explore annotation and STP. For example, a flat plane, which parallels the 2D geographic plane, in the STC model stands for the moment where the surface intersects with the temporal axis.

Another example is the volume in the STC. A space contained by a cube is the interested space and is selected. It helps viewers to focus on this part of space within which research activities takes place during a time period and in some spatial area.

4.5. Summary

In this chapter are discussed the six conventional visual variables (size, shape, color, value, orientation and texture), as well as the two variables (shading and depth perception) for 3D applications. The six conventional variables are default to be analyzed in 2D domains, and their effects in 3D spaces are also discussed.

This chapter specifically discusses the applications of the visual variables in annotation and the STP. For annotation, the discussed visual variables include size, shape and color. For the STP, the discussed visual variables include size, path width, color, and value.

In next chapter, conceptual framework of solving visual clutter problem

5. CONCEPTUAL FRAMEWORK

5.1. Problem Statement

5.1.1. Visual Clutter

In his earlier work, He (2009) combined annotations with the STP model based on spatial and temporal information, and derived the Annotated-STP model. It is known that the STP model not only records the spatial movement, temporal advance and attributes of a moving object, but also enables examine the interactions among them and their joint effects. The Annotated-STP model extended the STP model's ability to display additional information by linking annotations to it. This is useful because the STP model has limited option to display attribute information.

However, additional improvements can still be made. Visual clutter, which is always a topic of concern in visualization, is a potential problem when referring to the Annotated-STP. According to Ruth Rosenholtz (2008) clutter is defined as the state in which excess items, or their representation or organization, lead to a degradation of performance at some task. It emphasizes that clutter is not a result of too many objects. Therefore, the usability and requirement of tasks are considered as the factors for defining whether or not a group of objects is called clutter. The clutter that causes confusing in one situation is context sensitive, and may not be a problem in other situations.

Maps are always complicated visual displays (InfoVis:WikiTeam, 2005) for its huge amount and diverse kinds of information and its limited 2D space for displaying. So is the STC. In the cube, movements are visualized both spatially and temporally, as well as some attributes of the moving objects. Furthermore, the annotations included in the Annotated-STP model must be visualized in the cube and can make the clutter problem more seriously.

In our context, an annotation is a 3D point symbol in the STC, and a STP object can be represented by a 3D line symbol. Visual clutter could be introduced into both of them. Phillips & Noyes (2004) concluded from experiments on geologic map that, "line symbols clutter other line symbols, and point symbols clutter other point symbols", or "the removal of minor point symbols and type led to larger improvements than the removal of minor line symbols". It revealed that visual clutter problems caused by different types of objects are independent. In the 3D STC, too many annotations gathered closely will certainly affect the visualization of STPs around them, since there is limited 3D space and the annotations might compete for space with STPs. Furthermore, annotations distributed in 3D can obstruct viewing STPs. The more the annotations, the higher is the possibility the annotations obstruct the STP objects. However, the visual clutter problems caused by large amount of annotations and by large amount of STP objects will visually interact but will be discussed separately. In the followings, visual clutter caused by multi-scale, by multiple trajectories and by annotations will be studied respectively.

5.1.2. Visual Clutter for Multi-scale

Here, multi-scale means that object in same view are represented at different scales. The multi-scale problem for the STP model is mainly caused by different modes of transport. The average speed of different transport varies greatly. Furthermore, the time period between the two consequent GPS records is the same, or the GPS records fixed number of times in every second. Therefore, distance between the two records can also vary.

One STP is established by linking all space-time points (every GPS point is transformed to one space-time point) with short lines in order in the STC model. Distance variation is also reflected in the STP by short lines of various lengths. Unless continuous short lines are exactly in the same direction and make up a long straight line, they will build turns in random shapes. Short lines will build much more detailed turns than long lines will, so scale, which is suitable for some path sections, will not be suitable for other detailed ones.

This abstract concept of multi-scale can be illustrated concretely by Figure 5.1. The STP model presented here has sections that occupy large 'space', either in spatial dimension (high speed) or in temporal (no movement) dimension. They will not cause problems. While, the sections highlighted in the boxes are too detailed to be viewed. This phenomenon can be explained by an example. A traveler's one-day travelling can be used to illustrate this. He (19xx) went out after rest in home, walked to the bus stop, and then took a bus to the airport, flied to another country before arrived at the destination, and finally walked to a hotel from train station. During this travel, diverse kinds of transport were integrated and thus the visual clutter problem was resulted from multi-scale.

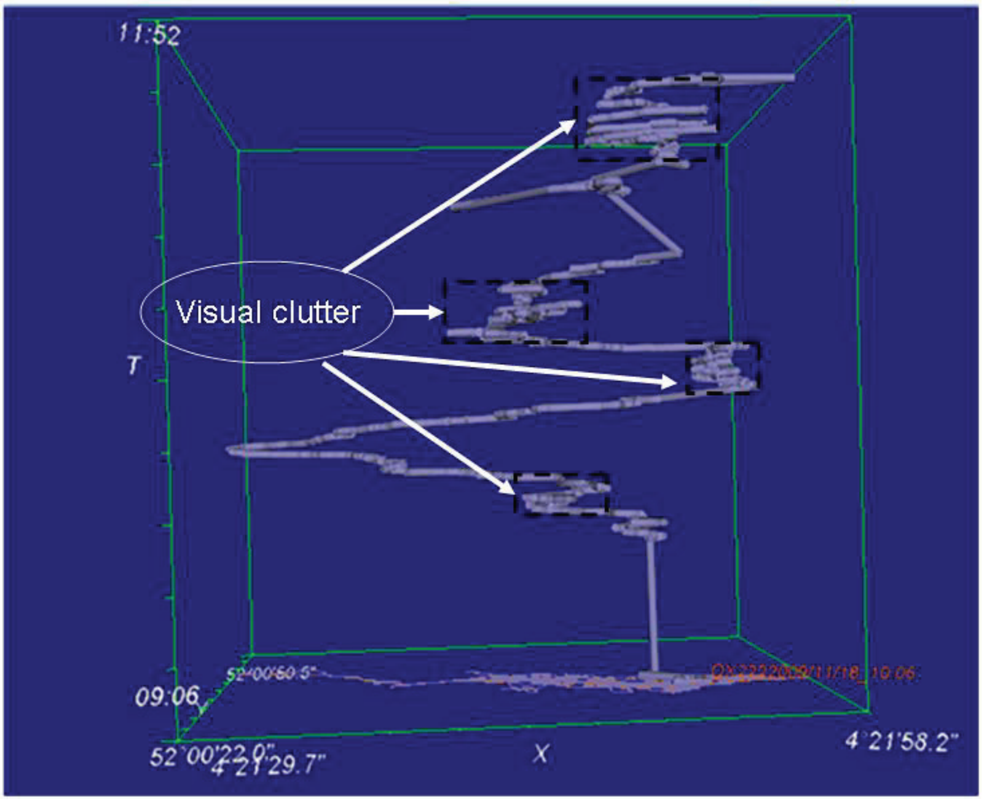


Figure 5. 1 - A traveler's STP using multiple modes of transport

5.1.3. Multiple Trajectories Problem

Besides of the multi-scale, visual clutter can also be caused when many STP objects existing in one STC. This phenomenon is termed multiple trajectories.

Figure 5.2 shows an extreme case of multiple trajectories. In this scenario, so many pieces of track information (including spatial, temporal and attribute aspects) are presented that no single track can be visualized clearly. The problems caused two types of confusion. They are:

- Limitation of the number of colors for distinguishing different trajectories - When trajectories amount is too high, some of the different trajectories have to share the same colors.
- Limitation of view points - From any view point, the trajectories closer to viewers will block the ones behind them. As a consequence, trajectories in the centre of the trajectories cluster are hard to be viewed.

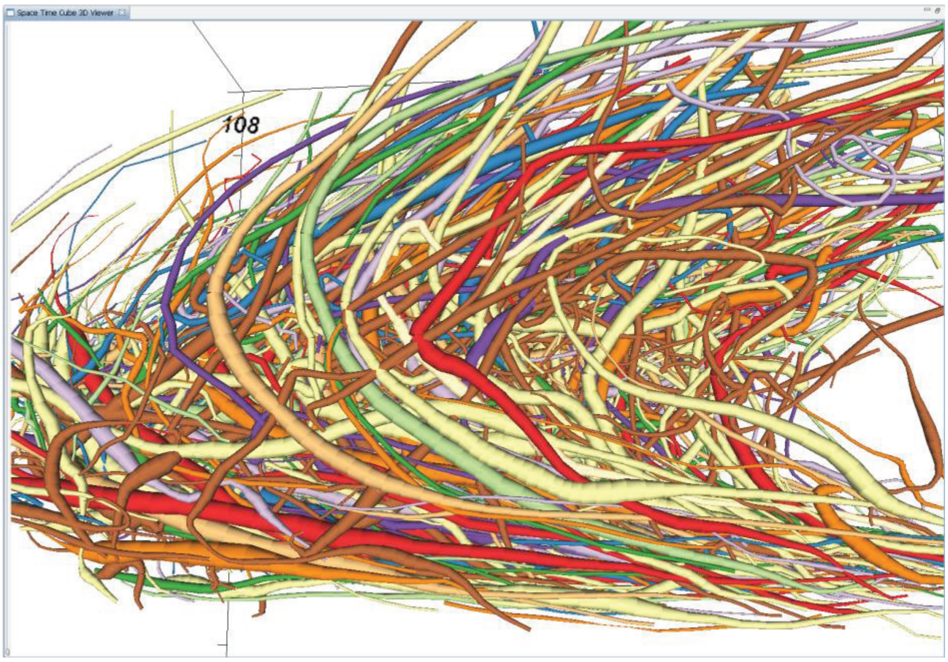


Figure 5. 2 - A large amount of STPs in a single STC

5.1.4. Visual Clutter in Annotations

Visual clutter problem can not only be introduced by the STP, but also by in annotations. Both the quantity and the quality of annotations can cause this problem.

Annotations, like the types of photograph, video, text and sound recording, are usually represented by point symbols. If every annotation is represented by one point symbol, as in He's model, when there are a huge amount of annotations belonging to a limited STP section, it will be too crowd to be viewed.

