THE VISUAL NARRATIVE OF EVENTS USING ALTERNATIVE TIMELINE REPRESENTATIONS

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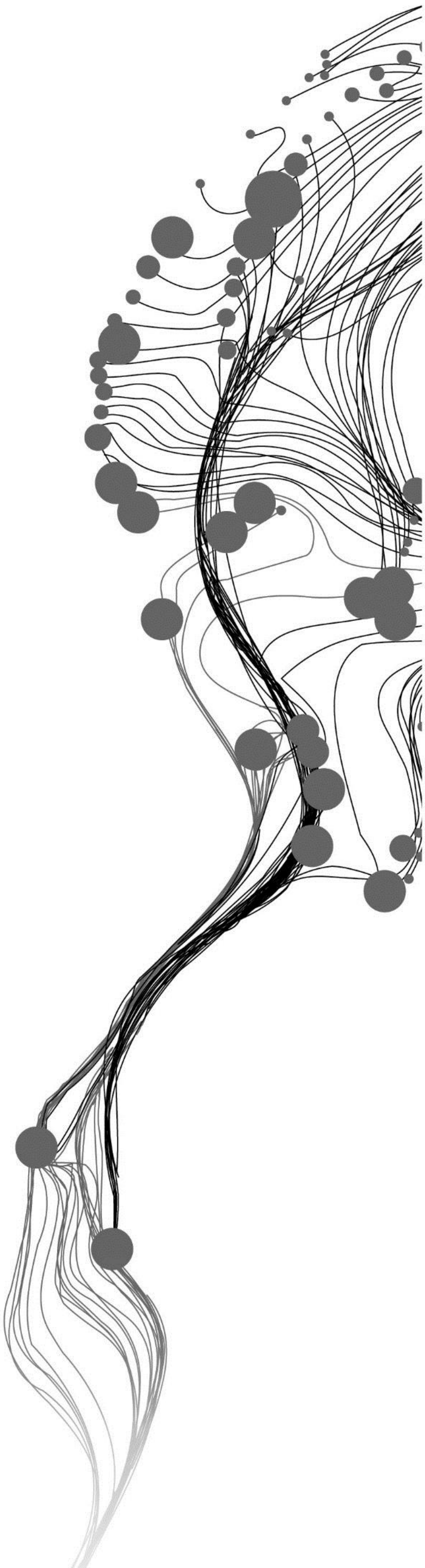

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ABSTRACT

A variety of methods have been developed for the purpose of visualizing movement, which assist analysts visually extracting significant spatio-temporal patterns and collecting information. These include a range of static and animated 2D maps and 3D space-time cubes. However, current techniques may not be effective when tried to extract detailed characteristics of movement and while differentiate the behavior of multiple movements.

This research developed a new timeline based visualization representation, with which most basic movement characteristics (e.g. distance, speed and time etc.) can be visualized in a one dimensional timeline. Benefit from this one dimensional design, the comparison of multiple movements becomes comprehensible. Two use cases were conceptually visualized by this method, from which different behaviors of movements in both cases were successfully revealed.

The conceptual design was further processed in the form of implementation. A representative orienteering data was utilized in this process. The outcome of implementation, a web based visualization system, not only indicates the applicability of implementing the conceptual design into real application, but also functionally supplement the timeline based visualization representation.

The usability of this timeline based visualization representation was evaluated by eight subjects in comparison with the evaluation of a popular movement visualization representation, space-time cube (STC), by other eight subjects. The result shows timeline based representation effectively and efficiently performed better than STC, in terms of extracting detailed characteristics of movements and differentiating behavior of multiple movements.

ACKNOWLEDGEMENTS

I owe particular thanks to Chang'an University for providing me such a wonderful chance to study in ITC. Without the joint project between Chang'an University and ITC, I will not have the chance to start this research. Meanwhile, great gratitude also goes to ITC. Thanks for ITC providing me such a good circumstance of learning. My life will be quite different after the study here.

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Finally, my greatest and deepest appreciation goes to my family for their warm encouragement. I have to apologize for the long-term absence, and I wish my parents and grandparents the life of happiness and prosperity.

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1. INTRODUCTION

1.1. Visualization of movement events

Visualization is a transformation, selection, or representation of data from simulations or experiments, with an implicit or explicit geometric structure, to allow the exploration, analysis, and understanding of the data. The process of visualization design is similar to the process of language translation. If people want to translate a sentence from one language to another, they should understand both language translated from and translated to. Visualization design has the same mechanism. When visualizing data, cartographers should have both a good understanding of data and rich knowledge about visualization concepts and methods. In this section, the concept and characteristics of movement data will be introduced, followed by comparison of several existing visualization solutions.

1.1.1. Movement and movement data

Movement events can be viewed as consisting of continuous paths in space and time (Hägerstrand, 1970). It is a central and fundamental aspect of human life and the development of our society. Many of the vital planning decisions of either individuals of society depend on a correct understanding of movement. For instance, which kind of transport should a commuter pick in the peak morning? How to design an optimal path for travelers, with which they can visit view spots efficiently? These questions can be answered by analyzing historical movement patterns of people or objects.

To analyze movement events, movement data relates to those events are needed, which describes the changes of spatial positions of moving objects (G. Andrienko et al., 2011). Nowadays the movement data are available in growing amounts by means of advanced tracking technologies, such as Global Positioning System (GPS), Radio-frequency identification tags (RFID) and radar etc. Normally, movement data consists of a series of tracking points and has three components, the objects (a set of entities that move), the geographical coordinates (a set of locations that can be occupied by the entities), and the "timestamps" (a set of moments when locations of tracking points were measured)(N. Andrienko et al., 2008).

These three components make movement data be a type of spatio-temporal data, because with which questions related to both spatial (where) and temporal (when) dimensions can be answered. Peuquet (1994, 2002) defined three basic formulas with respect to the three basic components of movement data, objects (what), space (where), and time (when). Each formula describes how one component can be explained by other two components. These formulas are:

1. When + Where → What

It describes the object or a set of objects that are present at a given location or set of locations at a given time or set of times.

The moving object or a set of objects refer to various physical and abstract moving entities. Objects can be classified according to their spatial and temporal properties. Except for being characterized by locations in space and moments in time, the moving objects can also be characterized by their own characteristics, such as speed, direction and acceleration etc. However, these characteristics can be derived from the values of the basic components.

2. When + What → Where

It describes the location or a set of locations occupied by a given object or a set of objects at a given time or a set of times.

Space is a set of locations, or places. An important property of space is the existence of distances between its elements. Another important concept in space is that the space has no origin and no natural ordering between the elements. Therefore, for distinguishing positions in space, it is necessary to set the positions into some reference systems, for example, a geographical coordinate system. Space can be treated as two-dimensional or as three-dimensional, which depends on the practical needs, but in specific cases, space can be viewed as one-dimensional as well. For instance, when we analyze a movement along a standard route, we can define positions as the distances from the beginning of the route, which means a single coordinate is sufficient.

3. Where + What → When

It describes the times or sets of times that a given object or a set of objects occupied a given location or set of locations.

Mathematically, time is a continuous set with a linear ordering and distances between the elements, where the elements are moments or position in time. In most cases, temporal referencing is done on the basis of the standard Gregorian calendar and the standard division of a day into hours, hours into minutes, and so on. However, in some cases time refer to relative time moment or specified the time as abstract time stamps like 1, 2, and so on. Unlike the physical time, abstract times are not necessarily continuous. Physical time is not only a linear sequence of moments but includes inherent cycles resulting from the earth's daily rotation and annual revolution, such as 4 seasons in one year and every month including fixed days. Besides these natural cycles, there are also cycles related to people's activities, for example, the weekly cycle. Temporal cycles may be nested like the daily cycle which is nested within the annual cycle. Therefore, time can be regarded as a hierarchy of nested cycles.

These three basic components constitute the general framework of spatio-temporal data. Movement data which records and describes movement events normally follow this framework. **Figure 1.1** shows the conceptual model of spatio-temporal data framework.

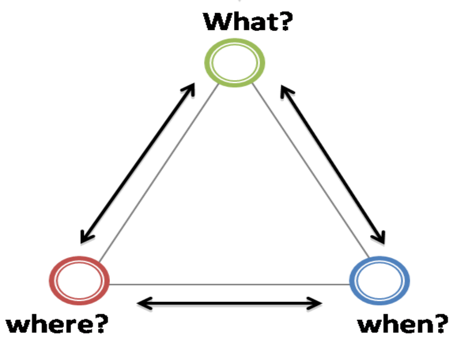


Figure 1.1 the conceptual model of spatio-temporal data

A well-known term that describes movement based on the framework is trajectory. It is the path made by the moving object through the space when it moves. Space is one important aspect of a trajectory since the path should be created in a spatial reference. At the same time the path is not made instantly but needs a certain amount of time, thus time is an inseparable aspect of a trajectory. Therefore the trajectory can be treated as 'space-time path'. **Error! Reference source not found.** illustrates a space-time path in continuous two-dimensional space.

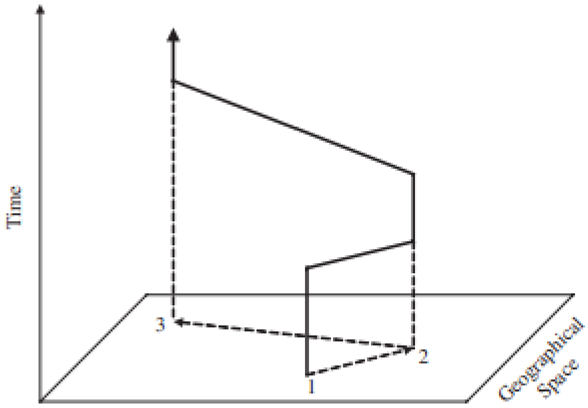


Figure 1.2 A space-time path (Miller, 2005)

According to N. Andrienko et al. (2008), the overall characteristics of a trajectory as a whole or a trajectory fragment made during a subinterval [t1, t2] of the entire time span [t0, tend] include:

1. geometric shape of the trajectory (fragment) in the space;
2. travelled distance, i.e. the length of the trajectory (fragment) in space;
3. duration of the trajectory (fragment) in time;
4. movement vector (i.e. from the initial to the final position), or major direction;
5. mean, median, and maximal speed;
6. dynamics (behaviour) of the speed:
   - periods of constant speed, acceleration, deceleration, and stillness;
   - characteristics of these periods: start and end times, duration, initial and final positions, initial and final speeds, etc.;
   - arrangement (order) of these periods in time;
7. dynamics (behaviour) of the directions:
   - periods of straight, curvilinear, circular movement;
   - characteristics of these periods: start and end times, initial and final positions and directions, major direction, angles and radii of the curves, etc.;
   - major turns (`turning points') with their characteristics: time, position, angle, initial and final directions, and speed of the movement in the moment of the turn;
   - arrangement (order) of the periods and turning points in time.

These characteristics provide detailed information of movement. To investigate the behaviour and pattern of movement, an effective way is to properly visualize characteristics of movement.

1.1.2. Current solution of movement data visualization

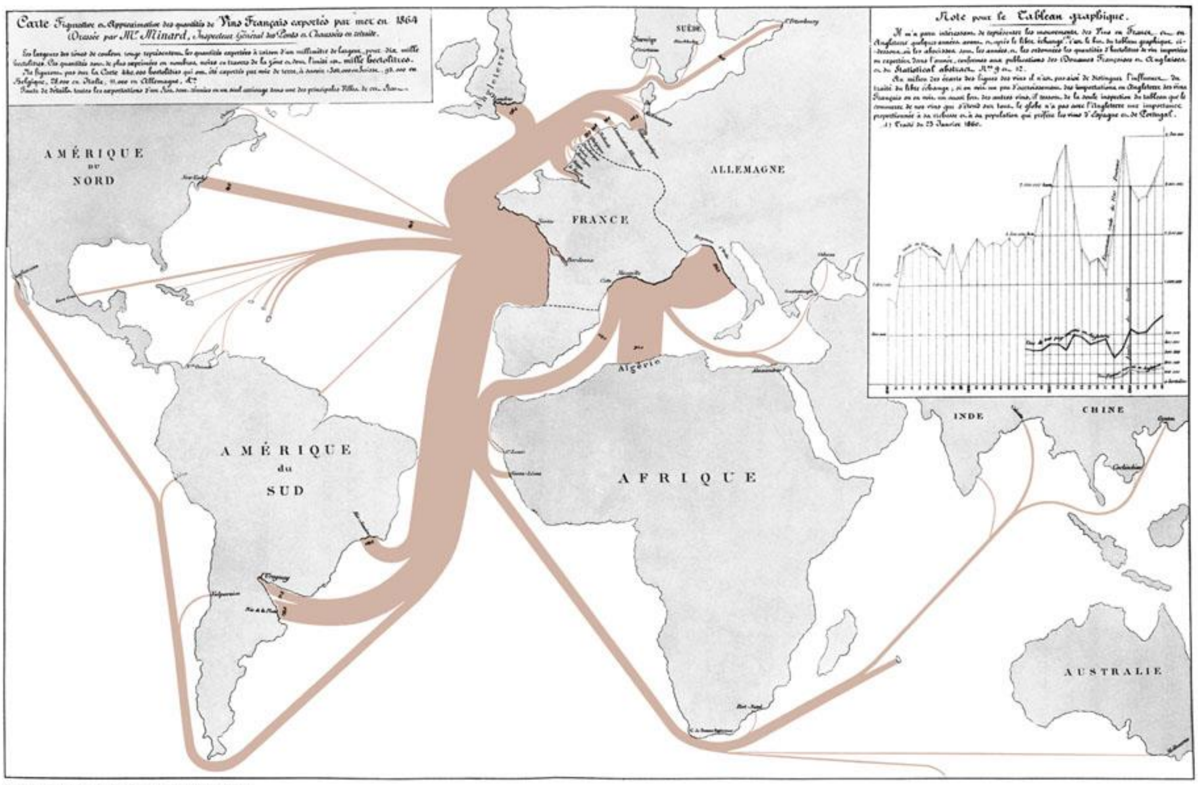
Nowadays, benefit from rapid developed modern computer technologies, an increasing number of computer based solution for visualizing movement data were developed. However, as they were designed from different perspective (e.g. from either geography or time), each of them has its own merit and drawback.

Some solutions are mainly from geography perspective, and they can present spatial information well but has a limited performance of presenting temporal information, such as flow maps (see section 1.1.2.1). By contrast, some other solutions are more focusing on temporal perspective. For instance, timeline can display the chronological order of moving objects' position and attributes well but cannot deliver enough spatial reference, like timeline (see section 1.1.2.2). In this section, some representative visualizations from geographical, time and a combination of geographical and time perspective will be discussed respectively.

1.1.2.1. From geography perspective

a. Flow maps

Flow maps illustrate the movement of objects among locations. A flow map shows the spatial distribution of univariate geographic phenomena. Cartographers have used flow maps to depict migrations, trade, and any data set with a from-to relationship. One well known example is Charles Minard's visualization of French wine exports around 1864 (see Figure 1.3). The width of each line represents the volume of wine exported from France. The lines decrease in proportion at each branch point. The flow map is also accompanied by time-series plots to illustrate the temporal information of the movement.



Charles Joseph Minard, *Tableaux Graphiques et Cartes Figuratives de M. Minard, 1845–1869*, a portfolio of his work held by the Bibliothèque de l'École Nationale des Ponts et Chaussées, Paris.

Figure 1.3 Minard's map of French wine exports around 1864 (http://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=00002j)

Another example is Minard's map about Napoleon's Russian campaign, which is a very classic case of using the idea of flow map. The path Napoleon march to and retreat from Russian was depicted by two bands in different color and position. The width of bands represent the population of army (see **Figure 1.4**). The temporal information is presented by a timeline at the bottom of the map.