Different kinds of annotations are usually symbolized by distinctive symbols of different shape, and/or different colors. This is the quality difference among annotations. The quality of annotations will aggravate the visual clutter problem, because the diverse shapes and colors can cause the annotations chaos, which significantly reduce viewers' judgment. This phenomenon also often occurs in 2D images (see Figure 5.3).

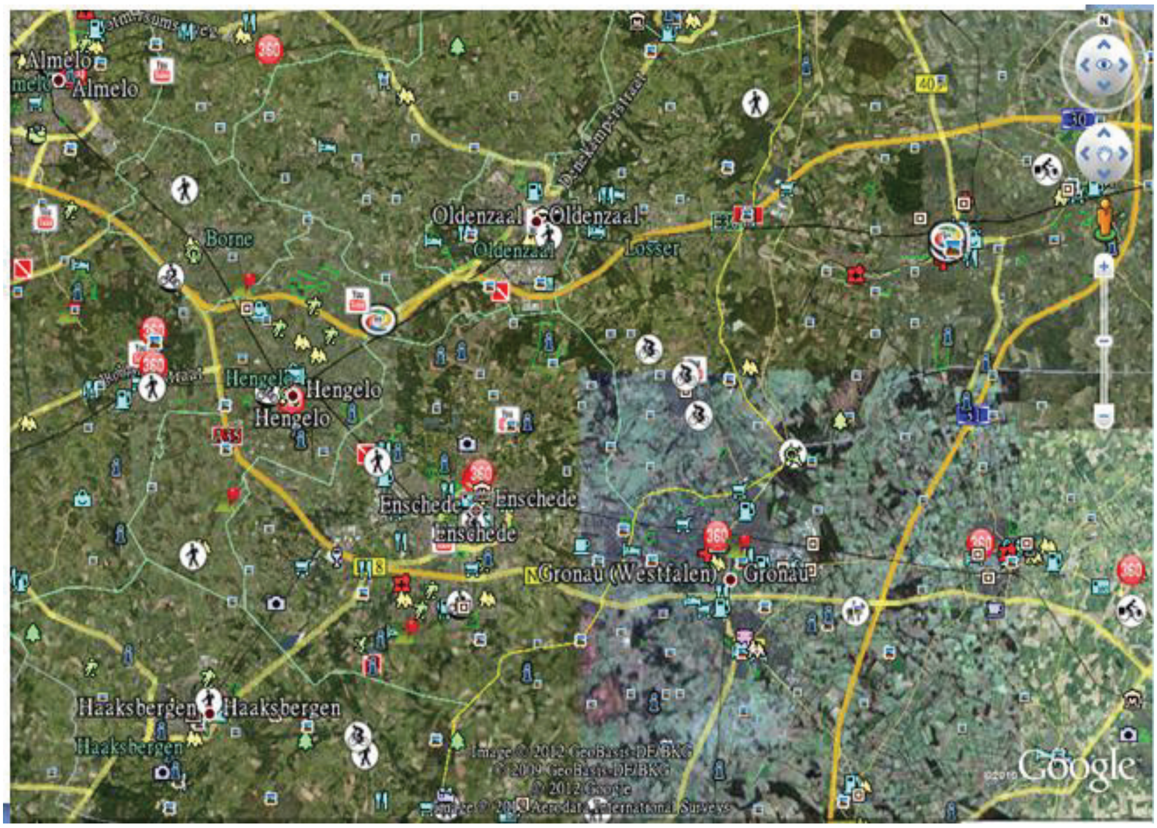


Figure 5. 3 - A Google Earth screenshot for annotation-caused visual clutter

5.2. Solutions

5.2.1. Solution for Visual Clutter Caused by Multi-scale

The "Visual Information-Seeking Mantra" is used to solve the visual clutter problem caused by multi-scale.

On the overview level, the problem is neither solvable nor actually necessary to have its solution. The generalization should have been applied on the STP sections where problems occur. However, detailed time and location information would lose and the precision and accuracy of the whole STP model is reduced. Furthermore, the visual clutter leads to visual confusion and results in problems to explore detailed information, which results in the catch-up of viewers' eyes and attention. This is good for viewers to get a general impression on the whole path, because high information density usually happens where there are visual clutters.

Zoom based on the "Visual Information-Seeking Mantra" can solve the multi-scale problem. Because the problem is caused by unsuitable scale for some path sections, zooming, which is used to change scale (in either time dimension or location dimension), may visualize any section with fit scale.

5.2.2. Solution for Visual Clutter Caused by Multiple Trajectories

Similar with the multi-scale situation, visual clutter caused by multiple trajectories is solved by applying the "Visual Information-Seeking Mantra".

On the overview level, no operation is implemented. Although few STP can be explored in details, the general trend of the STP cluster is revealed. This is exactly the intention of overview visual level. From Figure 5.2 again, the tendency (Figure 5.4) (shown by the arrow) achieved easily will be hardly revealed if analyzing the STP objects one by one.

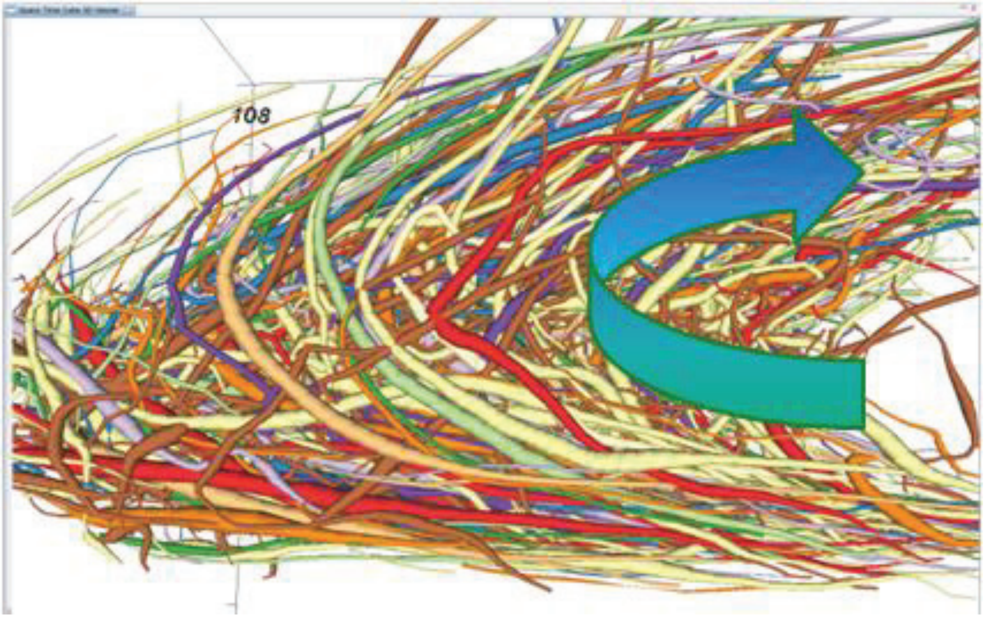


Figure 5. 4 - General trend revealed by multiple trajectories

Filter is adaptable to explore one or several trajectories. Then the trajectories can be distinguished by different colors and will not be affected by others' existence.

5.2.3. Solutions for Visual Clutter Caused by Annotations

At the overview visual level, only general impression is expected, so some kinds of aggregation are needed for annotations. The most general information for annotations is the number of them (quantity information) to one path section. The types of annotations (quality information) will be handled later. There are four options to aggregate annotations on overview level. All of them apply visual variables to STP or annotations.

Value and size are the most suitable visual variables to reveal amount difference in the 3D visual environment, the STC. The maximum length for selection of all these three options, size on point, size on line and value on line, as a glance are the same, 4 in the 2D environment (Kraak & Ormeling, 2009). The maximum length for selection in 3D environment need further study. Here, 3 are used for all three options. The value of annotation symbol is not included as an option because it's more difficult for people to distinguish value of points than that of lines.

The size of object may be affected by depth perception in 3D space. This problem cannot be avoided but can be reduced by rotating the STC and leading a right impression to viewers. The size of annotation symbol (point size) and the size of the STP (path width) are the first and second options. Value of the STP is the third one. Since different visual variables can be used to represent one phenomenon change, there is the fourth option, using value and size of annotation symbol.

(1) Size of Annotation Symbol

People are sensitive to size, so it can represent number and order. One annotation symbol stands for one cluster of annotations and its size represents the amount of the cluster. It should be considered that how to divide the crowded annotations to several annotation clusters. Distance between the present annotation and its neighbour on the STP can be used. First set a value of distinguishing distance, if the distance between two nearby annotations is large than that value then break them to different clusters, or group them to the same cluster.

The size of symbol can be calculated based on annotation number. But here only three sizes are used to just show its general amount. As see in Figure 5.5(1), three different sizes of the same object show different number magnitude, 10, 10^2, 10^3.

The advantage of this method is that it's acceptable for viewers to use a big point symbol to stand for large amount of point symbols. It's usually seen in 2D map and can be recognized by publish easily. And size is sensitive to people and can be compared easily. It can represent number so annotation symbols of one path can "sum up" and thus annotation amounts of different path can be compared.

The disadvantage of this option is that besides the 'space' which STPs occupy there is other 'space' taken by annotation symbols. As the 'space' is limited, the adding of annotation symbols maybe results that fewer trajectories the STC can contain. What's more, since one annotation symbol (although it stands for one cluster of annotations) is linked to one spatio-temporal point on STP, the length of the section which cluster belongs to cannot not be shown, or the boundaries of the section are not conveyed to viewers.

(2) Path Width

The second option, using path width represent annotation amount, is illustrated in Figure 5.5(2). Although path width can also be used to show annotation density (the volume of section then represents annotation amount), annotation amount is represented be path width here for easily comparison of different section.

The advantage of it is that only a little extra 'space' which is around the original STPs is taken. And the boundaries of section are obvious. Furthermore, if total annotation amounts of paths vary greatly, it can be represented.