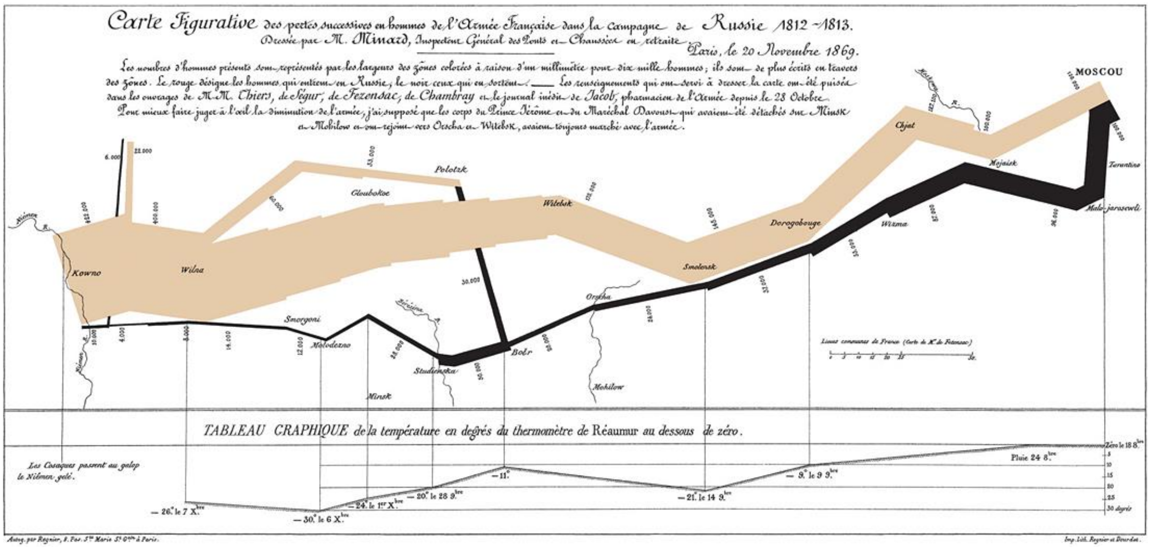


Figure 1.4 Minard's map of Napoleon's Russian invasion (http://www.itc.nl/personal/kraak/research/projects-1812.html)

b. Schematic maps

Schematic maps are highly generalized maps used for representing routes in a transport system or in any scenario where the flows or directions of objects at nodes is important, such as cartographic schemas for gas, water, or electricity mains (Avelar and Hurni, 2006). In graphics and language, schematization is an important method to emphasize certain aspects and to deemphasize others (Dong et al., 2008). In schematic maps all routes are usually drawn as straight lines and the lines vary in direction via fixed, stylized angles, commonly of 45 and 90 degrees or of 30, 60, and 90 degrees, or are merely simplified with arbitrary angles. **Figure 1.5** shows the latest version of London underground schematic map, which was first designed in 1931 by Henry Beck (Garland and Beck, 1994). In this map links between different routes are simplified in order to help passengers get to the right stations, make the right transfer and get off at the right destinations. The main advantage of schematic maps is that they provide a quick overview of the layout of the network, without showing unnecessary information like the precise shapes of the connections. Beside the widely use in transport system, the schematic map can also be used for presenting the route of movement. The significant position in the movement will be emphasized and the unnecessary details can be omitted. But in this case it will be difficult to present temporal information on schematic map simultaneously, which is the main limitation for using schematic map to depict movement data.

Figure 1.5 London underground map (http://www.tfl.gov.uk/assets/downloads/standard-tube-map.pdf)

1.1.2.2. From time perspective

A typical way to visualize movement from time perspective is timeline. It is a way of displaying a list of events in chronological order, which shows a long bar labeled with dates alongside itself and events labeled on the time when they happened (see **Figure 1.6**). A timeline can be used to visualize time intervals between activity, durations of each activity and the simultaneity or overlap of spans and activities. In consideration of these characteristics of timeline, it is also suitable for presenting the movement data. A timeline can show the sequence of activities in movement, the precise occurrence moment of every important position or activity in movement, the stop duration of every important position and event, and also the time intervals between them. The temporal component of this movement can be presented by timeline unambiguously and efficiently.

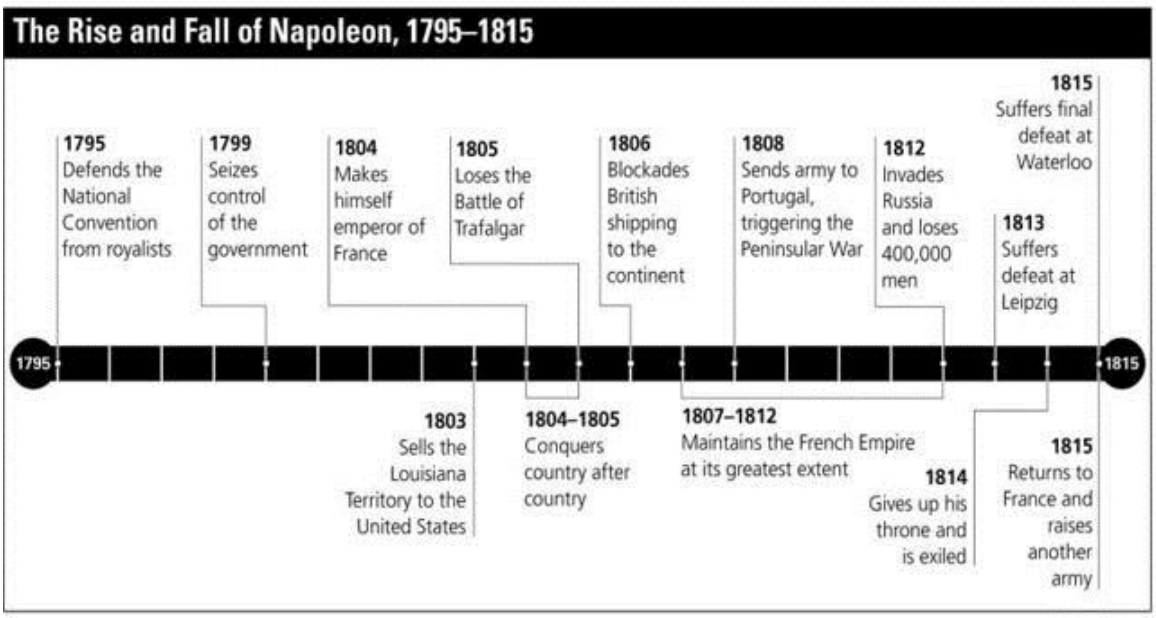


Figure 1.6 The rise and fall of Napoleon presented by a timeline
(http://mcclureshistoryhub.wikispaces.com/Napoleon+Project)

1.1.2.3. From both geography and time perspective

a. Animations

Animated maps, sometimes called movie maps or change maps, are primarily used to describe geographic changes and processes. According to Ogao and Kraak (2002), 'Animations enable one to deal with real world processes as a whole rather than as instances of time'. Therefore this characteristic ensures the animated maps to directly effect on conveying dynamic environment phenomena such as movement. Usually it is a rapid display of a sequence of 2D or 3D images. **Figure 1.7** shows a snapshot from an animation which shows the two tourists' movement in Acropolis; it reflects the moving process of each tourist in this area and the stop on each view spot. If the display change (tourists' moving process) is abrupt, the reader may experience change blindness (Nowell et al., 2001), which makes the changes hard to recognize. This problem generally exists in the animation map. Although the amount of data that can be represented within an animation is virtually unlimited, the amount of information which can be absorbed from the animation and stored in the short-term visual memory by the users is finite (Harrower and Fabrikant, 2008).

Figure 1.7 A snapshot of the animation for two tourist movement in Acropolis

b. Space-Time-Cube

Hägerstrand (1970) introduced a framework of time geography which include space-time path and space-time prism. His theory has been applied and improved to understand movements in space in following years. The STC (space-time-cube) is the visual representation of this framework where the cube's horizontal plane represents space and the 3D vertical axis represents time. But when the concept was introduced at first, the options to create the graphics were limited as a result of low-level computer techniques. Creating a space-time-cube was a very complex and time-consuming work at that time. With the development of computer science and cartography nowadays, creating a STC is no longer a difficulty. **Figure 1.8** is an example of space-time cube visualization of Napoleon's Russian campaign created by ITC group.

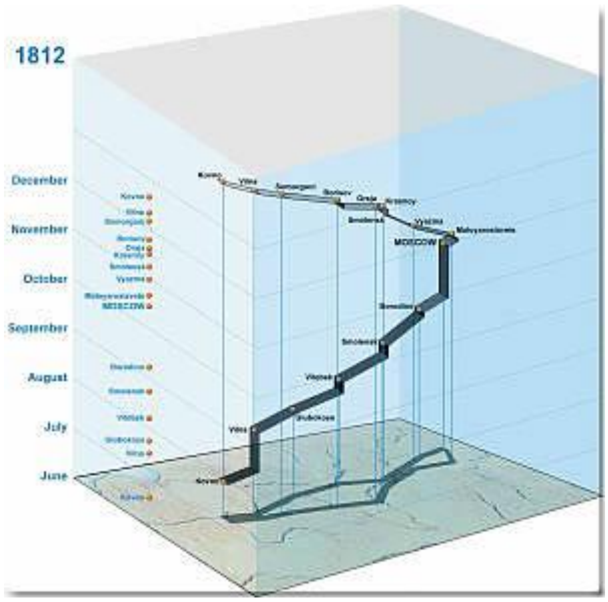


Figure 1.8 Napoleon's Russian invasion visualized in STC
(http://www.itc.nl/personal/kraak/1812/minard-itc.htm)

The Space-Time-Cube (STC) is a good example showing both the spatial information and the temporal information at the same time. STC is three-dimensional visualization developed by Hägerstrand (1970). It presents the two-dimensional geographical information (along the x- and y-axis), while the cube's height represents time (z-axis). When researchers intend to visualize and analysis patterns of human activity-travel behavior, the path can be presented as lines connecting various destinations in 2D graphical method, but the information about the timing, duration, and sequences of activities and trips will be lost. Compared with tradition 2D map, STC has good performance in answering time-related questions. There are, however, several difficulties in the use and development of this 3D method. STC as a 3D visualization is more complex than traditional 2D visualizations. This natural complexity may bring some barriers to researchers. For example, there is limitation in human ability to identify patterns and relations when dealing with complex movements or multiple layers and variables viewed simultaneously (Gahegan, 1999; Kwan et al., 2004).

Comparing with tradition 2D map, STC has better performance in answering time-related questions. However, there are several difficulties in the use and development of this 3D method. STC, as a 3D visualization, is more complex than traditional 2D visualizations. This natural complexity may bring some barriers to researchers. For example, there is limitation in human ability to identify patterns and relations when dealing with complex movements or multiple layers and variables viewed simultaneously (Gahegan, 1999; Kwan et al., 2004).

1.2. Research problems

Current visualization representations for movement are either not well enough to represent all the characteristics of movement or too complicated to make user understand when comparing multiple trajectories.

Specifically, the representation designed from geography perspective hardly present temporal information, whereas that designed from time perspective barely express spatial information. Seen from Both French Wine Export Map and Napoleon's Russian Campaign Map, these two flow maps are good to show the track of movement but the temporal information are missing. They need to be associated with time series plots or timestamps in order to, to some extent, visualize temporal characteristics of movement. Similarly, timeline as a typical visualization representation mostly focus on the temporal characteristics of movement but it is not appropriate to visualize spatial information.

Although some representations were designed from both geography and time perspectives, which can better represent spatial and temporal characteristics, due to the complexity they might bring cognitive obstacle when users try to interpret movement, especially when comparing two of more trajectories together. For instance, in **Figure 1.9** eye tracking movement data from six participants was represented through the space-time cube. It is obvious that as all the trajectories were mixed together, the comparison of them are quite difficult, or even impossible.

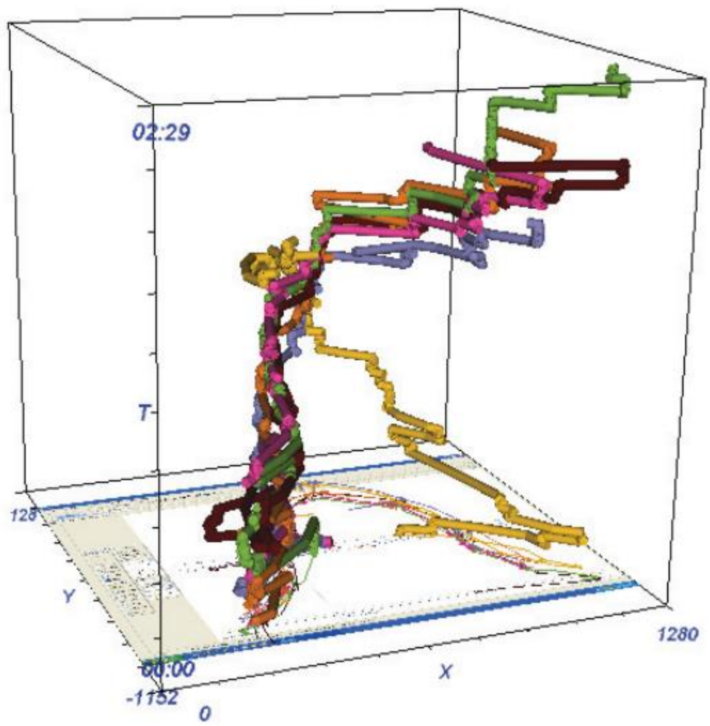


Figure 1.9 STC for eye movement tracking data (X.Li, 2010)

1.3. Research objectives

This study is set to designing a timeline based visual representation (alternative timelines) for the purpose of visualizing characteristics of movement, and making the visualized information easily understandable and comparable, in turn, to help people get insight into the movement data and its related event. The term 'alternative timeline' refers to a timeline based representation, which is also in combination with other techniques.

The main objective can be attained by reaching three sub-objectives:

1. To conceptually design a visualization representation for movement data.

2. To implement the design in the context of several applications in a web environment.
3. To evaluate the usability of the implemented design.

1.4. Research questions

1. What is the characteristic of movement data?
2. What kinds of graphic representations are currently used to visualize the temporal aspect of movement data and what are their limitations?
3. How can an interactive timeline support the visualization of movement data and clarify the temporal aspect?
4. How to present geographic information on a timeline and which method will be used?
5. How can cartogram principle be applied on a timeline in relation to movement data?
6. What is break point and how to link break points to movement data?
7. How can the above ideas be implemented in a web environment?
8. Are their constraints caused by the nature of the application data in respect to the implementation?
9. What techniques will be used for evaluating the usability?
10. How to setup a usability evaluation to get insight in the users' satisfaction and efficiency and effectiveness of the tool?

All research questions are going to be answered based on not only the outcome of the design and the implementation, but also the result of usability evaluation.

1.5. Structure of the thesis

Firstly, investigate the foundation of concept and techniques, from which the new representation will be built, and introduce the general perception of design based on those discovered foundations. Secondly, classify the type of movement and make the design of visualization representation accordingly.

Chapter 1: In the first chapter, the background of this research is introduced. Meanwhile, the existing visualization solution for the movement data is reviewed, and followed by posing research objectives and questions.

Chapter 2: This chapter
Introduces the work flow, and also focuses on the core concepts and techniques that will be employed as foundation of this research.

Chapter 3: This chapter describes the conceptual design of the alternative timeline representations. Firstly, several important concepts and techniques used in the visual representations are introduced, and then the method utilizing and integrating those concepts and techniques to visualize movement data.

Chapter 4: This chapter illustrates the development of the prototype implementation in the context of an application dataset. It mainly contains two parts, the preparation part and the visual representation implementation part. In the preparation part, the criteria for break point extraction are discussed.

Chapter 5: This chapter focuses on the usability evaluation for the implemented prototype.

Chapter 6: The conclusion and recommendation of this research is introduced in this chapter.

2. WORK FLOW AND CORE TECHNIQUES

2.1. Work flow

This research can be summarized into five stages, literature review, data preparation, conceptual design, implementation and usability evaluation.

1. Literature Review

Several relevant aspects and core techniques of this study is going to be reviewed from literature, such as concept of movement data, the existing visualization method for spatio-temporal data and movement data, the concept and application of timeline, cartogram and schematic map, the technology for implementing conceptual visualization design, and the usability evaluation techniques etc. Those reviews will contribute to this research as theory base.

2. Data Preparation

Movement datasets for both conceptual design and implementation have to be collected and processed beforehand. Most of data came from GPS tracking, which cannot be directly used for neither design nor implementation, as the data structure and field of attribute of different GPS receivers might different. In addition, GPS tracking data always has errors that results from factors like weather and obstructions of signal, which might affect the differentiation of stop and moving. Sometimes the extraction of stops needs Manual intervention. Therefore, it is necessary to analyze and process the raw datasets to make them have same structure, and the stops can correctly be extracted.

3. Conceptual design

In this phase, the proposed visualization representation will be conceptually designed for a single movement, and then extend to for multiple movement. The way of how to define stops, how to integrate time and geographic parameters together into a one dimensional line, and how to make multiple movement data comparable etc. will be introduced in this stage. The conceptual design will reveal the process of a conversion from idea to feasible design, which is the fundamental of the implementation.

4. Implementation of the prototype

Based on the conceptual design, a prototype of application is developed. An orienteering dataset including two trajectories is utilized for the implementation. The implementation is based on web environment, which gives better accessibility for the usability evaluation and future use.

5. Usability testing and evaluation of the prototype

In this phase, the usability of the prototype application will be evaluated. The method, with which this evaluation is conducted, and the result that reveal some advantages and disadvantages of this visual representation will be introduced in this part.

2.2. Core concepts and techniques

The stage three, four and five, conceptual design, implementation and usability evaluation, are the core parts of this study. A number of core techniques need to be employed to support the conducting of each steps.

2.2.1. Core concepts for conceptual design

Timeline is chosen as the basis of the design because it is a one dimensional representation (a line). If the characteristics can be visualized by a one dimensional representation, it will be much more understandable and comparable. However, a one dimensional representation is difficult to represent more than parameters (e.g. time and distance). Therefore, cartogram principle is employed to make a one dimensional timeline to represent multiple parameters.

A cartogram is a map where the geographic features distorted based on some variable in order to express this variable (which has no geographic characteristics) efficiently. It can visualize statistical data about a set of regions, where the size of a region in a cartogram is corresponded to a particular variable (van Kreveld and Speckmann, 2007). Since cartograms change the geographic space depending on a certain attribute, it is not a geographically-correct map but rather a geographically-distorted map. Cartograms offer an alternative visualization and provide the user to look into the problem from a different prospective. It has become an increasingly popular tool to visualize geographical or statistical data due to their captivating design and creativeness (Bhatt, 2006; Kocmoud, 1997).

There are three major types of cartograms: area, linear and central-point. An area cartogram is a map transformation in which the map regions are reshaped according to some variables such as population or economic indices (Tyner, 1992). There are two basic forms of area cartogram, namely non-contiguous cartogram and contiguous cartogram. The non-contiguous cartogram is one of the simplest forms of cartogram. It keeps the shapes of every geographic object correctly, but those objects do not touch each other and they are separated by empty spaces. The gap between objects allows the objects to grow or shrink their size and still maintain their shape. In contiguous cartogram, the topology (connectivity between objects) is maintained and there are no gaps between objects. The shape of geographic objects is distorted based on the attribute value. In this case cartographers should make sure the size of objected is appropriate so that it can be easily interpreted and recognized(Dent, 1999).

In linear cartograms, the length of geographic objects is resized according to the attribute being mapped. Usually the normal distance can be replaced by travel-time or travel-cost. According to Tyner (1992), linear cartogram can be also called as distance-by-time cartogram which creates the map more based on the length of travel time between two places than actual geographic distance. Shimizu and Inoue (2009) present a new algorithm of distance cartogram and provide an application for it. They visualize the changes of railway transportation in Japan over years (see **Figure 2.1**). The distance cartograms show the difference in region and the changes over time of the transportation service level. From the figure it is obvious most of the connections between regions are getting shorter, which means the quality of transportation service is improved.

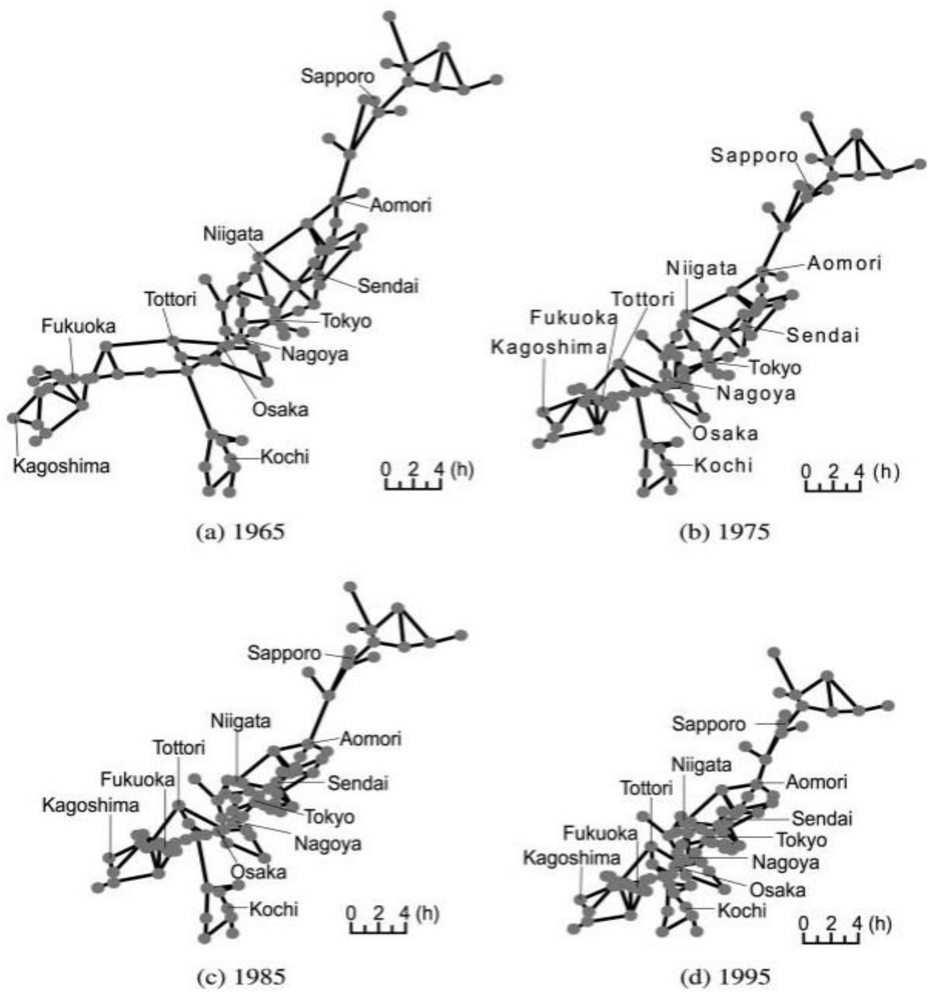


Figure 2.1 Railway service in Japan over years by Shimizu and Inoue (2009)

A point cartogram shows travel-costs or travel-time form a center starting point to other locations in a region. In this map direction is significant since time cannot be fixed between any other points of the map because all points are related to the center. Concentric circles, which have the function of equal time isochrones line, distort the geographic base by removing some locations from the center and moving others closer. In 2005 Carden presented the interactive map of the London Tube map where he distorted geographic space in order to create equal travel time, which illustrates the shortest path from one station to other stations (see **Figure 2.2**).

Figure 2.2 London underground point cartogram (http://www.tom-carden.co.uk/p5/tube_map_travel_times/applet/)

It can be seen from the above-mentioned statement related to cartogram that a cartogram is one of such maps where it is possible to replace geographic-coordinates by time-coordinates. That is, the geographic space can be distorted based on time and the geographical-distance can be replaced by the travel-time (Tyner, 1992). Cartograms, which provide different form of maps to illustrate time information, provide a solution to analyze movement, to show future scenarios, and to visualize changes and trends over time.

2.2.2. Core techniques for implementation

D3.js (D3 for Data-Driven Documents) is a JavaScript library uses digital data to drive the creation and control of dynamic and interactive graphical forms which runs in web browsers. It is a popular tool for data visualization recently, which provides a way to bring data to life using HTML, SVG and CSS. "In contrast to many other libraries, D3 allows great control over the final visual results (http://www.datameer.com/blog/uncategorized/whats-behind-our-business-infographics-designer-d3-js-of-course-2.html)". D3.js works on the web environment so it makes the data visualization can be seen by more people, on the internet, in their browsers. It is very flexible because it works seamlessly with existing web technologies, and can manipulate any part of the document object model. The visualization created by D3.js could be interactive and dynamic, which gives users more useful information in an efficient manner. In conclusion, it is better to use D3.js to implement the conceptual design of timeline representations.

2.2.3. Core techniques for usability evaluation

Think-aloud testing

Think-aloud is going to be used as the main testing method in this study as it is one of the most widely used method in usability testing, which is a techniques that evaluating the usability of somebody's work by encouraging users (or subjects) to think out loud as they use the products or services. It is a way to gain insight into test participants' thought processes, and plays an important role in usability data collection (Boren and Ramey, 2000).

The basic principle of this method is that potential users are asked to complete a set of tasks with the artefact tested, and to constantly verbalize their thoughts while working on the tasks. The method has high face validity, since the data obtained reflect the actual use of an artefact, and not the participants' judgments about its usability (Van Den Haak et al., 2003).

Eye-tracking

Sometimes self-report measurements, like think-aloud protocols or questionnaires, produce biased or even wrong data which are not predictive for behavior (Schiessl et al., 2003). This is because subjects are aware of the test situation. The description and verbalization of their own behavior might be biased in terms of subjective factors, such as willing to please experimenters or simply to give a good impression.

One of the tools that helps us delve deeper into user behavior during online search is eye tracking. Eye tracking has been used to study human behavior for decades and has contributed to our understanding of activities such as reading, scanning, and overall processing of visual stimuli (Lorigo et al., 2008). If we can track someone's eye movements, we can follow along the path of attention deployed by the observer. This may give us some insight into what the observer found interesting, that is, what drew their attention, and perhaps even provide a clue as to how that person perceived whatever scene she or he was viewing (Duchowski, 2007).

Therefore, eye-tracking techniques is employed to provide additional information to be a supplement of evaluation data acquired from think-aloud method.

3. CONCEPTUAL DESIGN

3.1. General perception

3.1.1. Timeline combined with schematic map

The proposed visualization method is designed for the purpose of fully presenting the three components of movement data, space, time and objects. It has a narrative function for the movement, with which people are supposed to easily understand the whole process and reveal hidden characteristics of movement. This design not only draws merit from exist visualization method, but also novelly combines timeline, schematic map and cartogram principle together.

The advantage of timeline is that it can efficiently display the chronological order of stops on important positions of a movement. However, it is weak in presenting spatial information. Most timeline-related applications were designed without any spatial-related information communication. In order to present both spatial and temporal information when trying to visualize a movement, therefore, it is better to combine timeline with a method that can well visualize spatial information.

One solution for visualizing spatial information is schematic map. It is a highly generalized map for showing routes in transport systems, which can also be used for visualizing movement data. It emphasizes certain aspects while deemphasizing others. Schematic map provides a quick overview of the layout of the network of system, or the route where the moving objects passing by. Therefore, it is possible to combine timeline with schematic map to visualize movement data, where the timeline allows readers have a temporal reference and the schematic map provides the spatial reference. The combination of two representations could have the ability to present all the three components of movement data.

This visualization method has two essential parts, timeline and schematic map. In order to represent both temporal and spatial information, these two parts need to be designed first. The timeline can be divided into a time units in accordance with the movement duration. The size of unit depends on the duration of movement and minimum time of stops. For example, if a movement lasts more than two months and the stop of moving object on each stop lasts at least five days, it makes no sense to use hours as unit (lead to too many units), but the reasonable unit can be one or several days. For a short duration of movement (e.g. 28 minutes), if the minimum time of stops is one or several minutes, then the unit can be defined as one minute (**Figure 3.1**).

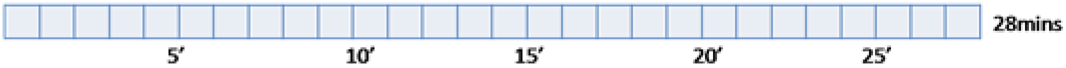


Figure 3.1 Timeline indicates the duration of movement, on which each unit represents one minute

The schematic map is created by stretching movement path into a straight line. The length of this straight line should be consistent with the timeline, in order to keep start and end points of the schematic map perpendicularly correspond to the start and end time of timeline. The next step is to calculate stretched distance between break points, in order to the plot the break points on the stretched line. Due to the real distance between break points, the real distance of entire movement and the stretched length of schematic map are known; the stretched distance between break points can be calculated by the formula:

$$\text{stretched distance} = \frac{\text{real distance} \; * \; \text{stretched length of schematic map}}{\text{real distance of entire movement}}$$

Figure 3.2 shows how a movement path was stretched to a straight line.

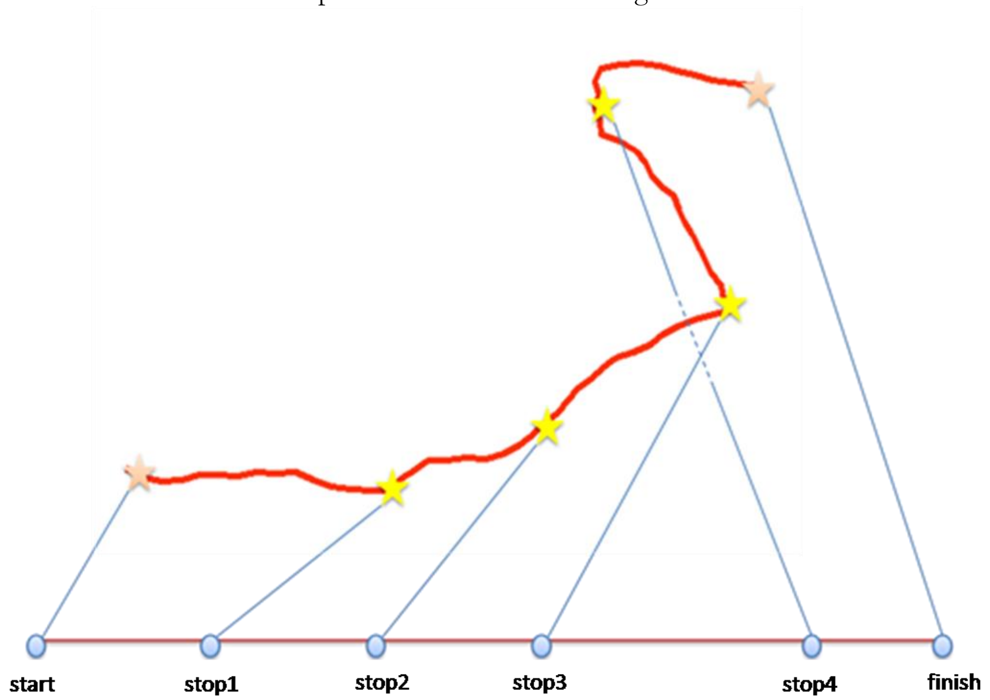


Figure 3.2 The transformation from GPS track to linear schematic map

The last step is to combine the timeline and schematic map together and build a logical connection via the break points (**Figure 3.3**). With this visualization representation, a movement can be described both temporally and spatially, and some relavent questions can be answered. For instance, how many stops that the moving object stopped and where are their relevant locations; when the moving object arrived at and departed from the each stop; and how much time did it take between every two stops etc.

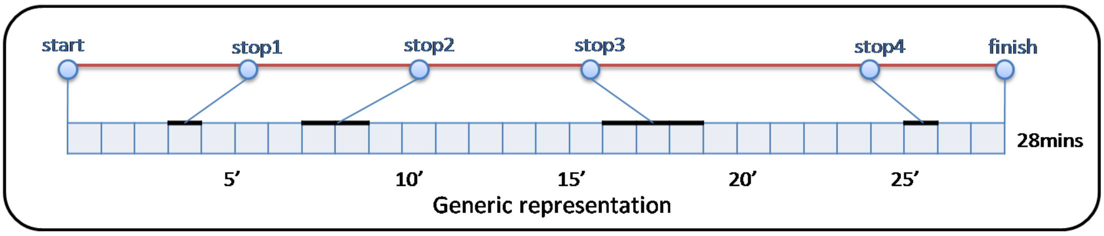


Figure 3.3 Timeline combined with schematic map

However, durations for both moving and static parts of movement have to be acquired from a combination of timeline and schematic map. While the number of moving entities increase, this combination have to be duplicated to visualize the movement of each entity. Nonetheless, simply duplicate timeline and schematic map makes the visualization of multiple movements incomparable and difficult to be interpreted. Moreover, some vital characteristics of movement, such as the change of speed, cannot be revealed from this representation. Therefore, in order to make the visualization representation easily understandable and information-rich, the cartogram is employed to deeply integrate timeline and schematic map.

3.1.2. Integrate timeline into schematic map

One solution is to integrate timeline into schematic map. Applying cartogram principles, the schematic map can be stretched or compressed by the length and unit of timeline. On the schematic map (**Error! Reference source not found.**), the stops on schematic map were stretched to strips, which have the same length as the stop duration on the timeline. As this representation is designed from time perspective and the geographic presentation has been distorted, it can be called that the representation "from time to geography".

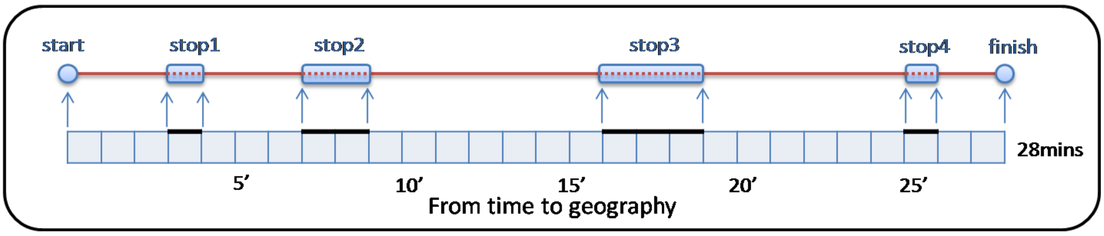


Figure 3.4 "From time to geography" representation

This representation not only clearly differentiates the moving and static part of moving entities, but also apparently shows the duration of each stage of movement on the schematic map. The advantage of this is that it is easy to compare multiple trajectories by only adding the integrated schematic maps (**Figure 3.4**).

However, due to the schematic map in this representation is distorted, it cannot convey distance information correctly. **Figure 3.5** demonstrates the comparison of former schematic map and the distorted one, where the ratio of length between two break points in new schematic map no longer represents the real distance ratio. To remedy the situation, another way of integration of timeline and schematic map is introduced.

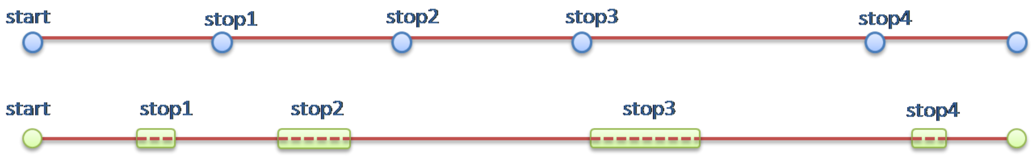


Figure 3.5 The schematic map in common representation and "time to geography" representation

3.1.3. Integrate schematic map into timeline

The other way is to integrate schematic map into timeline. In this integration, the timeline is going to stretch based on the spatial information of relative moving distance from the schematic map. The key point of this integration is that the stops on the schematic map should be perpendicularly projected on timeline. This projection makes it impossible to show the duration of stops on timeline. So the total amount of time units becomes less than the un-stretched timeline, and the time units of each moving part (the part between stops) either expanded or shank for the purpose of fitting both moving distance and the amount of time that spent for these distances. In other words, the timeline firstly was divided into several moving process by stops, and each part of the timeline represents different moving parts. Those parts will be divided separately into timeline unit according to their own moving duration.