The disadvantage is that if the path width is increased at path sections where there is the visual clutter problem caused by multi-scale, the problem will be aggregated. Also, if path width is used for annotation amount it cannot be used for other attributes, like the people number included in the sections

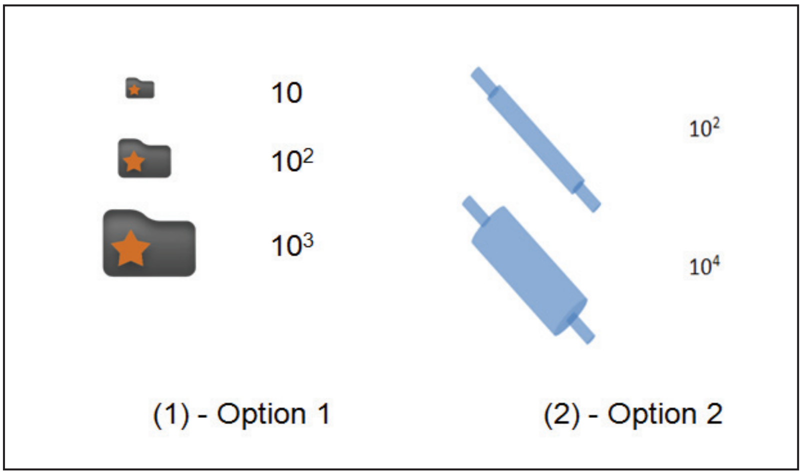


Figure 5. 5 - Use of size to represent amount

(3) Value on Path

Value, on theory is not suitable to show absolute number, so it conveys annotation density (annotation number divided by path section length) here. The advantages are that no extra 'space' is needed and people can tell fussy boundaries of annotation-existing sections.

There two disadvantages. First is a similar problem with option 2, viewers who first see it may confuse about using path width to show annotation attribute. The second one is that same value of different colors can result in different impression of value to viewers. This makes it hard to choose suitable colors and value.

(4) Value on Path + Size of Annotation Symbol

This option combines option 1 and option 3. Annotation density is represented by value and annotation amount is represented by annotation symbol size.

The advantages include that symbol sizes are easily be compared. Different symbol sizes can "sum up" and then total annotation amounts of different paths can compare.

5.3. Further Exploration of the A-STP

5.3.1. Extend Detailed Annotation Information

The annotation generalization provides a general quantity impression to viewers at overview level. Other detailed information like annotation types (quality information) and content is needed in exploration of the annotations. Similar with the trajectories, the "Visual Information-Seeking Mantra" and visual variables are used to solve the annotation-caused problem.

On the overview visual level, only the annotation quantity is shown and is represented by the point size, path width, path value or their combination.

- Zooming Option

Zooming on annotations is applied to one annotation cluster. If the cluster is at overview level and all types of annotations in the same path section are generalized, the zooming option is for viewing all annotation species. Unlike at overview level, annotation symbols can have implied meanings (see Figure 5.6 as the example). If zooming further on any particular annotation type, all annotations classified to this species are shown in sequence. After that the detailed content of each annotation is ready to be viewed at "detail on demand" level.

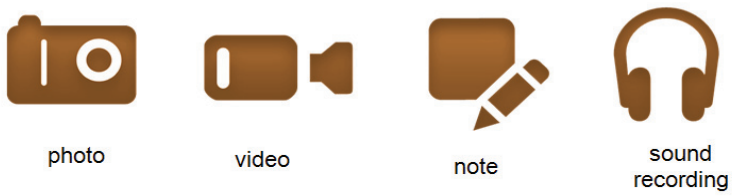


Figure 5. 6 - Symbols implying annotation types

- Filtering Option

Filtering option is available for selecting annotation of interested species in any situation, either in multi-scale or multiple trajectories scenario. Once filtering one type of annotations at overview level, all annotation symbols, which were just for showing annotation amount, are now substituted by particular symbols that stands for the chosen annotation species. This specific species are included in any annotation cluster. No matter which of the three annotation generalization methods is used, after filtering, annotation symbols will be represented by point symbols. The size of presented symbols is used represents annotation quantity. vTo view more detailed annotation information, zooming option can also be used.

5.3.2. Exploration of the Annotated-STP

The "Visual Information-Seeking Mantra" can not only be used to solve multi-scale and multiple trajectories problems, but also useful in the exploration of the Annotated-STP model.

- Zooming Option

Zooming to a particular time period or a regional area helps get details about time or location. This is also applicable for annotations.

- Filtering Option

Filtering on trajectories or annotations results in the focus on interested track or annotation species. The selection of trajectories based on region area or time period is also a kind of filtering.

- Discussion

Because both annotation and the STP objects contain such three components (location, time and attributes) as that of other geographic objects., they can be linked through time and location (see details in Chapter 3). At given time or location, other information (for both the annotations and the STP objects) can then further be explored.

5.4. 3D Timeline

Station is a significant behaviour for analysis. For example, Kwan developed analysis methods for activities which are simplified as stations. Important events also usually happened at stations. So stations always worth to research.

3D timeline which realized in GeoTime is a useful tool for analyzing stations. The 3D timeline is line vertical to the 2D plane in the STC, events at it happened at one location at different moments. If extend the station period of the STP (vertical line) and intersect with the 2D plane, the location is where stations happened. By combining the locations' geo-names and other attributes, annotations for example, the intension of the stations can be revealed.

What's more, the 3D timeline is also useful to analyze tracks' intersection points. If a intersection is found on map and what see their situations in STC, the 3D timeline can be used to intersect the given location. Viewers can see whether these paths meet both in time and location or just in location.

5.5. Summary

This chapter discusses visual clutter problem introduced by multi-scale multiple trajectories or high-density annotations. This is a usual situation for the Annotated-STP. By applying the visual variables and inheriting to use of the "Visual Information-Seeking Mantra" to both annotation and the STP objects, possible solutions of visual clutter problem are given and concluded. These solutions intent to reduce visual clutter problem introduced either from the STP objects or from annotations and increase the efficiency of exploration and readability of viewers. After that, exploration about station is discussed, which helps viewers to understand the travel trajectories.

6. IMPLEMENTATION

6.1. Statement of the Task

The task of this chapter is to implement the designed solutions for visual clutter phenomenon. These solutions were the results of the prototype program conducted in this university.

6.2. Preparation

6.2.1. Software and Space-Time-Cube Plug-in

The software applied in this implementation is the uDig, a type of GIS software. It was coded in Java and built in the Eclipse Rich Client (RCP) environment.

The Space-Time-Cube plug-in was developed by Mr. Retsios in ITC for the particular STC application. The author also added some functions about annotation special for this implementation.

This software with the STC plug-in provides an interactive environment to users. It allows rotating the STC, and zooming In/Out. It is able to represent the GPS tracks and annotations in shapefile (.shp) format. Particularly, the user interface (see Figure 6.1) can be used to setup the two variables:

- track's thickness, which varies based on value of 'Width'
- annotation size, which is generated automatically according to annotation amount

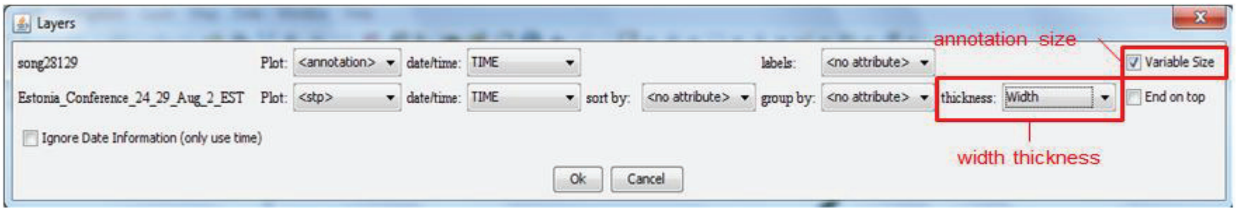


Figure 6. 1 - Variation of annotation size and/or width thickness

6.2.2. Data

The area tracked is Estonia in Northern Europe. The data was collected during Aug. 24 ~ 29, 2010. The data includes:

- Two GPS tracks
- 2D map of Estonia
- Annotations

The row GPS tracks were processed to .shp format by Miss. Kveladze. Both time and location are included and can be represented by the uDig with the Space-Time-Cube plug-in. I created the annotations shapefile. In the files, annotations are rendered by either simple marker symbols (identical in size) or the clustering, which symbolizes multiple points with a single symbol by providing a more aesthetic, efficient, and usable rendering solution.

6.3. Implement of the Prototype Program

Due to the limitations in time and the available resources, the prototype program developed is not fully complete. However, to provide a comprehensive picture, the incomplete parts were included in the implementation.

6.3.1. Visualization Environment

Types of the Views

Four types of multi-view techniques were used to visualize the prototype. They are:

- Space-Time-Cube View - It enables rotating, zoom in/out, and selection operation. Viewers can observe from different perspectives for interested details. There is a selection box. The space selected by it can substitute the original STPs, and is displayed in the cube (see Figure 6.2).
- Map View – It represents the geographic projection of STPs and annotations.
- Annotation Content View – It displays annotation details.
- Timeline View – It shows the study time period. Especially, the annotation distribution of every track is represented by 2D curve (See Figure 6.3).

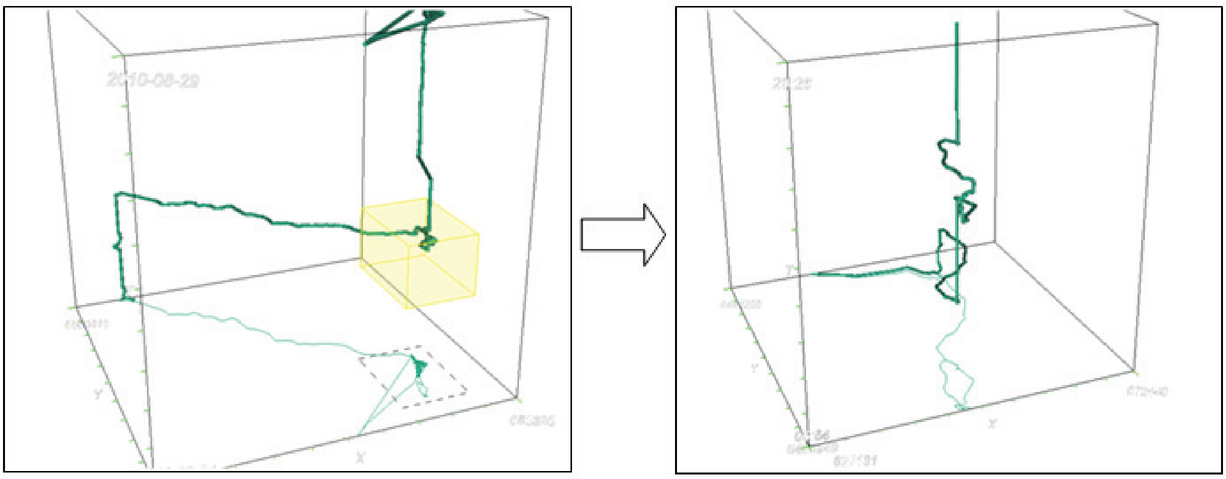


Figure 6. 2 - Selection box

Interactivity

All these views are encapsulated in the same package. Operations in a view will also interactive with the others. For example, when exploring an annotation in Space-Time-Cube View (yellow point), the location of this cluster is also highlighted in Map View (yellow point), the time of the object is highlighted in Timeline View (yellow point), and the content of the object is displayed in Annotation-Content View (see Figure 6.3).