This representation keeps the schematic map so the geographic information is correct as generic representation, but the timeline is resized based on the unchanged schematic map. Therefore, it can be called as "from geography to time" (see **Figure 3.6**).

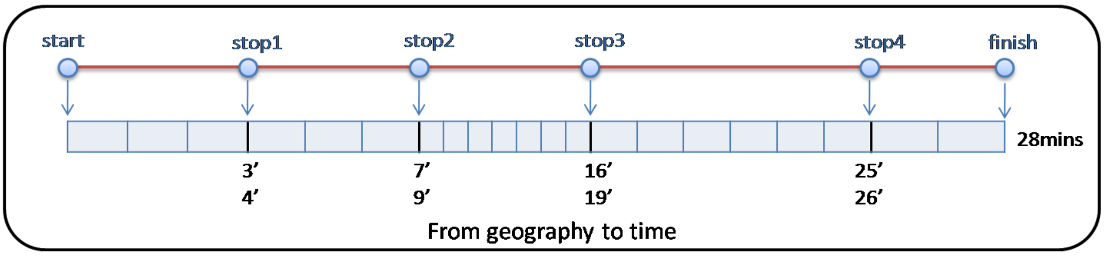


Figure 3.6 "From geography to time" representation

The integrated timeline not only keeps the spatial information (relative moving distance), but also reveals another vital characteristic of movement, the relative speed, which is represented by the length of time units. The longer the unit, the higher the speed, because of the moving object went through longer distance within the same time unit. However, as the length of time unit on the timeline depends on the moving distance and obviously there is no movement happened at stops, the duration for stops cannot be represent by time units.

Thus far, two different integrations of timeline and schematic map were introduced for the purpose of visualization of movement. Either of them has its own merit and drawback. For instance, the first one can clearly visualize and let people easily compare the stop duration of moving entities, but cannot reveal spatial information. By contrast, the second one can visualize both spatial and temporal information, but it is weak to visualize the duration of stops. Nevertheless, utilizing both of them together, the drawbacks will be compensated by each other. Therefore, in this study, the proposed visualization representation is based on the combination of these two integrations, with which, most of types of movement can be visualized properly.

3.2. Target movement

Before doing conceptual design, it is necessary to know the target movement, which means which kind of movement and how many of them can be applied with the proposed visualization. Normally there are two forms of movement that are ususally going to be analyzed, single trajectory and multiple trajectories. However, as single trajectory is just a specific case of multiple trajectories, it is feasible to apply the visualizatoin representation on single cases if it works on multiple cases. Therefore, different types of multiple trajectories are investegated mainly based on the characteristics of movement that introduced in section 1.1.1, in order to exam the applicability of the proposed visualization.

The multiple trajectories can be classified into different combination, from the perspectives of paths consistency (Do moving entities have the same path?), stops consistency (Do moving entities visit same stops or not?), and stops sequence (Do moving entities visit stops in a same order or not) etc. Therefore we have three parameters, paths, stops and stop sequence. Each parameter has two possible values, 'same' and 'different'. Based on the multiplication priciple of probability theory, 8 (2*2*2) scenarios are classified, which are listed below.

1. Trajectories with same paths, same stops, and same stops sequence.
   In this case, multiple moving entities share the same path, same stops and visit each stop in same order. A typical example is the bus line. The same bus line always travel on the same path, stop at the same place and visit the stops sequentially.

2. Trajectories with same paths, same stops, and different stops sequence.

This scenario does not exist. Because once any moving entity visits any stop disorderly, the path has to be changed. It is impossible to keep path constant, but only change the sequence of visiting.

3. Trajectories with same paths, different stops, and same stops sequence.
   The typical example of this scenario is also bus line. Buses do not stop at some stations if no people is waiting there and no passenger is asking to get off. Therefore, even the same buses line would have different stops.

4. Trajectories with same paths, different stops, and different stops sequence.
   This scenario also does not exist, as it is impossible to keep path be constant, but change both the number of stops and the sequence of visiting.

5. Trajectories with different paths, same stops, and same stops sequence.
   The typical example of this scenario is the orienteering competition. The competitors are asked to go through all the stops and following the fixed order, which means the path that the competitors passed could be different, but the stops and the visiting sequense of these movements should be the same.

6. Trajectories with different paths, same stops, and different stops sequence.
   Slightly different from the example in scenario 5, if the competitive rule does not force the competitors passing all the stops in the same order, the sequence of visiting stops could be different.

7. Trajectories with different paths, different stops, and same stops sequence.
   This scenario can be explained with an extended example from scenario 6. If competitors missed one or more targets (stops), then the final stops he/she made is different from others.

8. Trajectories with different paths, different stops, and different stops sequence.
   An example of this scenario can also be orienteering competition. If some competitors missed some targets (stops) and went back to visit some of them, then the trajectories become different in paths, stops and visiting sequence.

Except for two nonexistent scenarios, the rest six are treat as target movement scenarios, in which the visualization representation is going to be conceptually designed.

3.3. Stops (break points) determination

There is one essential step for conceptual design which is stops (break points) determination. Normally the break points of movement data is either known or unknown. For the break points known cases, no further steps are needed, but for the unknown cases, the break points must be extracted by predefined rules and manual intervention.

When researchers analyze the movement data, they are possibly interested in occurrences of certain movement characteristics such as stops, the shift from low speed to high speed or high speed to low speed, high acceleration (G. Andrienko et al., 2013). For example, in urban traffic analysis of the premise of having tracks of multiple cars in a city, analysts first need to identify the places where traffic jams occur first and then investigate in which time those jams happen and how long it last. The characteristics of a traffic jam are that the driven speed is relatively low even stop on some position without moving during a period of time. The track of moving objects can be visualized using a schematic map, where stops and any other significant position are the important nodes for creating the schematic map. We can call those positions or nodes as "break point".

In this design， the term "break point" is used to describe the important stops of movement. When applying the schematic map method, the break points will be highlighted on the schematic map, in order to emphasize these important positions. Break points also play a vital role in the algorithmic function for cartogram distortion. However, break points do not originally exist in the raw GPS tracking data.

Currently there are many approaches for "stops" recognition and extraction from movement data. Spaccapietra et al. (2008) proposed a semantic formalization for stops as a part of a trajectory, where a moving entity does not move. Based on this theory, Palma et al. (2008) presented a method called CB-SMoT (clustering-based stops and moves of trajectories), which was used to analyze each trajectory and to generate stops when the speed value is lower than a given threshold for a minimal amount of time. Zheng et al. (2009) also put forward to an algorithm for "Stay point" extraction, which depends on two parameters, a time threshold and distance threshold. When the time interval of series GPS record point is greater than a given time threshold, and the distance between each record is less than a given distance threshold, those series of record points can be viewed as a "Stay point".

Learn from these two methods, the threshold of both speed and time are key parameters in determination of break points. In this research, hence, these two parameters, speed threshold ($\mathrm{S_{threshold}}$) and time threshold ($\mathrm{T_{threshold}}$), are introduced for break point extraction.

Movement data normally comes from GPS tracking records. It consists of series location records and a couple of universal attributes, i.e. id, latitude, longitude, and time stamp ($\mathrm{p_i, Lat, Lngt, T}$).A group of consecutive GPS records can be treated as a break point, when the speed of each record in this group is less than the speed threshold and the time interval from first to last record must greater than time threshold. This determination can be expressed by formula below:

For a given GPS points data set $\mathrm{P} = \{\mathrm{p_1}, \mathrm{p_2}, \dots, \mathrm{p_n}\}$
We have a subset $\mathrm{P'} = \{\mathrm{p_m}, \mathrm{p_{m+1}}, \dots, \mathrm{p_k}\}$
For any given i, where $\mathrm{m} < i \leq k$
If $\mathrm{Speed_i} \leq \mathrm{S_{threshold}}$ & $|\mathrm{p}_k.\mathrm{T} - \mathrm{p_m}.\mathrm{T}| \geq \mathrm{T_{threshold}}$
Then P' can be treated as a break point

3.4. Visual narrative representation of movement

The design of visual narrative representation is based on the six movement scenarios. As the designs for scenarios with same and different paths are different, they will be introduced with a sample dataset for each type of scenario respectively. After then, two use cases that have specific demands from uses will be conceptually visualized by the designed representation in order to the feasibility and applicability of conceptual designs.

3.4.1. For movements with same paths

The Metro Red Line bus in Minnesota, USA is going to be utilized as scenarios that have same paths (scenario 1 and 3) for conceptual design. This bus line travels on bus-only shoulder lanes along Cedar

Avenue, with stations at Apple Valley Transit Station (start), 147th Street (2 km), 140th Street (2 km), Cedar Grove station in Eagan (12 km), and the Mall of America (10 km). The total distance of this line is 26 km and it takes approximately 30 minutes to travel on average. Figure 3.7 shows the trajectory of the Metro Red Line bus. Two buses which depart at different time are selected as sample movement.

Figure 3.7 Schematic map of Metro Red Line but in Minnesota

There are two ways to design the timeline. One is that defining the timeline with absolute moment (e.g. 6:50 am), and the other is that with relative time or duration (e.g. 40 minutes). The difference of these two representations is that the later one normalize the timeline, with which the different trajectories can share the same start moment (see Figure 3.8). Which representation is much appropriate is highly depends on the demands of users. In this study, the timeline labeled with relative time is chosen to visualize movement, as it is easy to visually compare multiple trajectories with the same start moment.

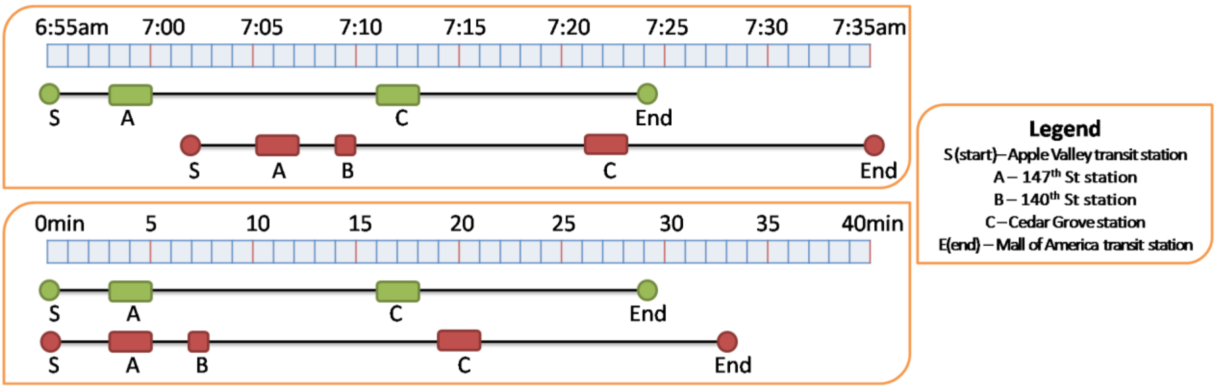


Figure 3.8 two ways of time display in “from time to geography” representation

The visualization consists of a combination of “from time to geography” (TG) and “from geography to time” (GT) representations. In TG, the timeline was defined by the average travel time (30 minutes) and slightly longer than it (40 minutes) (see Figure 3.9). The schematic maps were stretched based on the value of movement characteristics. For instance, two buses stopped at 147th St station after three minutes of departure, and stayed there for two minutes. After that one bus directly went to Cedar Grove station, whereas the other stopped at 140th St station for one minutes and then went to Cedar Grove station. Both of them stayed in Cedar Grove station for two minutes and then spent 12 and 13 minutes respectively until reaching the destination. No matter whether two buses stopped at the same stations, the duration of travel and stop were clearly revealed and easily compared by this representation.

In GT representation, the timelines of two buses were stretched by the schematic map which represent the total length of travel (26km). However, as the total time that spent for travel were different, the size of time unit were different. Apparently, the bus that did not stop at 140th St station traveled faster than the other one between the Apple Valley transit station and Cedar Grove station.

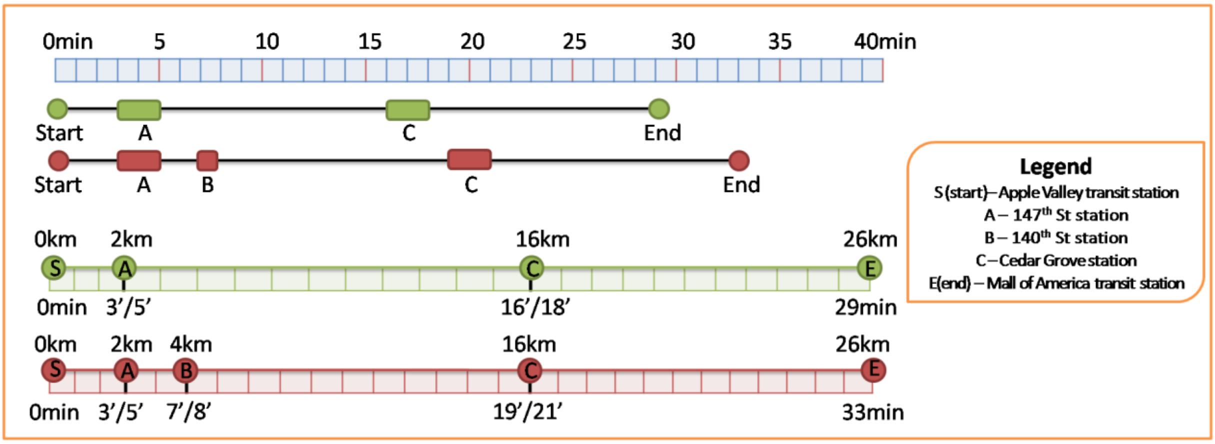


Figure 3.9 from time to geography" (TG) and "from geography to time" (GT) representations

The design of visualization representation for the movement scenarios that have the same paths of trajectories, successfully reveal both spatial and temporal information. This representation not only visualize multiple trajectories, but also makes the visual interpretation of comparison of these multiple trajectories feasible.

3.4.2. For movements with different paths

The conceptual design for the rest four scenarios of movement (trajectories with different paths) were conducted with the Fantasia Park String-Orienteering data. It consists of start, end and six control points (**Error! Reference source not found.**). Four trajectories (A, B, C and D) of four competitors are used for design (see Figure3.11). A and B covered all the control points and followed the predefined order of points; whereas C missed control point 2 but followed the predefined order. By contrast, D missed two control points 2 and 3, but turned back to visited point 3 after visiting point 5.

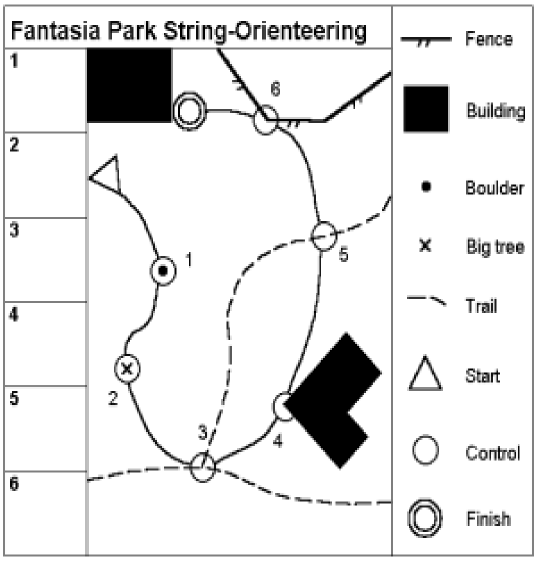


Figure 3.11 map of Fantasia Park Orienteering

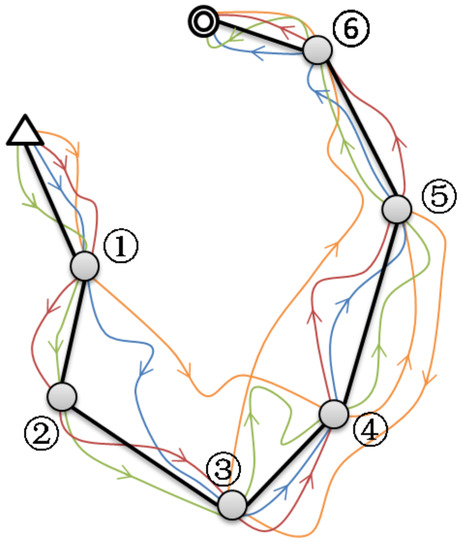


Figure 3.10 4 trajectories for 4 competitors

The design of TG representation has the same procedure as the design for the same paths scenarios. Whether trajectories have same stops or followed same vising order or not, the duration of moving and static parts of movement can be clearly visualized on the stretched schematic maps (see Figure 3.12). However, the GT representation is quite different from the same paths cases, because the length of paths are no longer consistent. Therefore, it is impossible to use one specific schematic map as a standard measurement tool to project it to each timeline. To solve this problem, and to make trajectories with different paths comparable, each trajectory is going to be represent by an integration of its own schematic map and timeline. All these schematic maps have to be under the same scale, in order to make comparison applicable (see Figure 3.13).

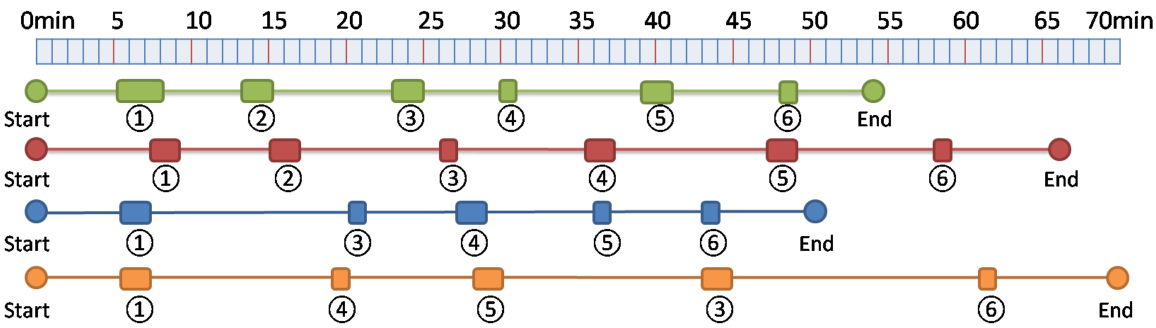


Figure 3.12 four trajectories presented in "from time to geography representation"

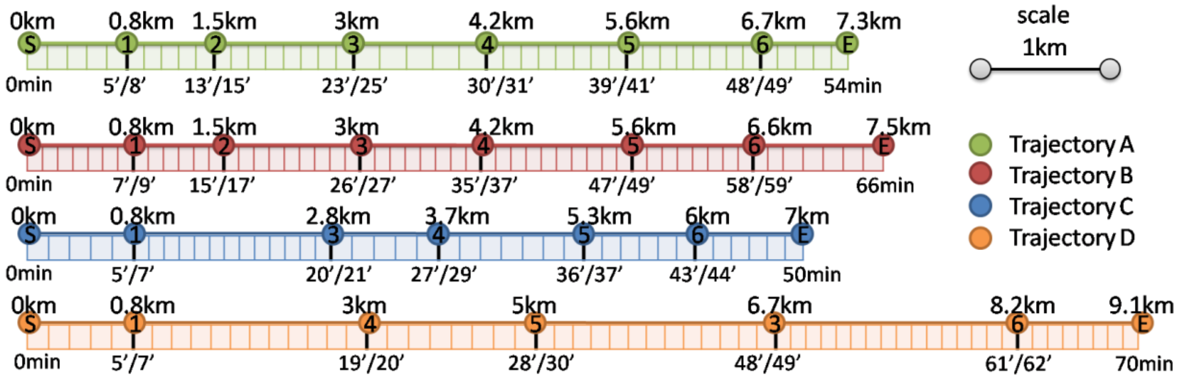


Figure 3.13 four trajectories presented in "from geography to time representation"

Seen from the Figure 3.13, although the paths, the stops and the visiting order might be different, the trajectories are still comparable under the GT representation, and relative distance and speed information can still easily be interpreted.

3.4.3. Conceptually visualize use cases

- **Case 1. Elephant migration in Congo**

For the purpose of preservation of elephant (see Figure 3.14), a number of countries built ecological corridors to ensure that elephant can migrate from one habitat to the other. An effective way for the evaluation of effectiveness of these corridors is to analyze the migration behavior of elephant. Zoologists and ecologists intend to know the migration path, average moving speed, and the location and duration that elephant stop during migration.

Figure 3.14 Elephant in Congo

Up to now, data for analysis of elephant migration behavior is mainly collected by GPS tracking. However, the immensity and complexity of data always makes researchers difficult to get the desired information (e.g. distance and duration of migration). Thus visualizing this 'useless' data into readable and analyzable form will provide desired information to researchers.

In this case, an ecological corridor was built in Congo from one national park Ndoki to another one Odzala (Figure 3.15). Five groups of elephant are expected to migrate from Ndoki to Odzala follow a designed route.Figure 3.16 shows the actual route of five elephant groups. The visualization objective is to reproduce the migration process, from which the movement characteristics of each elephant groups, such as duration for migration, duration of intermediate stops, and average moving speed etc., can be demonstrated.

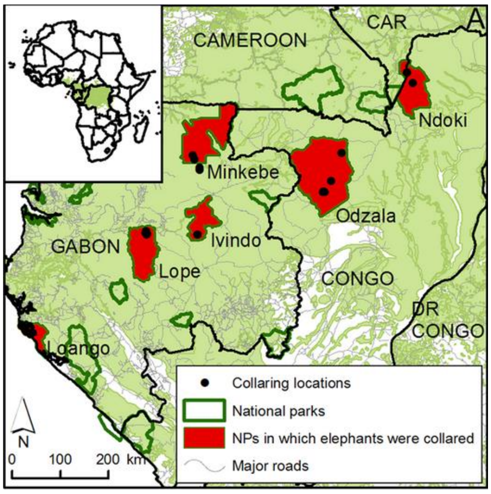


Figure 3.15 National park in Congo

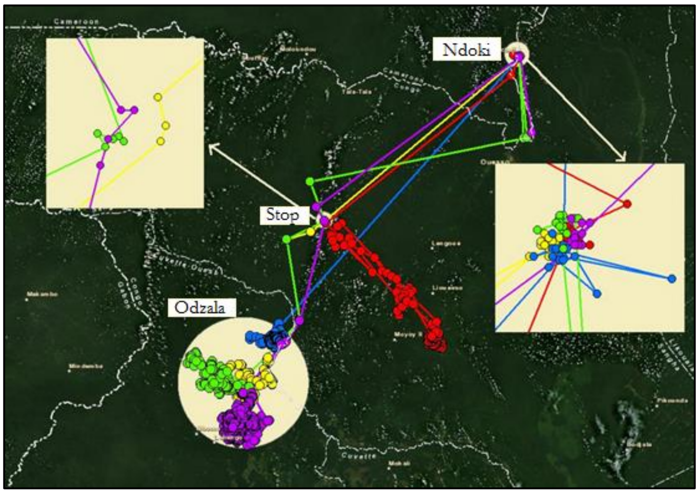


Figure 3.16 Actual routes for migration

Based on the conceptual design, a schematic map was generated to provide geographic reference, especially distance. After then the timelines for each group of elephants were created. As show in **Figure 3.17**, the different colors represent the different group of elephants. The break points in movement are indicated by a black thick line between two units. If the elephants do not stop in the halfway the units on timeline are in same size, i.e. the 4th group. The second half part of 1st timeline is missing, which means the 1st group elephants are deviate from the planned route.

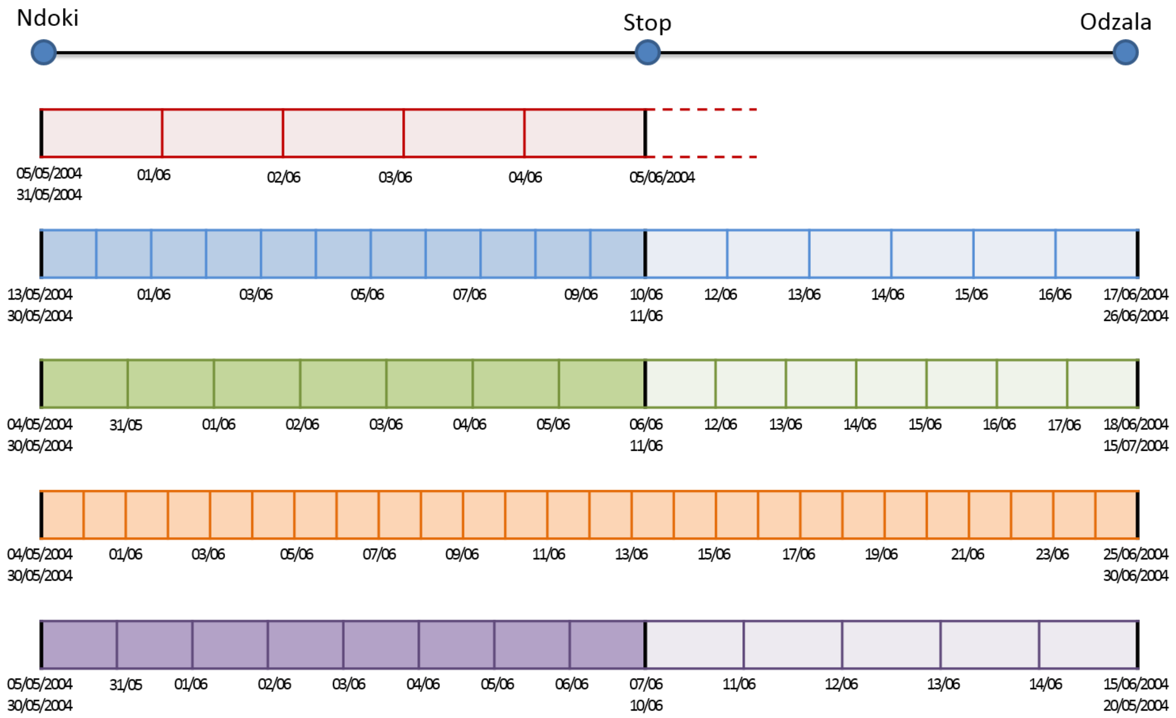


Figure 3.17 Visualization of five elephant groups' migration

Seeing from this visualization representation, most of zoologists and ecologists desired information is demonstrated, and several relevant questions can be answered. For instance, "Do the all groups of elephant follow the planned route?"; "Do the elephants migrate from Ndoki directly to Odzala or stopped in some place in between?"; "In which part the elephants move in a relative higher speed?"; "Which group spent the shortest time from Ndoki to Odzala?" etc.

In summary, the use case of elephant migration behavior can be conceptually visualized by the designed visual narrative representation. The desired information about elephant groups' movement characteristics is properly demonstrated by this representation. The comparison of the movement behavior among five groups is feasible and simple.

- **Case 2. Tourists behaviour in Acropolis of Athens, Greece**

Recently increasing number of tourists' travel tracking data is available. It promotes researches on investigating travelers' behavior, in turn, on understanding travel demand. Those kind of information is significant for the administration department of tourism because the information related to tourists' behavior and preference provide important support for scenic site selecting, facilities setting in scenic area and travel route planning.

Acropolis of Athens is a UNESCO (United Nations Educational, Scientific and Cultural Organization) world heritage site which covers more than 3 hectares area. There is a large number of view spots in this area. As we can see from **Figure 3.18** the six main view spots (A. Temple of Athena Nike, B. Temple of Artemis, C. Parthenon, D. Temple of Erechtheion, E. Odeon of Herodes Atticus, F. Theatre of Dionysus Eleuthereus) are scattered distributed in Acropolis and the path connect them is massive and complex, which bring many difficulties to the visitors when they travel in this area. For example, since there is a lack of clear travel routes designed for visitors and not enough instruction, visitors often go a wrong direction and miss some view spots or re-visit some view spots. **Figure 3.18** shows the paths of eight tourists presented with eight different color in Acropolis. Properly visualize visitors' travel behavior will provide evidences of deficiency of facilities.

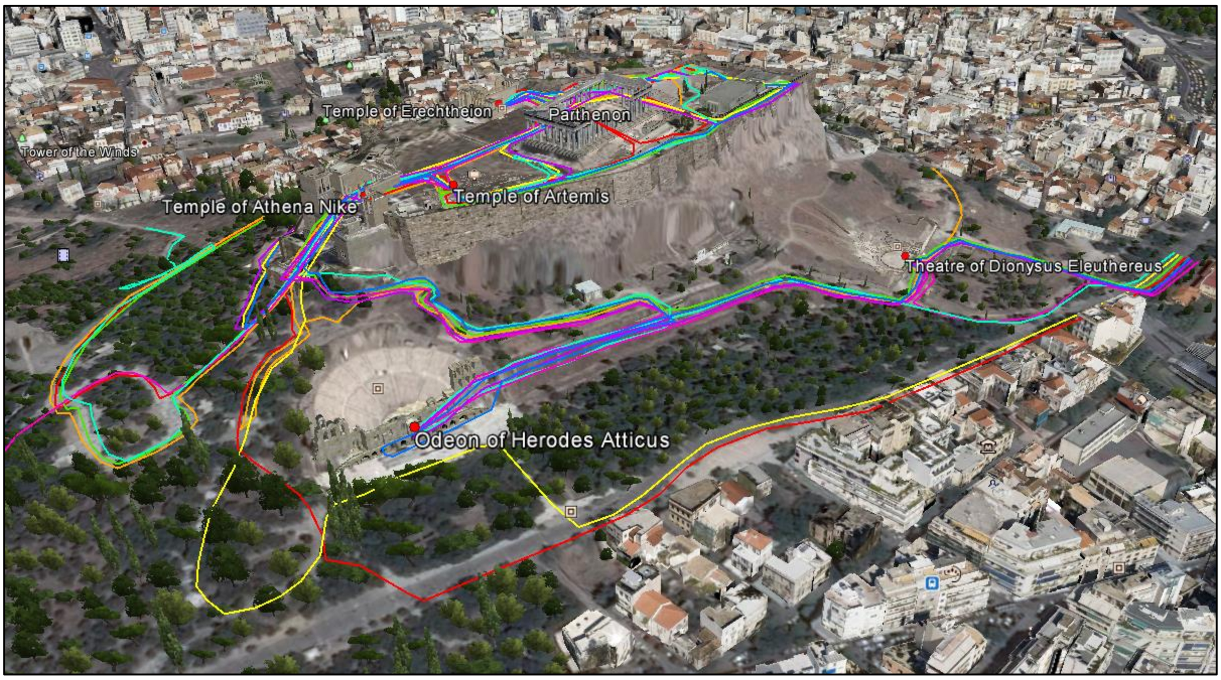


Figure 3.18 Trajectories of eight tourists in Acropolis

The demand of this case is to visualize the tracking data of tourists. From this visualization the comparison of eight tourists' moving behavior is applicable. Specifically, for instance, which site is the one that mostly missed; which site tourists spent longer time stay etc. Considering temporal information and spatial information are both essential to get insight into movements of tourists, the tracking data could be visualized by the designed timeline representation.

The common behavior pattern of tourists is that they stop at the view spots for a certain while and then continue their visit to the next view spot. The view spots in Acropolis can be treated as several pre-defined stops, tourists could visit some of them and by different order. The questions such as which view spots are most often visited and which are most skipped, and what is the sequence of view spots for tourists are highly concerned in this case. According to this situation, the "from time to geography" representation was chosen to present stop-related information.

With "from time to geography" representation, when dealing with the multiple data, the timeline is treated as a no deformation part. Based on this timeline, the different schematic map can be generated to present different movements. The representation makes it possible to compare the passing location of each tourist and the stopped duration on each location. Because the starting and ending time of the visit is different among the tourists, the span of common timeline should range from the earliest starting point to the latest ending point. According to the principle introduced in section 3.1.1, schematic maps for multiple movements can be generated.

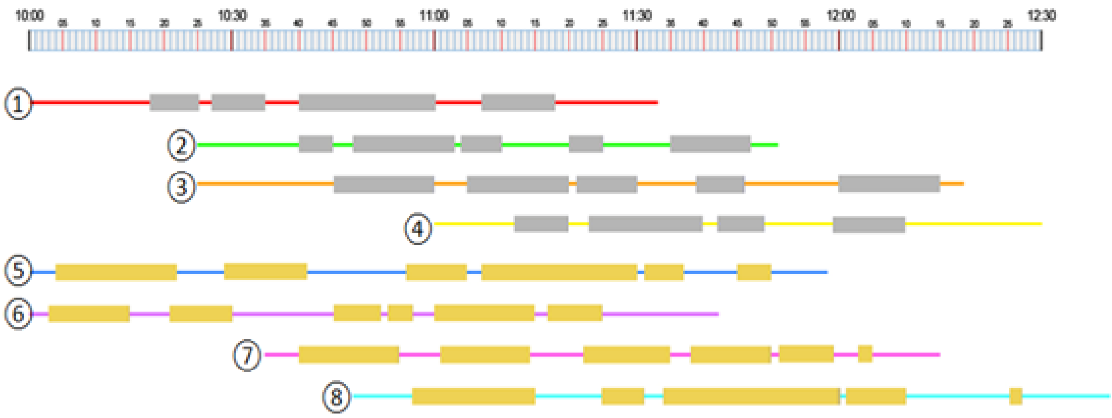


Figure 3.19 Distorted schematic maps for multiple tourists' movement

As shown in **Figure 3.19**, different visit movements of tourists are presented by linear schematic map in different colors. And the length of rectangles on the schematic map indicates the duration of stop on each view point. Since most visits are started and ended in different time, the schematic maps are scattered. This representation increases the difficulty of comparison and analysis for different movements, it is better to formalize all the schematic maps to the same starting point. In other words, the reference of timeline is no longer the physical time but the earliest starting time of the visit. According to **Figure 3.20**, it is easy to compare the total length of schematic map with the length of rectangle on it, which represents the total duration of visit and the stop duration on each view point respectively. In this representation the rectangles have two colors, which distinguish two typical visit routes, one is starting from view point A and the other is from F.