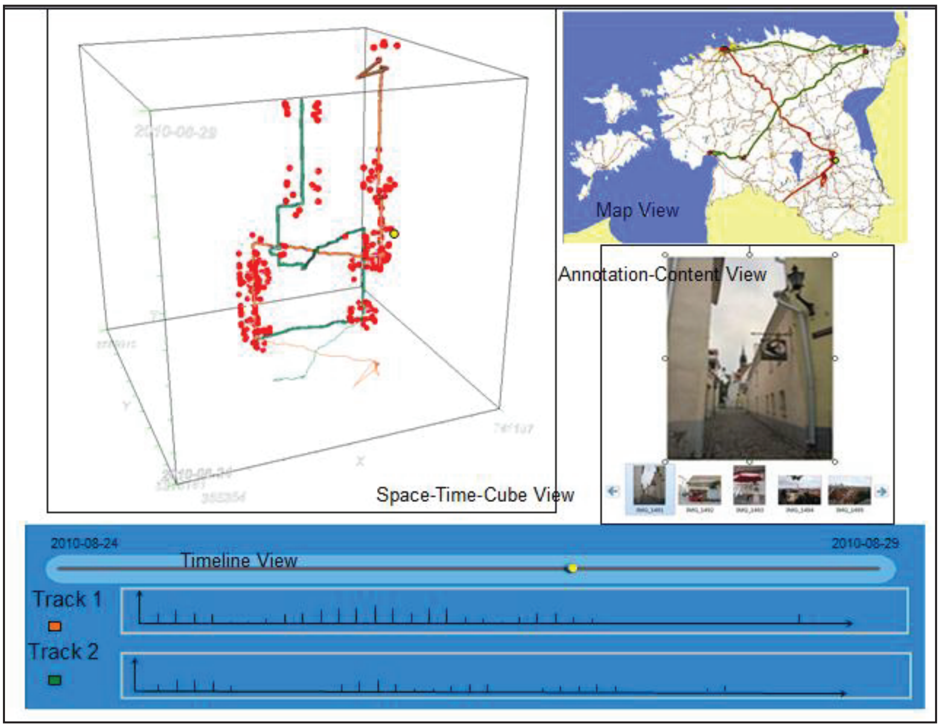


Figure 6. 3 - Interactive multi-view

6.3.2. Situation with Visual Clutter Problem

Even though a multi-view enables viewers to observe the Annotated-STP from more than one perspective, it cannot handle the visual clutter problem. If the given data set is displayed without operations on it, the visual clutter problem occurs (See Figure 6.4).

Visual clutter is introduced from three aspects, such as:

- the annotations crowdedly distribute around tracks and cover some details of them
- multi-scale problem results in unclear on details
- different trajectories may cover or merge with each other and thus cause confusion

In the following sub-sections, operations to solve these problems are provided.

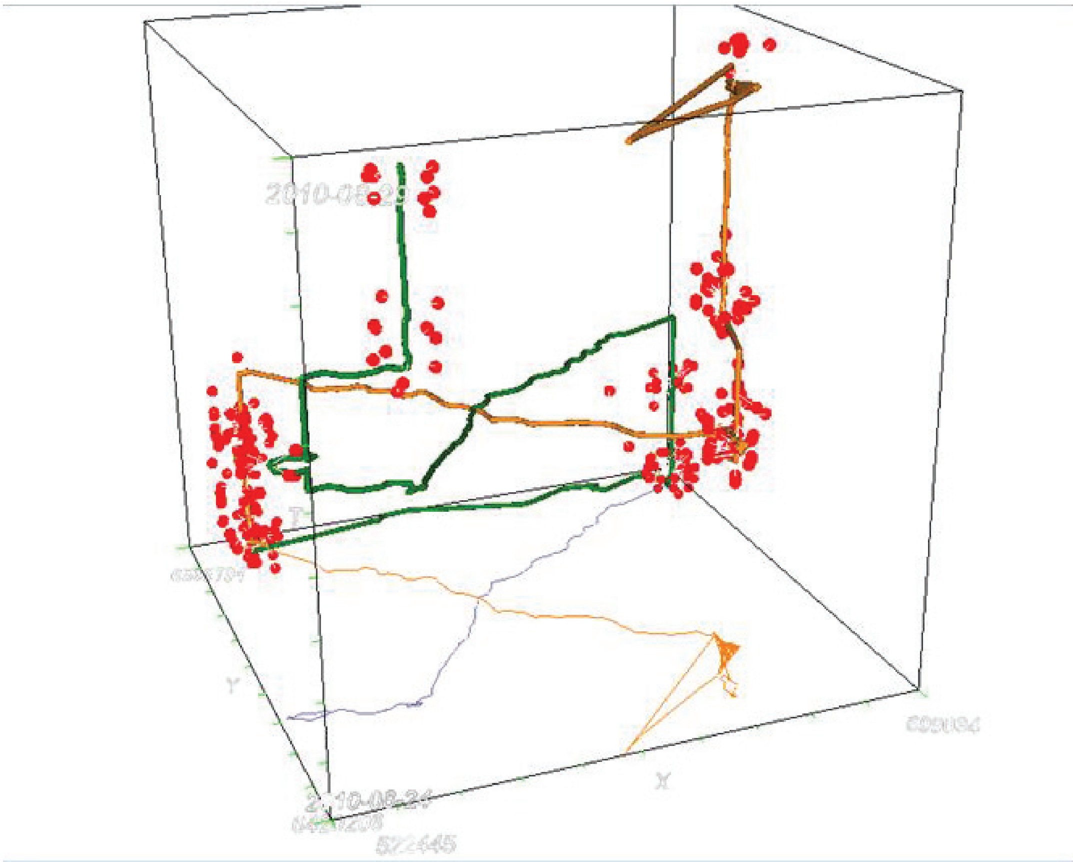


Figure 6. 4 - Visual clutter phenomenon

6.3.3. Aggregation of Annotation to Resolve Visual Clutter

Annotation generalization is used to solve visual clutter problem caused by too many annotations. The main concept of this method is that at overview visual level only general quantity impression is conveyed to viewers. More detailed information (like annotation species, exact number of each species and the annotation content) tends to be displayed at other visual levels.

There are three methods to generalize annotations, such as:

- using one annotation symbol stand for one annotation cluster and its size is for quantity
- using path width display annotation amount comparison
- applying value on paths to show amount of annotation clusters

The three methods will be illustrated in details in the followings.

Annotation Symbol Size

Since only general quantity impression is required at overview level, one annotation symbol can be used to stand for one annotation cluster, and its size represents the amount of the cluster. It is a problem that how to decide the cluster. Solutions to it could be to calculate the distance between two near-by annotations on the STP object, and to compare with the value which is set by viewers. After the gathering, hundreds or thousands of annotations are substituted by only couples of symbols of various sizes (See Figure 6.5). Annotations are usually produced at stations on 2D map. Annotations gathered at one location usually overlap each other. The annotation symbols after the generalization are projected to the map with the size that represents of the amount of the symbols. Annotation clusters presented at the same location are still possible to overlap but can be solved by dislocation.

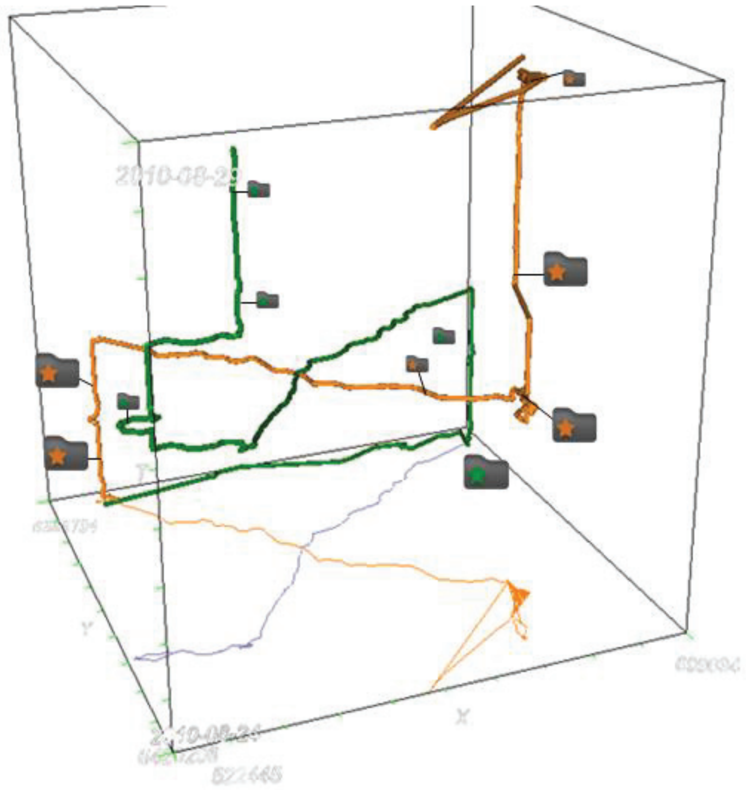


Figure 6. 5 - Annotation size for quantity

Path Width

There is a problem of annotation symbol size. One symbol is linked to one point at the STP, which may mis-impress viewers that all annotations belong to this spatio-temporal point. Actually, they belong to period of the path, but this period can hardly be conveyed to viewers.