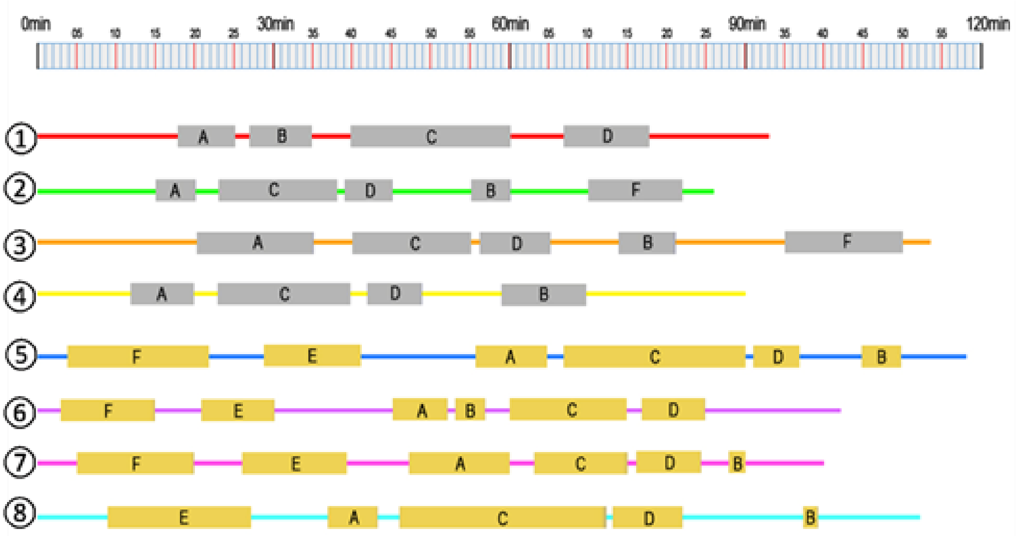


Figure 3.20 Formalized representation

After being conceptually visualized, the requirement of comparing the moving behavior of eight tourists is feasible. It is straightforward to analyze tourists' behavior. For instance, obviously most of tourists spent longer time at site C which is Parthenon and the mostly missed site is E which is Odeon of Herodes Atticus. This case is also properly visualized by the designed representation.

4. IMPLEMENTATION

Although the design of alternative timeline representation has been conceptually applied on two use cases and successfully revealed the behavior of different types of movement, whether it is applicable to interactively implement (computer based) this representation on a representative movement dataset is still not convinced. A computer based visualization representation not only functionally provides more information, but also brings possibility of interactivity that might make users easy to interpret characteristics of movement. In this study, therefore, the alternative timeline will be implemented with computer and GIS techniques. The result will be published online, which can be played by subjects or potential users.

4.1. Requirement

The sample case for the implementation is an orienteering in Dresden, Germany, which consists of two movement trajectories from two competitors. There were 21 targets in total that need to be visited. **Figure 4.1** shows the map and planned route of orienteering. The requirement of implementation of this case is to interactively visualize both spatial and temporal characteristics of the orienteering movement. Specifically, for instance, the overall distance and duration of each competitor, the overall path they travelled and the time they spent between each two targets, and the time they spent on each target etc.

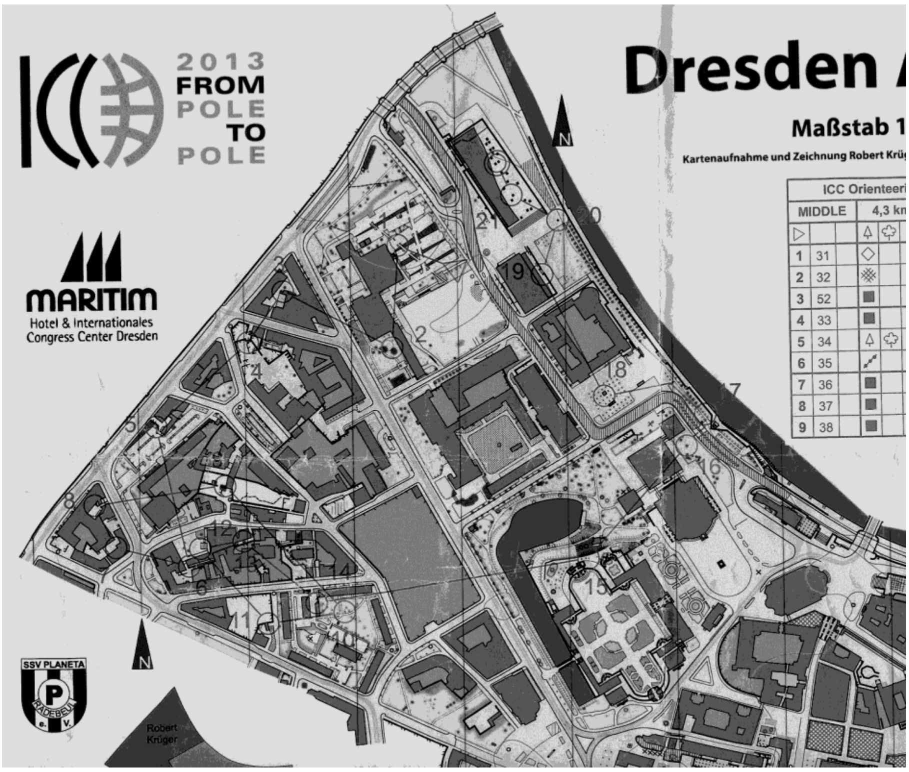


Figure 4.1 Map for orienteering competition

4.2. Interface and Function

The interface consists of three parts, on the right part is a map view which shows the trajectories of movement and the base map, and on the left part are two alternative timeline views (see Figure 4.2).

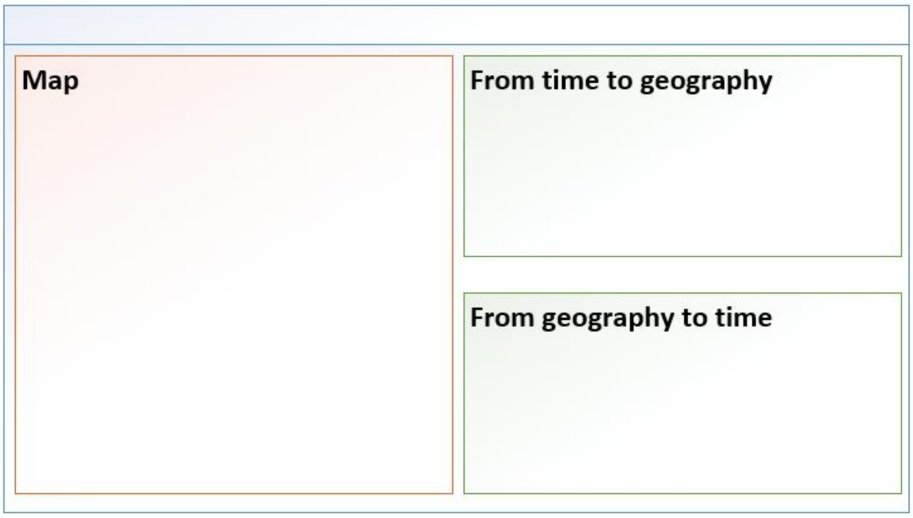


Figure 4.2 The frame of interface

Functions of this implementation are mainly designed for the purpose of providing supplementary information and serving interactive experience, which will be listed below.

- Pan, zoom in and zoom out the map
- Show stop info on trajectories (map).
  When moving mouse on and hover it on stops of trajectories, the stops' info will be shown on tips, including stop ID, arrival and departure time, and the distance between hovered stop and the previous one.
- Show stop info on timeline.
  When moving mouse on and hover it on stops of timelines, the stops' info will be shown on tips, including stop ID, arrival and departure time, and the distance between hovered stop and the previous one.
- Link stops of map and timelines
  When moving mouse on and hover it on stops of either the map or timelines, the hovered stop and its corresponding stops (same ID on different view) will be highlighted.

4.3. Data structure and preparation

The orienteering data is in GPX format and often includes 'track name', 'latitude and longitude of track points', 'elevation of track points' and 'time stamp of track point'. Firstly, the GPX file could be converted into an Excel file as shown in **Error! Reference source not found.**.

However, this kind of raw track point data cannot be directly used in D3.js. On the one hand, the data format for D3.js should be *.json file, and on the other hand, it is complicated to extract interested points and records from the raw data when implementing the representation by programming and structure of raw data often verifies. So, it is important to generate a general dataset which only stores the necessary information for timeline representations.

Table 4.1 original GPS tracking data

type	time	latitude	longitude	altitude	speed	distance (km)	
T	2013-08-28 14:48:14	51.057502747	13.731056213	117.4	0.0	0.0000	0.00
T	2013-08-28 14:48:17	51.057506561	13.731059074	116.9	0.6	0.0005	0.47
T	2013-08-28 14:48:22	51.057636261	13.730922699	115.0	12.4	0.0178	17.31
T	2013-08-28 14:48:25	51.057723999	13.730819702	113.1	14.5	0.0299	12.14
T	2013-08-28 14:48:29	51.057750702	13.730613708	111.2	13.2	0.0447	14.74
T	2013-08-28 14:48:34	51.057716370	13.730336189	111.7	14.2	0.0645	19.83
T	2013-08-28 14:48:38	51.057750702	13.730131149	113.1	13.3	0.0794	14.87
T	2013-08-28 14:48:44	51.057727814	13.729837418	114.5	12.4	0.1001	20.75
T	2013-08-28 14:48:46	51.057758331	13.729748726	114.5	12.7	0.1072	7.08
T	2013-08-28 14:48:52	51.057868958	13.729496956	117.4	12.9	0.1287	21.52
T	2013-08-28 14:48:53	51.057876587	13.729481697	117.4	4.9	0.1301	1.37
T	2013-08-28 14:48:58	51.057956696	13.729357719	117.4	8.9	0.1425	12.45
T	2013-08-28 14:49:03	51.058021545	13.729129791	115.5	12.6	0.1601	17.53
T	2013-08-28 14:49:08	51.058025360	13.728888512	114.1	12.1	0.1770	16.92
T	2013-08-28 14:49:09	51.058017731	13.728837013	114.1	13.3	0.1807	3.71
T	2013-08-28 14:49:15	51.057975769	13.728586197	112.1	10.9	0.1989	18.19
T	2013-08-28 14:49:18	51.057983398	13.728474617	112.1	9.4	0.2068	7.87
T	2013-08-28 14:49:22	51.057933807	13.728304863	112.1	11.8	0.2199	13.12
T	2013-08-28 14:49:27	51.057842255	13.728299141	111.2	7.3	0.2301	10.19
T	2013-08-28 14:49:31	51.057716370	13.728250504	106.4	13.0	0.2445	14.41

Based on collected data, a dataset for break points is designed, which will be used for generating the alternative representations. The whole data processing will be done by following the work flow shown in **Error! Reference source not found.**. The break points should be recognized the following principle introduced in section 3.3. And then they are marked in the excel file. The dataset of track points with marked break point will be used for the base map visualization, which will provide geographic reference for the timeline representations.

Once the break points are extracted from excel file, there will generate a new dataset. The structure of this dataset is shown in **Table 4.2** Break point table, in which the field 'stop' is calculated by the difference between 'Departure' and 'Arrival' of one break point and the moving time is calculated by the difference between previous 'Departure' and this 'Arrival'. Based on the break point dataset, the dataset for each timeline representation will be generated. According to **Figure 4.3**, each dataset will be used for creating correspondent representation.

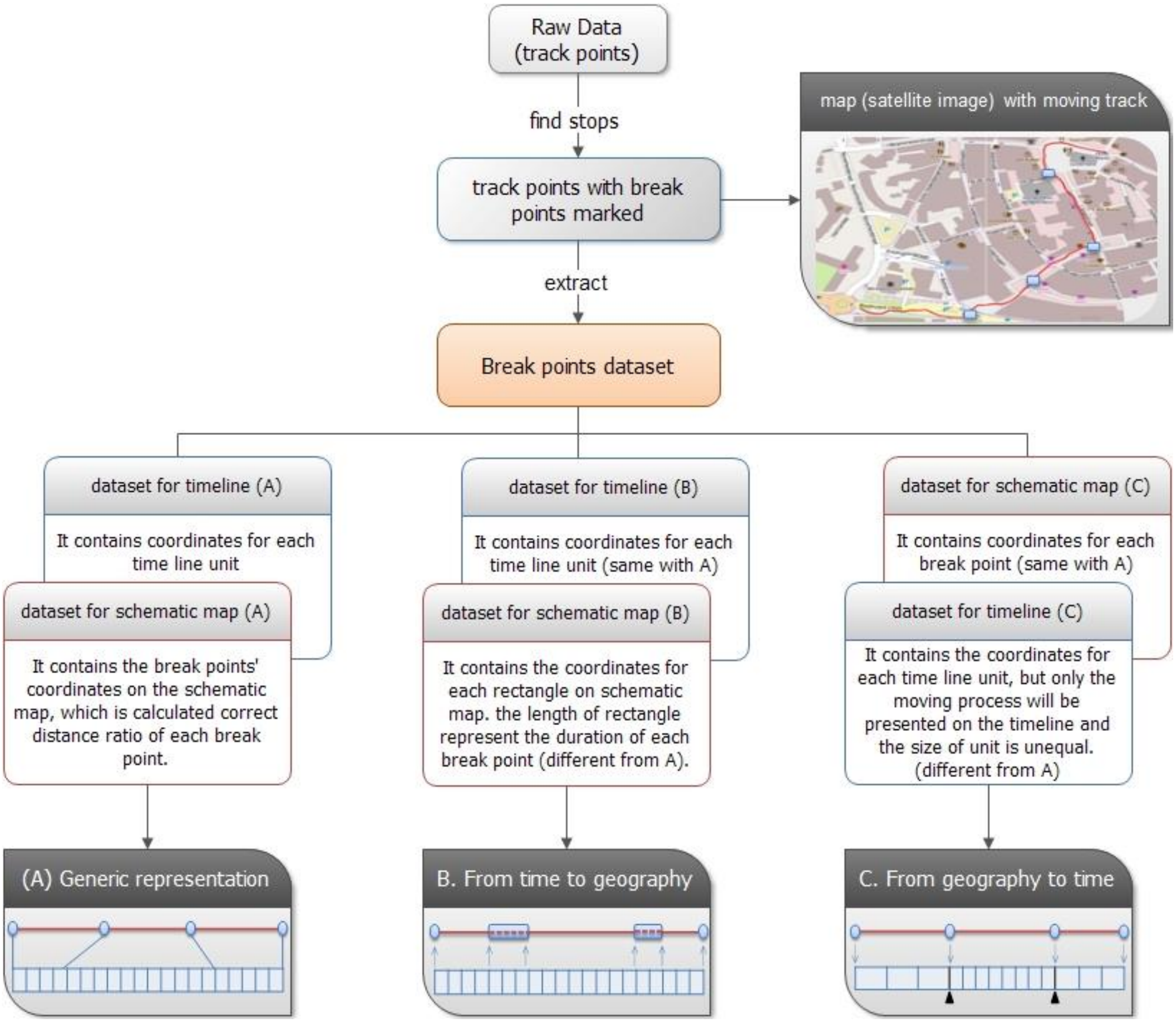


Figure 4.3 Data processing work flow

Table 4.2 Break point table

Field name	Data Type	Description
ID	Number	The id of break point
Coordinate X	Float	The latitude of break point
Coordinate Y	Float	The longitude of break point
Arrival	Date/Time	The arrival moment/day on break point
Departure	Date/Time	The departure moment/day on break point
Distance	Float	The cumulative distance between start point and break point
Stop	Date/Time	The stop duration on break point
Moving time	Date/Time	The time from previous break point to this break point

4.4. Algorithm

In the from geography to time representation, as timeline will integrate three parameters, distance, time, and speed, a particular algorithm is developed to merge this three parameters into a one dimensional representation.

In this representation, the size (length) of grid (L) between each two stops represents the average speed (s) in this duration. It is a scaled length of speed based on the scale of actual distance and distance of timeline on screens. The average speed (s) between each two stops is calculated by utilizing three parameters, the distance between two neighboring stops (D), the time that the moving object spent between these two stops (t), and the unit time that each grid represent (t_u).

$$s = \frac{D}{t} * tu$$

Therefore,

$$L = s * \frac{\text{Screen length between two stops}}{\text{Actual distance between two stops}}$$

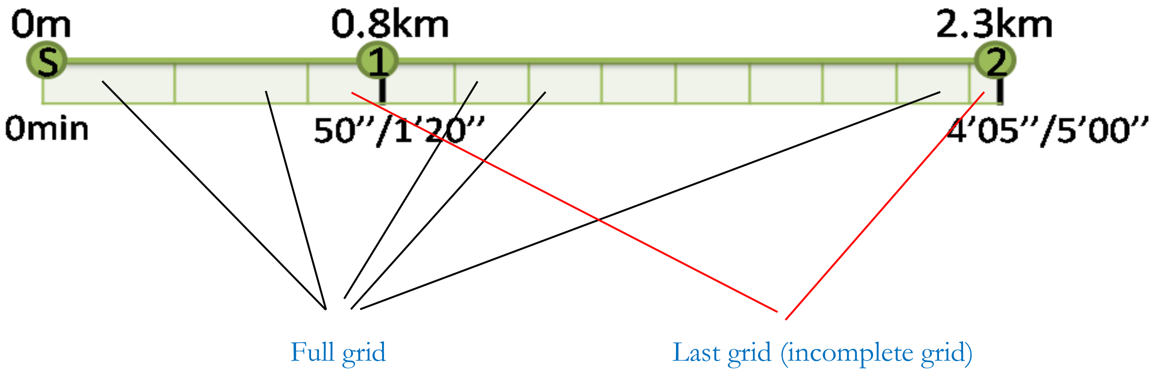
The number of grid (N), which represent the total amount of time that the moving object spent between two stops, equals to dividing t by t_u.

$$N = \frac{t}{tu}$$

The D and t can be got from movement data, and t_u depends on the space of the interface for timeline, and the time interval among each two neighboring stops. t_u should smaller than the minimum t (t_{min}), and ideally should be a common divisor of all the t, in order to get integer number of grid in each moving part. However, as a common divisor cannot always be found (except for the number '1'), the number of grids is hardly integer. Therefore the last grid in each moving part, in most of cases, does not represent neither average speed in this period nor the unit time, as it is not a full grid. In this particular case, the t_u is set to 20 seconds. For instance, if an object spent 50 seconds moving 0.8km from start point (S) to first stop (Stop 1), then we have D = 0.8km, t = 50", t_u = 20". Let us assume the screen length between these two stops is 5cm. Based on the formula, we can get:

$$s = (0.8 / 50) * 20 = 0.32 \text{ (km/20s)}$$
$$L = 0.32 * 5/0.8 = 2 \text{ cm}$$
$$N = 50/20 = 2.5$$

Obviously, only the first two grid represent the average speed and unit time, but not the last one, which should not be take into consideration when interpreting movement behavior.



Similarly, from Stop 1 to Stop 2, D = 1.5km, t = 165”, t_u = 20”. The screen length between these two stops is 9cm.

$$s = (1.5 / 165) * 20 = 0.18\ (km/20s)$$
$$L = 0.18 * 9/1.5 = 1.08\ cm$$
$$N = 165/20 = 8.25$$

The length of full grid represents the average speed is 0.18 (km/20s), and each grid represents 20 seconds. However, the last 0.25 grid cannot represent anything.

4.5. Programing

The implementation is developed under D3 environment. As the time limitation and lack of experience, the coding work is done by Barend.J. Köbben, Geo-information Processing Department, ITC.

4.6. Implementation result

The implementation is developed by using D3.js in web environment. The final output of implementation includes a map on one side of screen and two timeline representations on the other side. The base map is an open street map, which provides geographic reference for the timeline representations (see **Figure 4.4**). Due to the limited time, some functions have not been implemented yet. For example, the pan, zoom in and zoom out function for the base map. Whether this implementation effectively visualized orienteering movement will be discussed in next chapter.

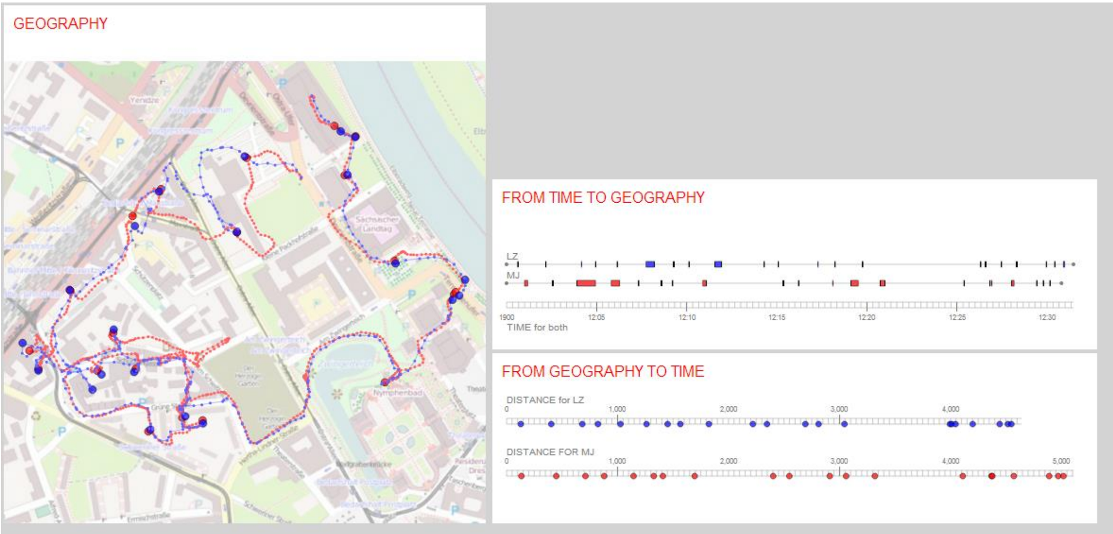


Figure 4.4 Final product of implementation

5. USABILITY EVALUATION

5.1. Introduction

Usability evaluation is an indispensable step for this study as it is the way to justify how well the designed and implemented visualization representation performs. Usability was defined as "the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (The International Organization for Standardization, ISO (241-11)). Therefore, the most vital parts for usability evaluation are:

- Effectiveness: the accuracy of the completeness with which users achieve specified goals
- Efficiency: the resources expended in relation to the accuracy and completeness with which users achieve goals
- Satisfaction: the comfort and acceptability of use

To conduct an evaluation on a map related products, both a qualitative and a quantitative character might have to be considered (van Elzakker, 2010). When a new product is going to be tested and especially no knowledge on how people answer geographic questions, a qualitative research is required. For instance, the think-aloud method, by which subjects' thoughts via verbalizing, when answering questions, can be qualitatively analyzed. Furthermore, a quantitative measure is also involved as a supplement for the justification of performance.

In this study, STC was introduced as a contrast to timeline based representation. Both of them were qualitatively and quantitatively evaluated for their performance of represent movement events. The justification of the performance is mainly determined by effectiveness, efficiency and satisfaction.

Three questions were formulated to specifically target to effectiveness, efficiency and satisfaction.

1. Which test questions can be answered by alternative timeline representation, and how many subjects got the right answer for each question? (Effectiveness)
2. How efficient is each representation (timeline and STC) in answering the different questions? (Efficiency)
3. What is the user satisfaction of both concepts and functions of each representation? (Satisfaction)

Relate to those three questions, three hypotheses were created.

1. All the test questions can be answered by alternative timeline representations and most of participants can get right answers for each question.
2. For each question, alternative timeline always behaves more efficient than STC.
3. Users are satisfied with both concepts and functions of alternative timeline representations.

5.2. Evaluation method and design

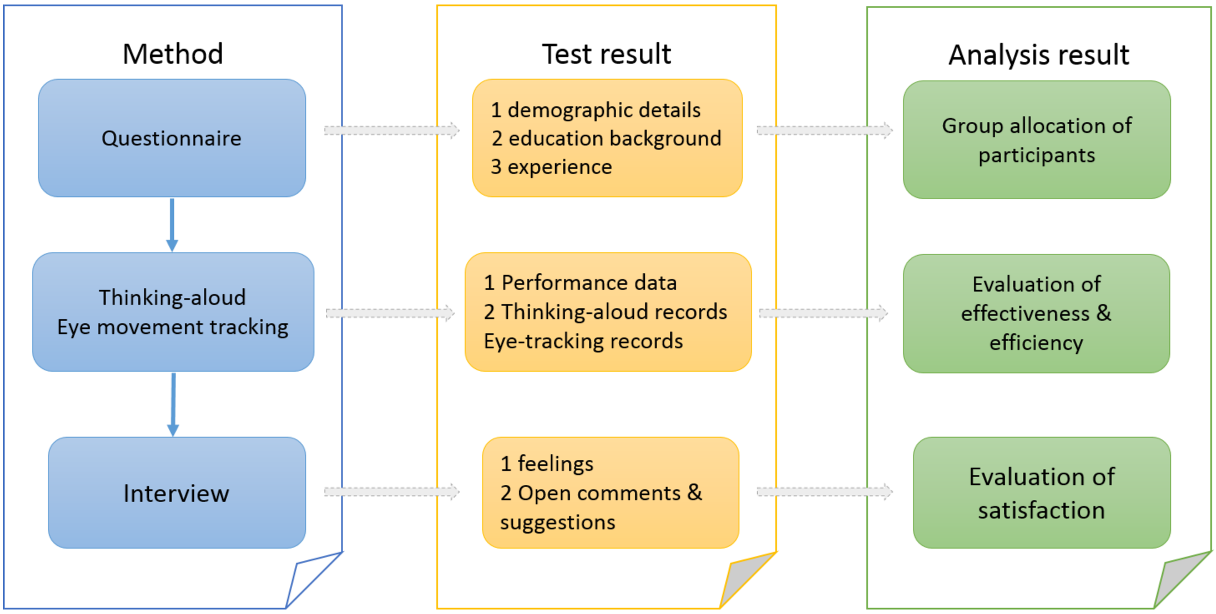


Figure 5.1 Evaluation method and design

In order to conduct usability research, it is important to select an appropriate evaluation method. In this case three method are adopted – the "thinking-aloud" method combined with "eye-tracking" then followed by an "interview" (see **Figure 5.1**). There is a pre-questionnaire given to all test persons, which is chosen to obtain information about the background and other characteristics of test persons. It is possible to let the users answer several particular questions which are related to the objects or attributes in the prototype by working with the tested product, and then the result of completeness and correctness can be collected and counted. But this method also has some disadvantages, for example, sometimes the questions may be misunderstood and the incomplete questionnaires may affect the quality of analysis. What is more, the process about how the users answer questions on questionnaire is unknown to the evaluators.

Supposed that if we only list several questions for the test persons, the correctness of result is not guaranteed, and it is only a part of the reflection of effectiveness. Although the time it takes for a specific question can be recorded by some equipment, the details about test persons' thought and their behaviors during the process of test are still unknown. This kind of disadvantage can be supplemented by the "thinking-aloud" and "eye movement tracking" method. For "thinking-aloud", it is a process the test persons are allowed to verbalize their thoughts that come into their mind when they working with the tested product to answer particular questions, and the process is recorded with audio and/or video techniques. It is better to speak out what they are looking at, thinking, doing and feeling. Therefore, 'think-loud' provides first hand insight into the perceive process associated with some certain questions. Also, the evaluator can easily identify the user's misconceptions about the product or the objects in the product (Nielsen, 1994). For example, the user has some difficulties when he/she is solving a particular question, the reason could be some elements in the product helps of influences he/she find answer; finally he/she gets the correct answer but without 'think-aloud' the confusion part will be never known by the evaluator. However, this method still have several limitations. Since in the thinking-aloud process test participants need to speak out while they executing tasks, it is a multi-task process for them. Considering the different level of cognitive and speaking ability some people may forget to verbalize their thoughts or their words may differ from their actual thoughts. To complement this limitation eye-tracking is also implemented in this test, which provide more objective evidence for understanding what participants looking and thinking. Recording eye movements does not rely on participants' words, therefore, it can be considered as an objective method and can enhance the result of thinking-aloud method. But in this research, the eye-tracking is used for provide supplementary information for thinking-aloud.

The interview after test aimed to get the information related the user satisfaction of the tested visualization. van Elzakker (2010) divides interview to two types, structured and unstructured. A structured interview is similar to a questionnaire, where the questions are pre-designed so the answers are structured and easy to analysis. The unstructured interview is more flexible and questions in it are formulated spontaneously, but still within a framework. In this test, the structured interview is chosen and more in-depth information related to participants' satisfaction or other comments and suggestions will be collected from the interview.

5.3. Evaluation preparation

5.3.1. Test persons

There were sixteen participants involved in this test. All of them are ITC students as they are assumed to have more or less some geo-information background, which is helpful for the accomplishment of this test. Some characteristics information (see Appendix 2) of participants were collected in order to justify which subject should allocated in which group. Sixteen participants were equally allocated in two groups, half in timeline group and another half in STC group. The criteria for allocation is listed below:

1. The allocation of the selected persons into two groups (STC and timeline) is mainly based on their educational background. Persons come from GIP department or having GFM courses are supposed to be much familiar with the visualization techniques. They are going to be equally allocated in two groups, whereas persons with other background are also equally allocated in two groups.
2. The second criterion is the experience of working with movement visualization. Persons who have the relative experience are supposed to be equally allocated in two groups.
3. The third one is the experience of STC or timeline. Persons who have experience of STC will be allocated in STC group, while who have experience of timeline will be allocated in timeline group. This is to make sure, in each group, people can properly answer questions with existing experience.
4. The level of education. Persons with different level of education will be equally allocated.

The weight of these criteria sequentially decreases. Therefore, for instance, if conflict happens between criterion 2 and 3, and the criterion 2 dominant the allocation.

5.3.2. Test prototypes

As mentioned in section 5.1, there are two visual solutions need to be compared in the test so it is necessary to implement visualization prototype for each solution. The data used in two test prototypes is orienteering data, which consists of two GPS tracks of two competitors of an orienteering competition in Dresden.

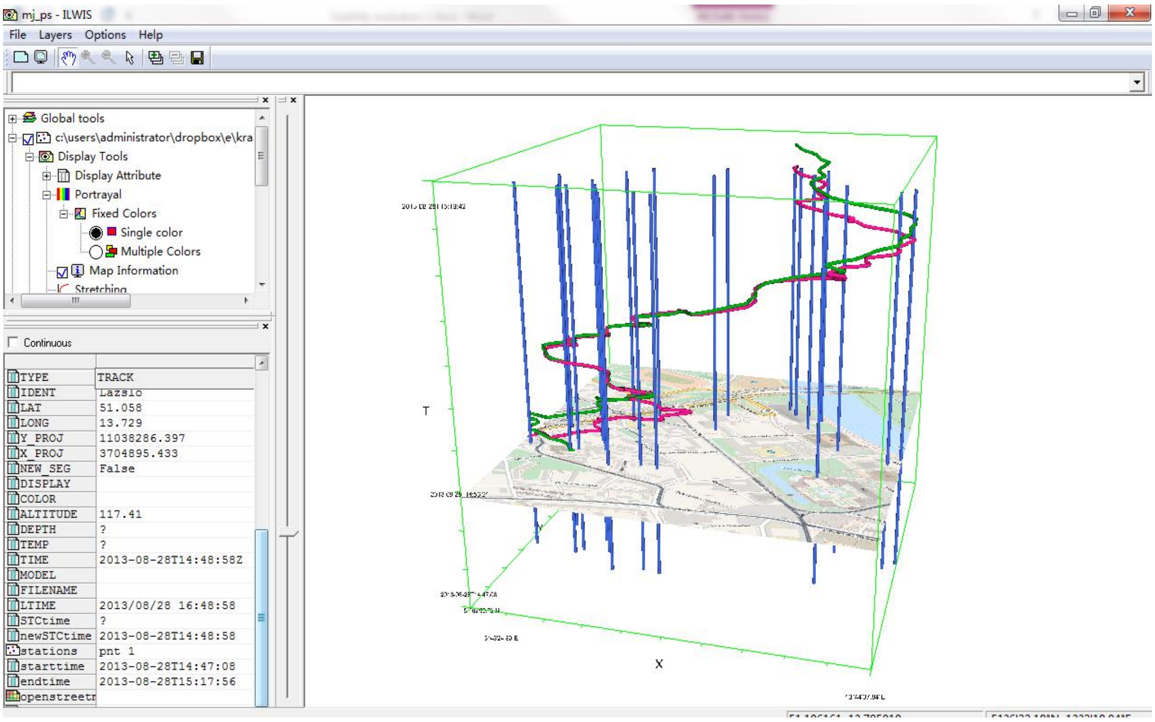


Figure 5.2 Prototype of STC in ILWIS

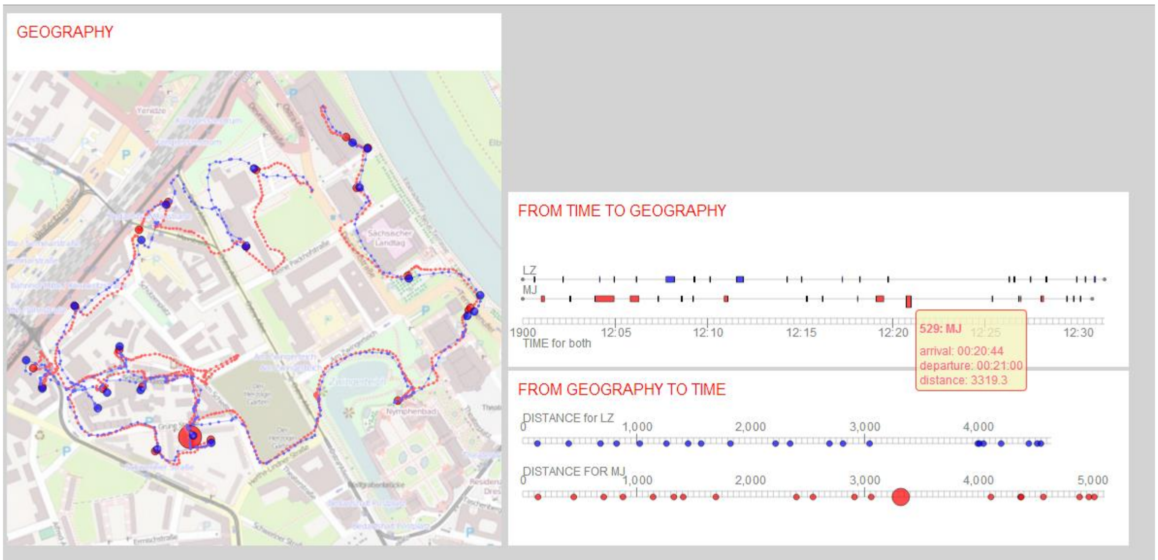


Figure 5.3 Prototype of alternative timeline representations

The prototype of alternative timeline representations (see **Figure 5.3**) has been already implemented in Chapter 4, which consists of three views; geography view shows the movement track on an open street base map, the from time to geography view (TG view) indicates stop and event duration, the geography to time view (GT view) shows distance of both competitors. Those three views are linked together. If user move mouse onto a stop there is a pop-up and some information related to this stop is shown, for example, arrival/departure time and cumulative distance, meanwhile this stop in other view are also highlighted.