Path width to represent amount is able to overcome this weakness. The thickness of width aims at showing annotation amount, and the length of expanded path section is which annotation cluster belongs to (see Figure 6.6).

Visual clutter introduced by annotation symbols is not a problem any more to this method. But the expanded width of STP may aggregate visual clutter because of multi-scale. Figure 6.6 shows that the path section is circled by the red.

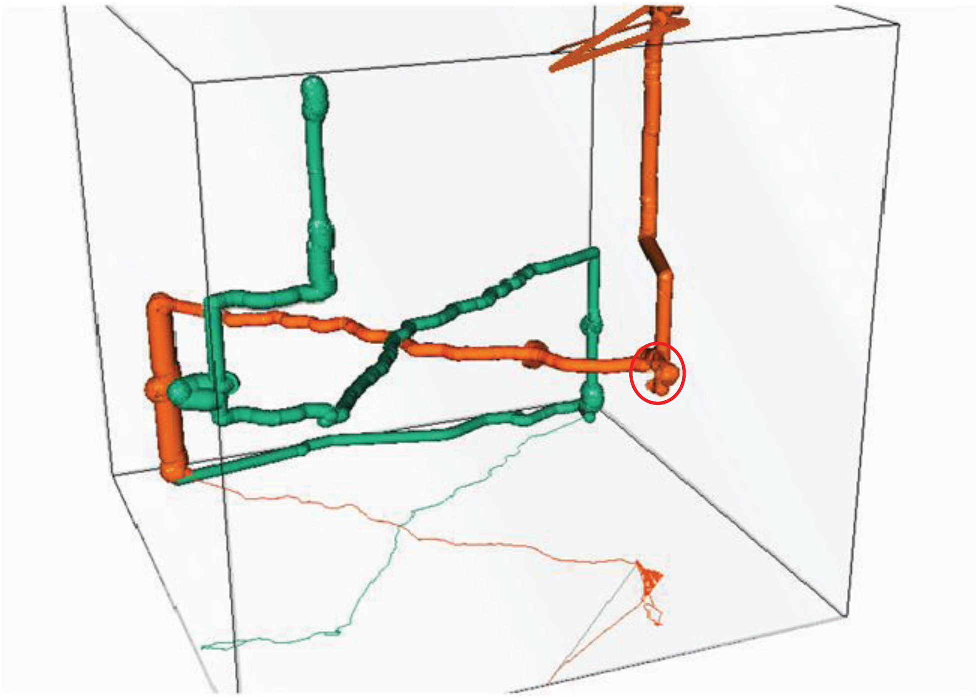


Figure 6. 6 - Path width for annotation quantity

Path Value

Value is a visual variable that is suitable to show general quantity comparison. It can be used to represent annotation quantity in this case. Similar with the last method, the length of operated path sections shows the one annotation cluster belongs to (see Figure 6.7). The problem to use value is that it is not obvious to viewers how many quantity levels are divided. To extend the value difference, only path sections with annotations are colored and others are gray.

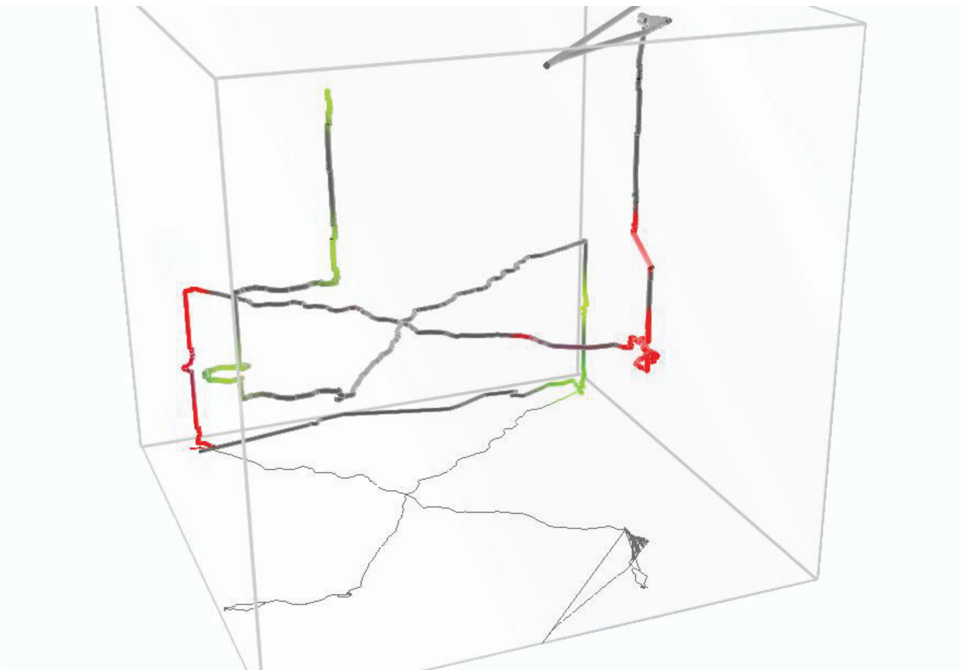


Figure 6. 7 - Path value for annotation quantity

Path Value and Symbol Size

There exist some problems in three methods stated in the previous sub-sections. For instance, size varied symbols cannot represent path sections they belonged. Path width and path values overcome this problem but they are not obvious to viewers and may also cause some kinds of confusions. The combination of different visual variables could make use of the advantages of them. The method "path value + symbol size" is to use value to illustrate which sections are annotation clusters belong to and the symbol sizes show annotation amount of each cluster (see Figure 6. 8).

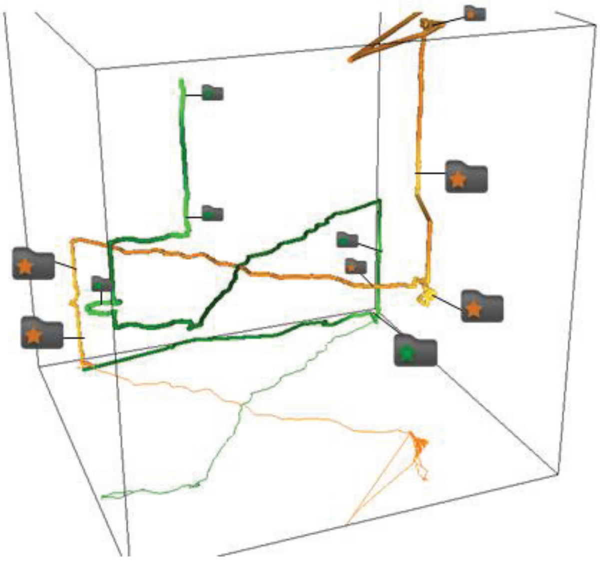


Figure 6. 8 - Path value and symbol size for annotation quantity

Annotation is generated at the overview level, and classification is needed when exploring details of the annotations. Click an interested annotation cluster, and all types of annotations it contained display. Click anyone of them, all annotations of this type show in sequence in Annotation Content View and each one can display in it (refer to Figure 6.9).

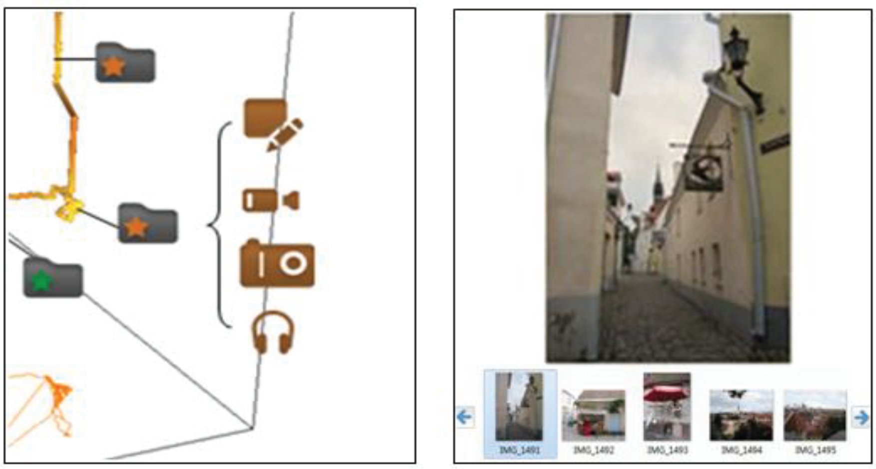


Figure 6. 9 - Zooming in annotations

The above operation could be seen as the zooming operation applied on annotations. Filtering can also be applied on annotations, which is to display one particular species (see Figure 6.10).

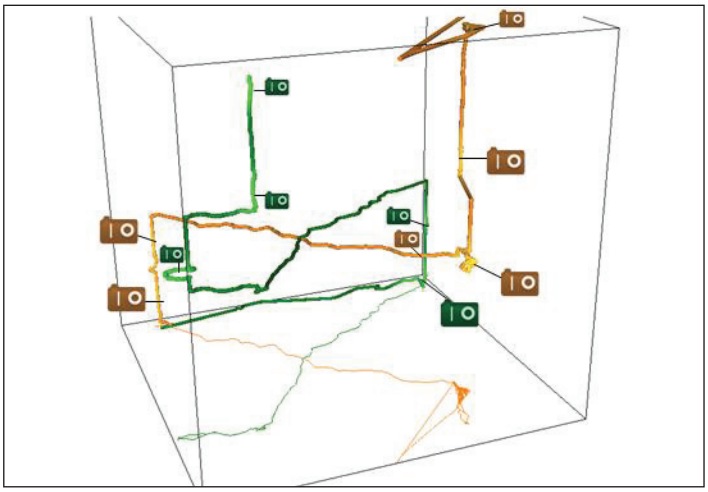


Figure 6. 10 - Filtering on annotations

6.3.4. Zoom and Filter to Resolve Visual Clutter

Visual clutter problems can be introduced by annotations as well as by STPs. Multi-scale and multiple trajectories may lead to visual problems and operations should be done.

Zooming enables viewers to observe objects at more detailed scales and thus aims to solve visual clutter introduced by multi-scale.

Filtering is to focus on interested trajectory and ignore others.

- **Multi-scale**

Although the interactive STC enables zooming in/out, it is uncontrolled and randomly to select interested spatio-temporal space. There is a selection box which can be used to select particular space (refer to Figure 6.11). The space selected by it can substitute the original STPs and is displayed in the cube. The displaying scale is changed and is enough to see details.

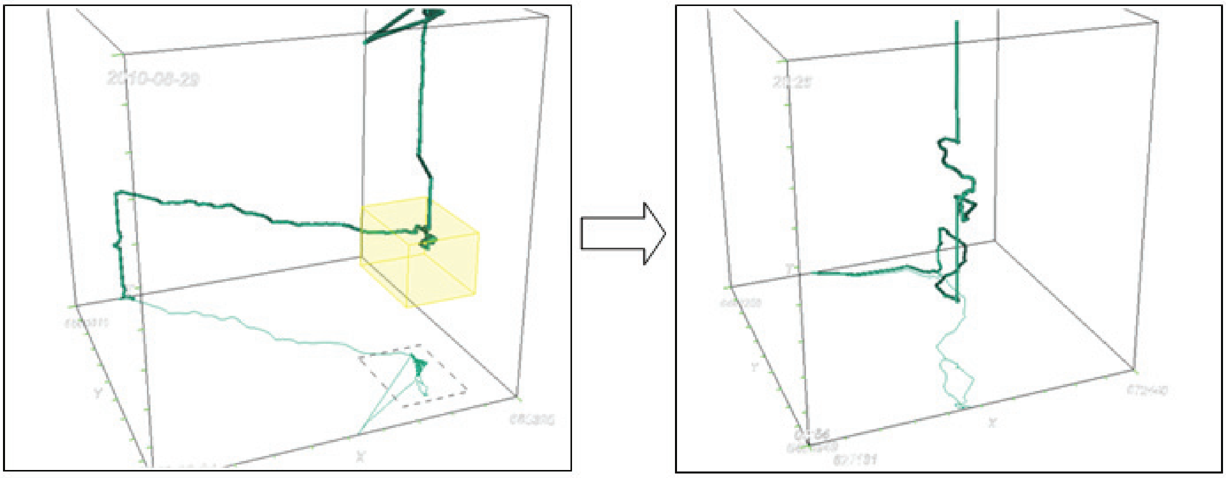


Figure 6. 11 - Selection box

- **Multiple Trajectories**

Different trajectories may overlap or merge with each other. Other trajectories will obstruct viewers to observe the interested one. This is solved by operation to filter on interested track and others disappear; and thus viewers can clearly visualize the track (see Figure 6.12).

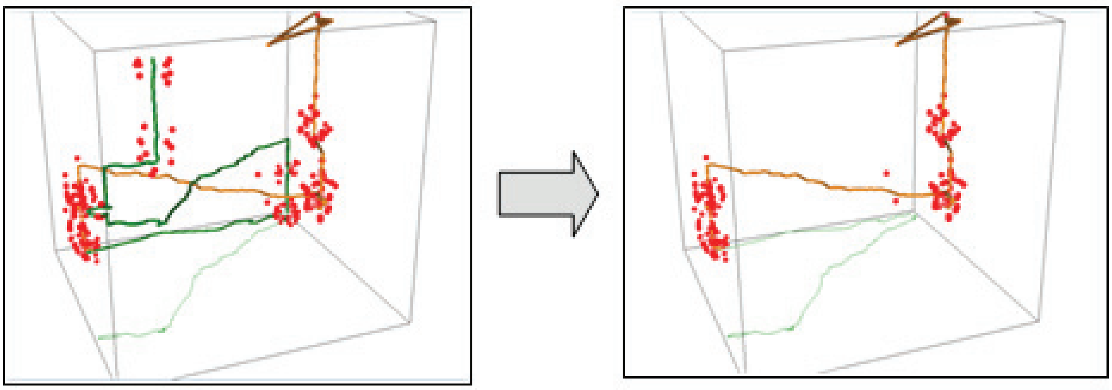


Figure 6. 12 - Filtering operation

6.3.5. 3D Timeline Explorations

A 3D timeline is line paralleled with the time dimension. It is used to find the location projection of some point at STPs.

➢ Stations

Stations are usually where events happen. 3D timelines help find projection points of stations. When combine with content of annotations and location detailed, the intention of the events is usually revealed (refer to Figure 6.13).

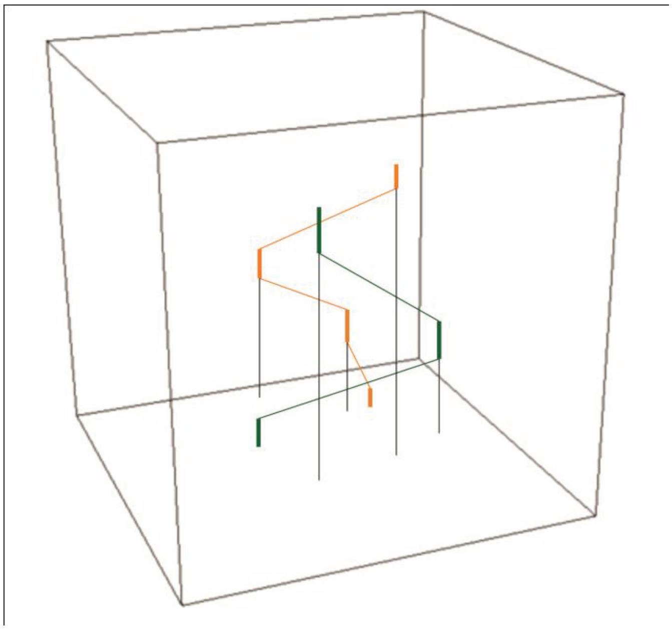


Figure 6. 13 - 3D timeline for stations

➢ Comparison

Different STPs (or their projections) may intersect. 3D timelines can be used to explore these locations and compare events and annotations of these locations (refer to Figure 6.14).

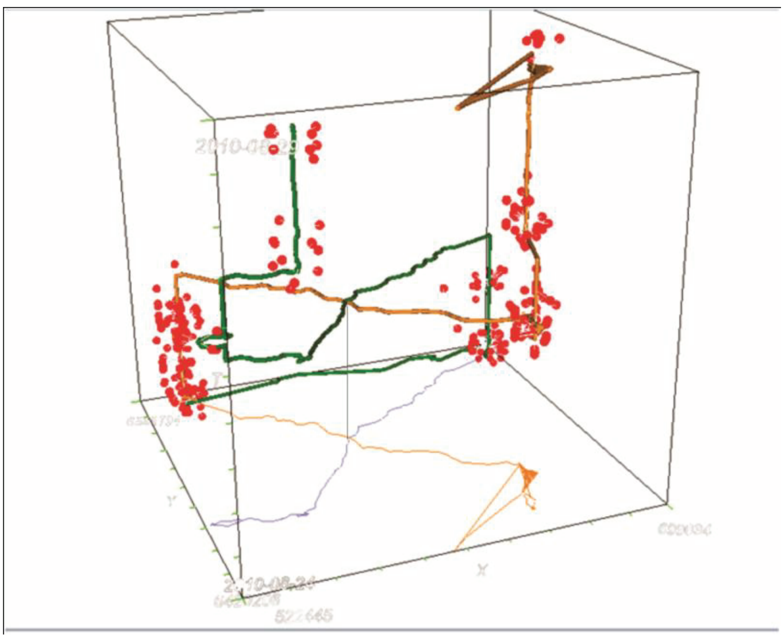


Figure 6. 14 - A 3D timeline for comparison of the STPs

6.4. Summary

The task of this chapter is to make a comprehensive study on the conceptually designed solutions for visual clutter phenomenon. These solutions were the results of the prototype program conducted in this university using the uDig, a GIS software.

In the implementation, four types of multi-view techniques were used to visualize the prototype. They are:

- Space-Time-Cube View
- Map View
- Annotation-Content View
- Timeline View

To solve the visual clutter problem caused by overloaded annotations, three types of annotation generalization are discussed,

- using one annotation symbol stand for one annotation cluster and its size is for quantity
- using path width display annotation amount comparison
- applying value on paths to show amount of annotation clusters

7. EVALUATION OF THE APPROACHES FOR VISUAL CLUTTER

7.1. Introduction

7.1.1. General Statement

Evaluation is defined as either the systematic assessment of the worth or merit of some object or the systematic acquisition and assessment of information to provide useful feedback about some object (Trochim, 2006). Both of the definitions agree that evaluation aims at getting useful feedback from users.

In this study, evaluation, mainly based on the second definition, is essentially validating different solutions provided for visual clutter of A-STP. Details like the objectives and used method of this evaluation test, the preparation, procedure and results of this evaluation test are discussed in this chapter.

7.1.2. Major Task

In Chapter 4 Conceptual Framework, three types of visual clutter problems are listed, such as

- multi-scale
- multiple trajectories
- crowd displaying

In that chapter, it also mentions that at overview level, using aggregation can effectively solve the problem of crowd displaying.

There are multiple aggregation approaches. In this chapter, the major task is to evaluate the aggregation approaches used for high-density annotation displaying.

7.2. Evaluation Approach

The Focus Group Approach was used in the evaluation. This approach is a kind of user study, namely collecting the feedbacks from a group of users.

The focus group is guided by a moderator. The participants discuss the topics provided and then feedback their options (Morgan, 1998a). The participants of the group are usually six to eight people who have the similar backgrounds.

There are four steps in general to develop a focus group research (Morgan, 1998b), such as

- Planning
- Recruiting
- moderating
- analyzing

In our study, the four steps were adopted specifically as three parts, such as

- Evaluation Preparation
- Procedure

- Analysis of the Results

They are described in the following sections.

7.3. Preparation

7.3.1. Participants

The top criterion for the group recruiting is the educational level and professional background. The participants for this evaluation session include eight Ph.D. students and one MS student. All of them were from Geo-information Processing Department of this university. These participants were familiar with the basics of the suggested cartographic topics, and thus could have professional-level discussion from visualization perspectives.

7.3.2. Facilities

The evaluation session was conducted at a Cluster. There were four touch tables and one interactive whiteboard in the room. Each of the touch tables and the interactive whiteboard is the computer unit with a touching screen. A participant can interact (e.g. draw a diagram) with the computer through the touch-screen.

In this evaluation study, the interactive whiteboard and one of the touch tables were used. The whiteboard was used for displaying introductive instructions to the participants, and its drawing function was used as a tool to receive and collect users' feedback for the provided questions.

7.3.3. List of the Prepared Questions

The prepared questions for this evaluation session are listed below:

1) Which is your favorite solution?

2) Compare the two paths, which of them contains more annotations?

- From which solution(s) can you find the answer?
- Is the answer obvious or not?

3) Focus on one path (the red one), can you tell which section(s) or part(s) of the path contains more annotations than other?

- From which solution(s) can you find the answer?
- If you can find the answer, please mark these sections.

4) Focus on one path (the red one), can you tell what the boundaries of the sections are or parts of the path contains annotations?

- From which solution(s) can you find the answer?
- If you can find the answer, please mark the boundaries.

Using the questions as the guidance, the participants would discussion their general impression and single designed symbols of each option.

7.3.4. Procedure

This evaluation session was conducted on February 8, 2012 at Room 3-145 in ITC. It started at 3:40 pm and ended at 4:30 pm. The whole session consisted of the 5 steps:

1) Welcome the participators and briefly introduce the interactive whiteboard.
2) Present them the background of research and the objective of the evaluation.
3) Show them a path with visual clutter problem introduced by high-density annotations (Figure 7.1) and four view options (refer to the description in Chapter 6) to solve it (Figure 7.2).
4) Provide the prepared questions and stimulate discussion among them.
5) Summary the session and appreciate their cooperation.

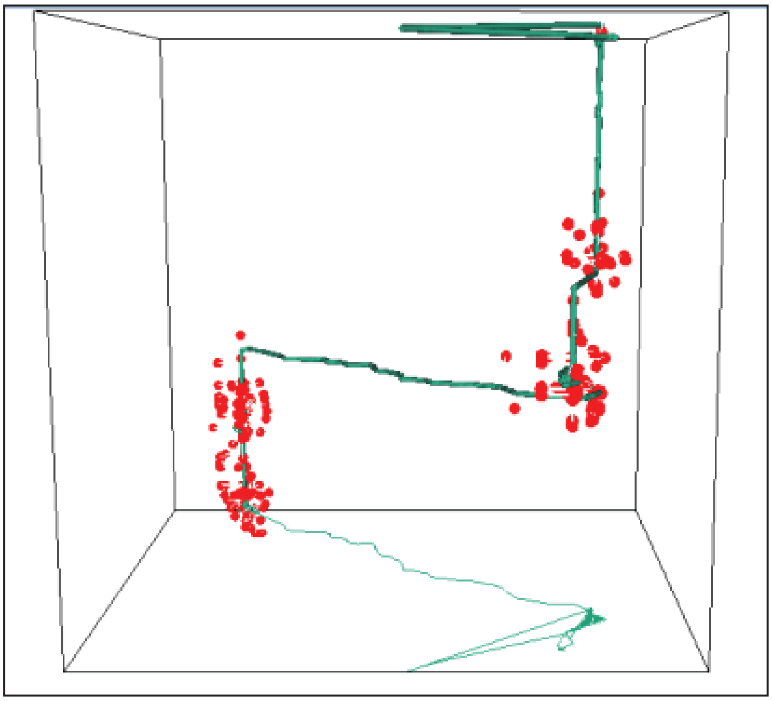


Figure 7. 1 - Visual clutter problem

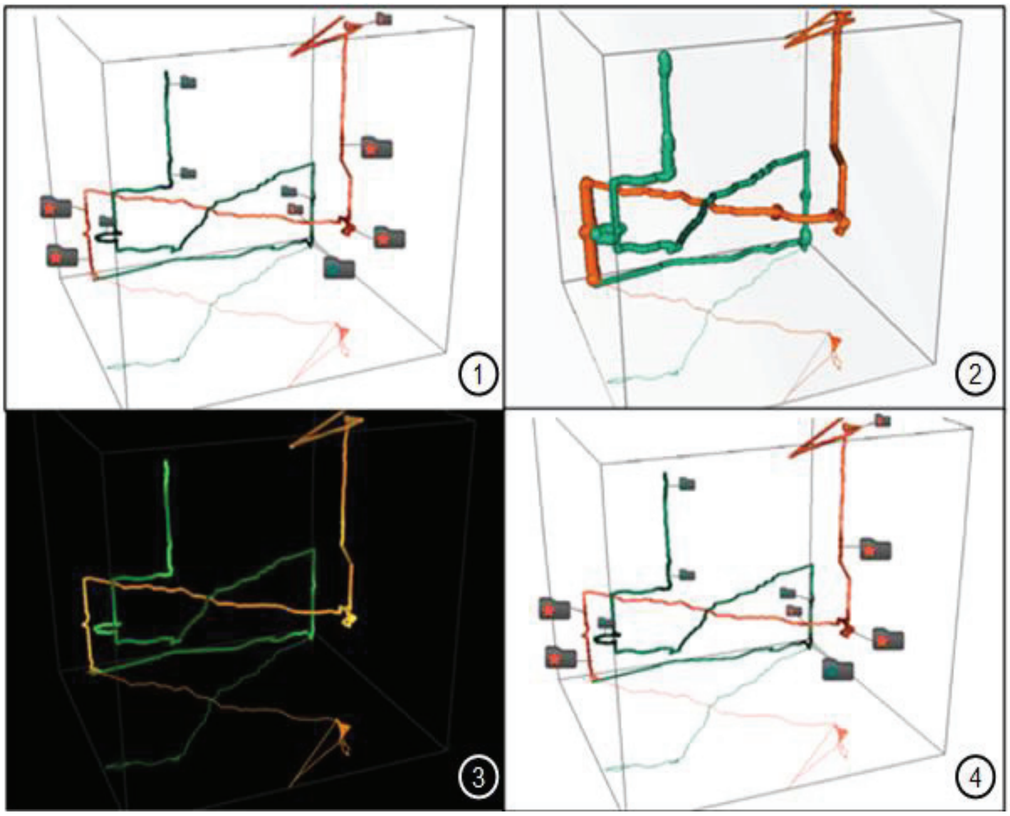


Figure 7. 2 - Four view solutions to aggregate annotations

7.4. Results and Discussion

7.4.1. Results

Results for Q1

The four view options (described in Chapter 6) were provided for the participants' pickups in their first glances. The results are below:

1) 1 participant thought the path width option might cause misunderstanding - The path width represents how many people rather than how many annotations contained. It shows using visual variable of path to show attributes of annotations may lead confusion.

2) Others thought the second one is the best since it was clear to see where more annotations were. The big size on path more easily results in impression of amount difference. The depth perception, the same size objects are bigger in front, is also referred. This cannot be avoided but can be reduced by rotating the cube.

3) 2 participants chose option two and 7 chose option 4 as the best option.

Results for Q2

Question Two asked which path contains most annotations. Participants had to count the total amount of each path.

The results show that only symbols of the first and fourth options could be counted and summed up.

Results for Q3 & Q4

Question Three concerned sections (or parts) of the paths and it asked the participants to compare annotation quantity of different sections belonging to one path. Question Four requested the participants to tell boundaries of sections that contain annotations.

General comment (refer to the marks in Figure 7.3) is that

1) Obvious difference could be observed in the annotation quantity difference using Option Two The
2) Only fussy boundaries between sections with different annotation quantities could be recognized in both Options Three and Four.
3) Nothing was observed in Option One.

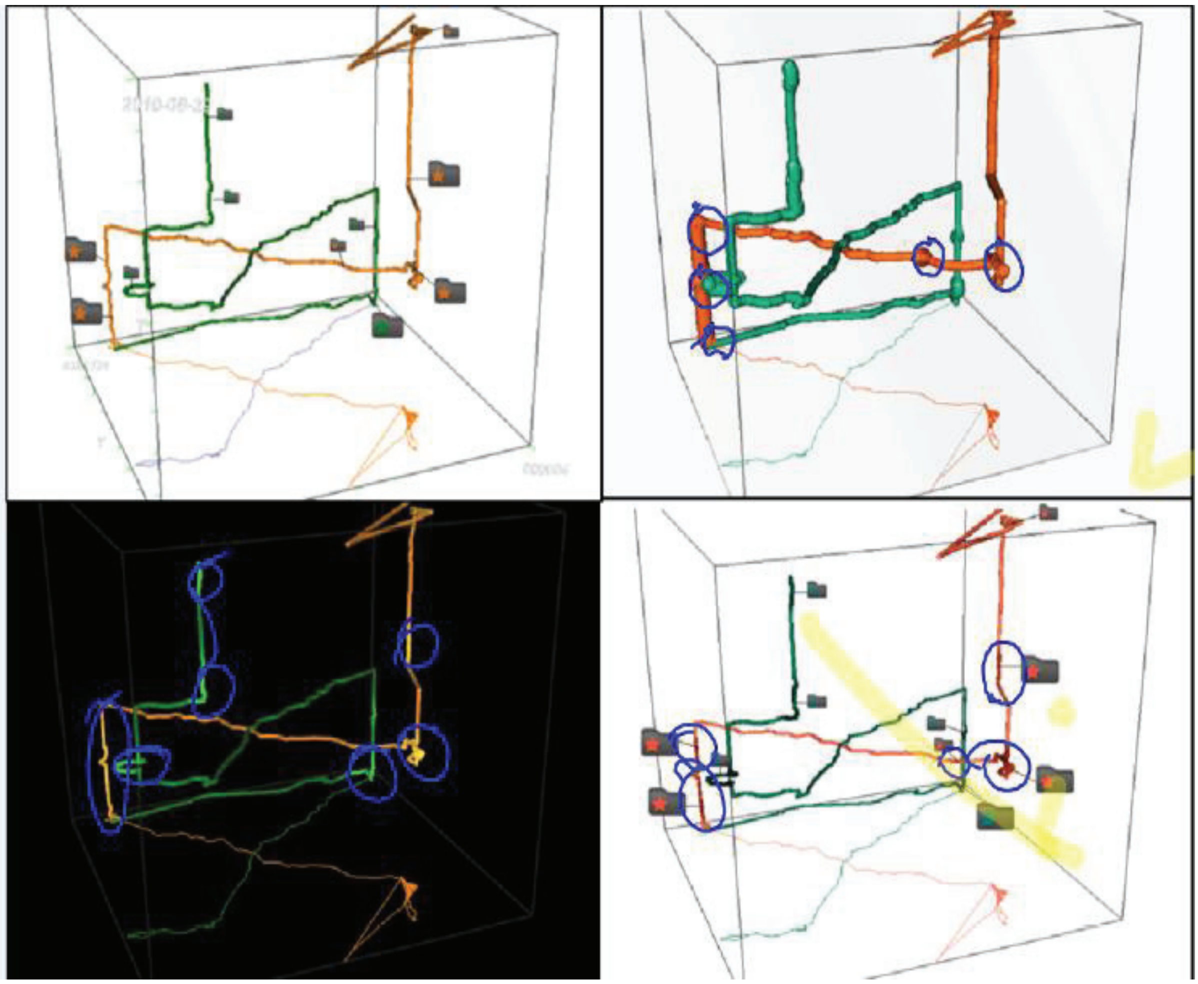


Figure 7. 3 - Illustrations of the participants answers to Q3 (upper) and Q4 (lower)

7.4.2. Discussion

In this survey, two problems were revealed when these marks were analyzed, as described below:

1) The path width aggregates the multi-scale problem; some part where multi-scale happens is thought to be a big size path section (see Figure 7.4 where the red arrow points). It seems this point's width is larger than its neighbours, but actually it is just because here the path twists. The same area of Figure 7.5 displays the real shape of the path.

2) In Option Four, dark value was used to show high annotation density, while in Option Three light value was used to show that. Because shading is used to the path to represent 3D and it is also dark value, it might cause misunderstanding at some parts in Option 4 (see Figure 7.5, where path section enclosed in the red circle didn't contain annotations actually but they were blue-marked by the participants).

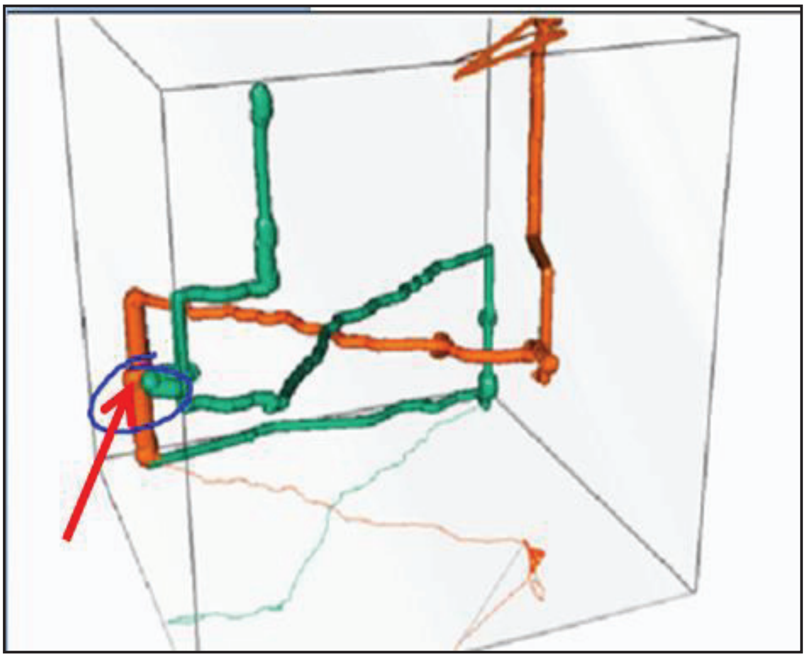


Figure 7. 4 - Path width aggregates multi-scale

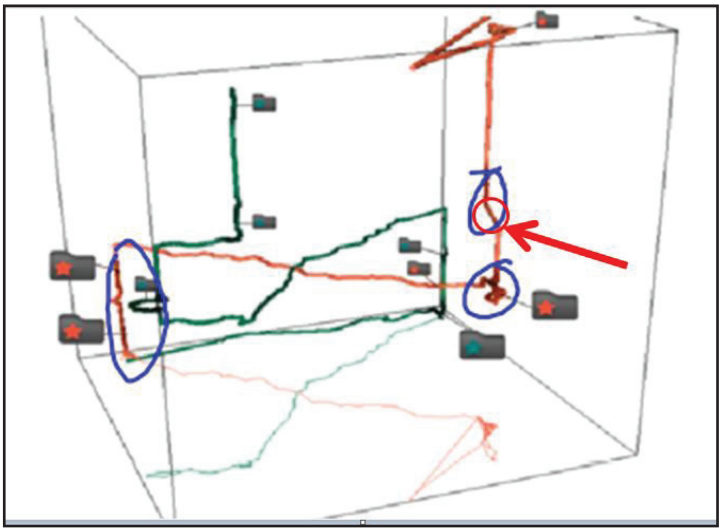


Figure 7. 5 - Shading with confused value

7.4.3. Findings

The general findings of this survey are stated below:

- When annotation (point symbol) size is used to represent annotation amount, different symbols can be "summed up".
- The boundaries between path sections with different annotation amounts are clear when path width is used and is fussy when path value is used.
- The multi-scale problem will be aggregated by path width.
- If dark value is used to show high annotation density, it is easily be confused with shading which is for 3D effect. Therefore use light value to show high density in a black background is a better choice.

7.5. Summary

This chapter describes the evaluation of the A-STP model based on the survey designed and planned.

In the survey, the Focus Group Approach was used in the evaluation using the facilities provided by the department. A well prepared questionnaire was prepared to focus on the visual clutter problems encountered in GIS mapping. Specifically, the user ability study were conducted on the four views (Space-Time-Cube View, Map View, Annotation-Content View and Timeline View) for the aggregated annotations. The recruited participants were highly professional and quite familiar with the subject involved.

The results obtained show that

1) The "summed up" phenomenon occurs when different symbols are used to display a certain amount of annotations.
2) The boundaries between path sections with different annotation amounts are clear if path width is used.
3) The multi-scale problem will be aggregated by path width.

8. CONCLUSION AND FUTURE WORK

The objective of this research focuses on solving visual clutter of the Annotated-Space-Time-Paths. Visual clutter can be introduced in three situations, multi-scale (high variation of path-point per time unit), multiple trajectories and high density of annotations. The suggested solution space is a multi-view environment with special attention to the design of symbology and its use based on Shneiderman's Visual Information-Seeking Mantra. The designing is partly implemented on the platform (uDig) based on available data. Finally, evaluation was executed to test solutions to visual clutter solutions for the high number of annotations.

8.1. Conclusion

The Annotated-Space-Time-Path is the combination of Space-Time-Path and annotation. They are linked based on the "Triad framework" (see section3.3.5). The Annotated-Space-Time-Paths are visualized in a multi-view environment with the Space time Cube as the core visual representation. Shneiderman's Visual Information-Seeking Mantra is applied to explore Annotated-Space-Time-Paths at different visual levels: overview, zoom/filter and details-on-demand. This research aims to solve visual clutter of the Annotated-Space-Time-Paths using three different options: annotation aggregation, zoom for multi-scale and filter for multiple trajectories.

8.1.1. Multiple views

A multiple-view environment is a good choice to visualize the Space-Time-Cube. The interactive, dynamic and alternative views make it easier to explore and understand (see section 2.2.2). Multiple-views are chosen as the visualization environment for the Annotated-Space-Time-Path. Four views are designed (see section 5.2.1), the Space-Time-Cube view, the Map view, the Annotation view and the Timeline view. The Space-Time-Cube view displays Annotated-Space-Time-Paths and allows different visual perspectives by rotating, zooming in/out operations. The Map view shows the tracks of Annotated-Space-Time-Paths in a traditional 2D map. The Annotation view displays details of all kinds of annotations. The Timeline view focuses on temporal projection of Annotated-Space-Time-Paths and shows the temporal annotation distribution.

8.1.2. Annotation Aggregation

Annotation aggregation can resolve visual clutter introduced by high density of annotations. Visual variables can be used to design different solutions (see section 4.1.2). There are four solutions provided (see 5.2.4):

- **Size of Annotation Symbol**

Use annotation symbol's size to represent the amounts of annotation cluster. Annotation symbol size is sensitive to people. Different symbols can "sum up" and thus annotation amounts of different paths can be compared. But the symbol links to point on path and it is difficult to tell to what range of the path section annotation cluster belongs.

- **Path width**

Use thickness of path to represent the amounts of annotations belonging to it. Boundaries between path sections containing different amounts of annotations are clear. But the expanded path width may aggravate multi-scale problem.

- **Path value**

Use different values at different path sections to represent varied annotation densities. Paths visualized like this occupy the least "space" in Space-Time-Cube. But absolute amounts of annotations of different paths cannot be compared.

- **Combine using path value and annotation symbol size**

Use symbol size to represent annotation amount and use path value to represent annotation density. Symbol sizes can "sum up" and compare. Path value can show annotation density of different sections. Boundaries of sections containing different amounts of annotations exist but are fussy.

8.1.3. Zoom for Multi-scale

Multi-scale may lead to visual clutter and details of paths cannot be seen. Although generalization on path can solve this problem, it does not display the realities. What's more, visual clutter caused by multi-scale can represent the high information density of the path sections. Therefore, the visual clutter is not to be solved at overview visual level because it is informative. Zoom is used when visualizing details of part of path (see section 5.2.2).

8.1.4. Filter for Multiple trajectories

Multiple trajectories situation which is similar with multi-scale situation may also lead to visual clutter. Different trajectories affect each other and details may not be visualized. But general tendency may be revealed by huge amount of trajectories. When details of one trajectory are required, filter can be applied to display only interested path and hide others (see section 5.2.3).

8.1.5. Summary

This research aims to solve visual clutter of Annotated-Space-Time-Path. Three situations can cause visual clutter, multi-scale, multiple trajectories and crowded annotations. Each of them is analyzed and solutions are provided to them. Solutions are based on design of symbology and Shneiderman's Visual Information-Seeking Mantra.

8.2. Future work

Besides the six traditional visual variables referred by Bertin (1983), there are some other visual variables which are briefly discussed but are not applied to the Annotated-Space-Time-Path. They can be studies further and applied to Annotated-Space-Time-Paths. What's more, in annotation aggregation method, it is just briefly illustrated that distance between one annotation and the next can be used to decide they should be grouped or departed. Some other calculations may be created.

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