The STC prototype (see **Figure 5.2**) is implemented in ILWIS 3.8.3.0, which provides a interactive environment for users. In this environment, the cube can be rotated, zoomed in/out and moved. The open street map is shown on the horizental plane as a background, and it can be moved up and down by dragging the scoroll bar. The blue pipes represent pre-defined targets in the orienteering competition, so the intersections of two movement path shown in **Figure 5.4** indicate that two competitor both visit that target. The default mouse function is to identify the object(s) at the mouse-pointer by showing the selected Display Attribule and the attribue information is shown in the lower left window.

Since there is short familiarization phase in the test, it is necessary to prepare two different prototypes because the prototype used for test cannot be shown to users before the test, both timeline and STC. Since the purpose of familiarization is introducing the visualization method and providing a simple prototype for users to work with so that they can well understand it, so visualizing one single movement is enough. The dataset for STC and timeline is different. The data for timeline is a personal walking track, another data for STC is a bus movement in Dublin. **Figure 5.5** and **Figure 5.6** shows the two prototypes for familiarization.

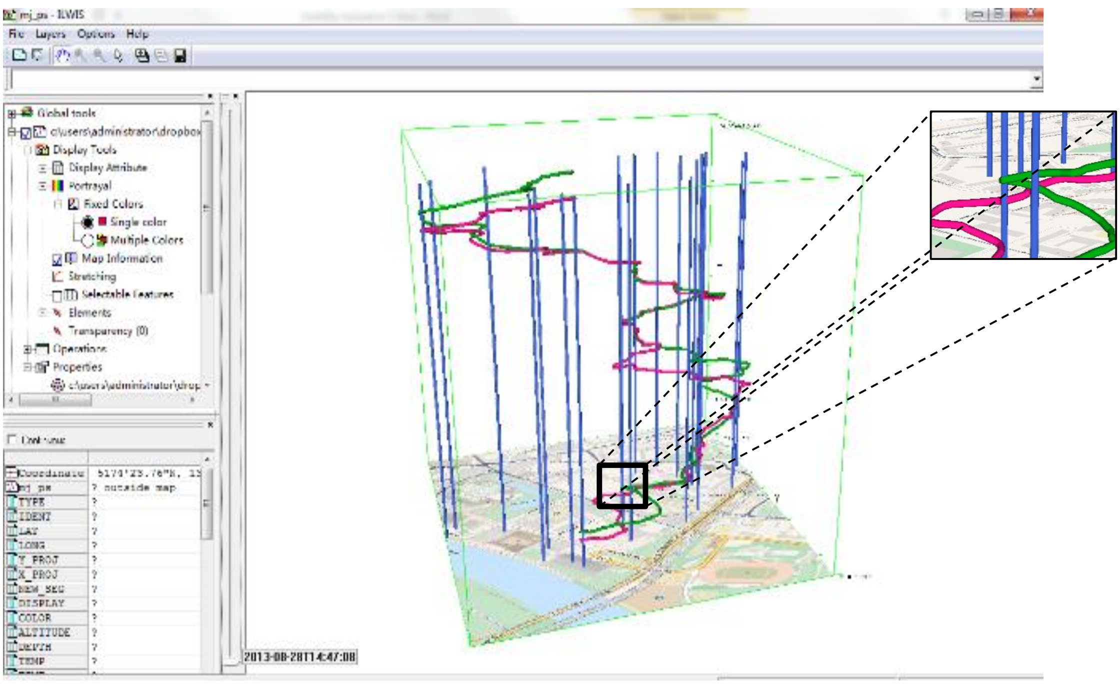


Figure 5.4 Intersection between space-time path and station

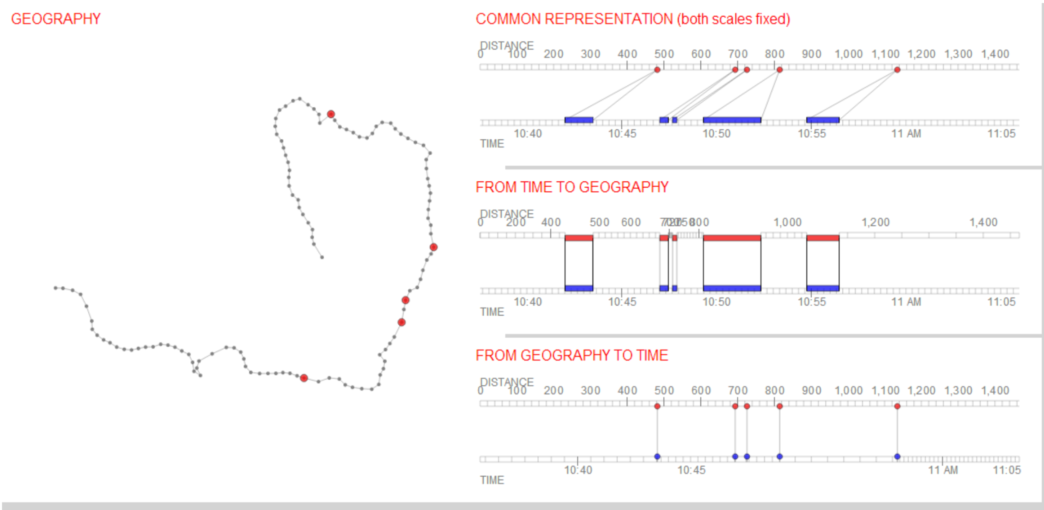


Figure 5.5 The prototype of timeline for familiarization

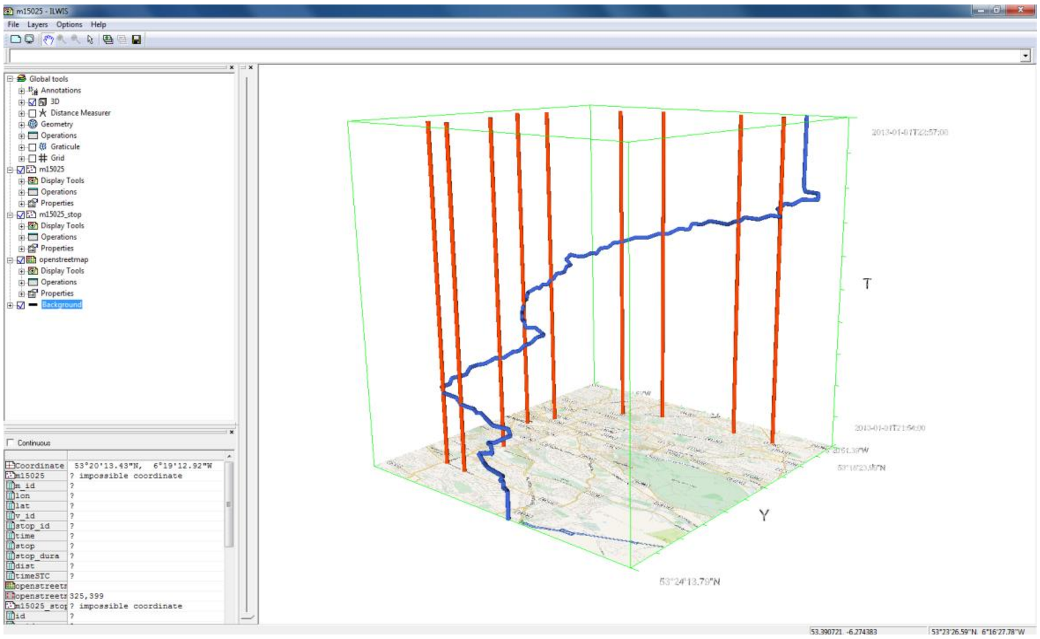


Figure 5.6 The prototype of STC for familiarization

5.3.3. Test questions

Questions for evaluation are designed mainly based on two aspects. Firstly, questions should cover as more characteristics as possible. Secondly, most of questions should include and reflect the meaning of comparison. These questions target on the objective of this study. There are overall nine questions which are listed below.

1. Did the two competitors follow the same path from target 1 to target 2?

2. Which competitor ran the longest distance during the event?

3. Which competitor took most time for the event?

4. Who was the first to reach target 2? When did he arrive and depart again?

5. Who ran a longer distance between target 3 to target 4?

6. Who spent more time between target 2 to target 3?

7. Who was faster when running from the start to target 1?

8. Who spent more time while staying at target 3?

9. Did the two competitors visit all the targets?

5.3.4. Test procedure

The test would be conducted in 3 phases:

- Phase 1-Introduction phase
  Evaluator gives a short speech for 5 minutes to welcome the participants and to introduce the objectives of this evaluation.

- Phase 2- Familiarization phase
  Evaluator show the hardcopy introduction of timeline/stc (see appendix 4-1 & 4-2) along with the prototype to participant, the participant will be given at most 10 minutes to read the introduction and interact with the prototype to get familiar with it. If the participant thought he/she already understand how the visualization prototype (timeline/stc) works, he/she will be given 2 warm-up questions (see appendix 5). If he/she successfully get the answer, then evaluator shows them the hardcopy introduction (see appendix 6-1 & 6-2) of test process and also the dataset used in test prototype. In this phase evaluator need to make sure every participant are clear that how the test prototype works and what they will do in the following test.

- Phase 3-Test phase (Think-aloud, eye-tracking & interview)
  After an eyes-calibration the thinking-aloud and eye movement tracking test starts. The test participant is given the prepared test questions to complete them whilst thinking aloud. An interview about their feelings and satisfaction comes after the test. Participant is also asked to give some open comments or suggestions to the test prototype. All above listed process is video recorded.

A script simulating the real test process is composed (see appendix 3) to help evaluator conduct the test.

5.3.5. Pilot test study

Before implementing the final evaluation experiment, a pilot study has been conducted. During the pilot test all the procedure of final test were executed. The expert related to visualization and usability was invited to attend the pilot study because they are experienced in this two field so their comments is helpful to find potential the weaknesses of test plan and improve it. Some issue has been figure out, such as "is the introduction of prototype is clear to test participant?", "if there anything wrong with the test procedure and how to improve it?", "if the test questions are well understood?", "if the eye-tracking and thinking-aloud works well and the process is recorded correctly?". All the defects were corrected before the final test executed.

The two pilot test were on May 2nd, in the morning and afternoon. The test is conducted according to the "test procedure" listed in section 5.2.4. Several problems were discovered from the pilot test and improvement were made according to those problems:

problems	improvements
1. The timeline prototype used for final test should not be shown in the introduction materials, which is unfair for STC group and will influence the test result.	1. The prototype of alternative timeline for final test has been deleted in introduction materials.
2. Several questions are unclear which may cause the misunderstanding of participants.	2. The questions have been rephrased.
3. The question 4 is asking for "average speed", which is highly correlative to question2 and question3. Participants may answer this question without reading visualizations, it is a not a suitable question for the test.	3. Question 4 has been deleted.
4. In the eye calibration process, evaluator did not give enough instruction before the calibration start, so the test person is confused at the beginning or calibration and did not how to react.	4. Evaluator should inform test participants what will happen when he/she press start calibration. There will be a red circle on the screen and it will move around 4 corners and center of the screen, participant need to look at it to do the calibration.
5. Do not ask general question. The questions in interview should be asked in a more open way. For example, if only ask "do you like it" or "are you satisfied with it", participant would answer yes or no then this question is finished without obtaining any valuable information.	5. Modify the questions prepared for interview to: Do you think the visualization is easy to understand and which part is difficult to you to read and understand? Do you like the design and what do you like about it?

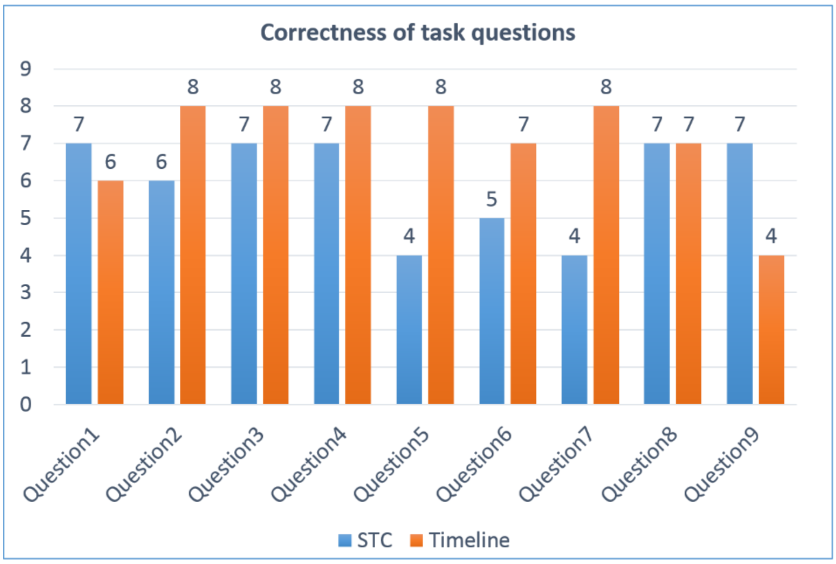
5.4. Evaluation execution

The tests took place on May the 6th to the 9th, 2014. From the experience of pilot test, each of the test was supposed to run continuously for around 50 minutes.
Sixteen participants took the test in two groups, one group worked with STC, the other was using alternative timelines. The procedure and questions to every participants should be consistent.

5.5. Test result analysis

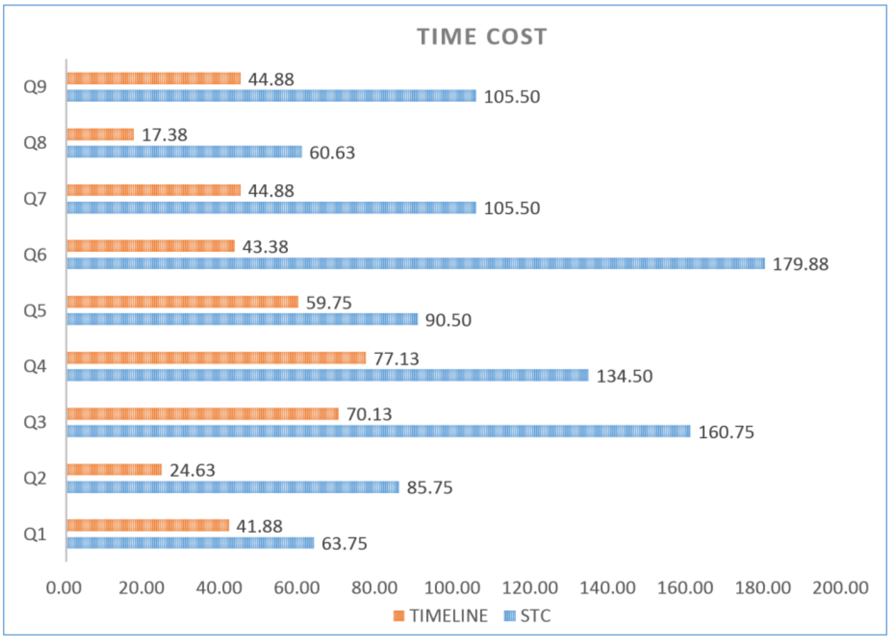
5.5.1. Effectiveness and Efficiency evaluation based on performance data

The effectiveness and efficiency can be evaluated from the performance data, such as which visualization prototype help people get more right answer, which prototype is more efficient so that most participants in that group complete all the questions in a shorter time. Since participants need to think aloud and their eye moment are also tracked in the test, so some interesting issues from participants' thinking process have been explored, such as which view in timeline is often used by participants to find answer, do the participants understand the interactive function in prototype well and is there any difficulty for them to interact with it, or participants may give some open comments and suggestions which may be useful to improve the design.



	STC	Timeline
Question1	7	6
Question2	6	8
Question3	7	8
Question4	7	8
Question5	4	8
Question6	5	7
Question7	4	8
Question8	7	7
Question9	7	4
correct/total	=54/72	=64/72

Figure 5.7 Correctness of test questions



	STC	TIMELINE
Q1	63.75	41.88
Q2	85.75	24.63
Q3	160.75	70.13
Q4	134.50	77.13
Q5	90.50	59.75
Q6	179.88	43.38
Q7	105.50	44.88
Q8	60.63	17.38
Q9	105.50	44.88
Total	991.30	428.50

Figure 5.8 Time cost for test questions

Figure 5.7 shows the number of correct answers for each test question. As can be seen from the right side table, for total 72 question in timeline group 8 participants get 64 correct answers, for participants working with STC the amount of right answer is 54. In **Figure 5.8** the average time consumed (unit: seconds) by eight participants in one group on each question is calculated and presented. The "total" row indicates the average total time cost of eight participants in one group for all the 9 test questions, where the total time cost for timeline user is significant shorter than participant in STC. This result could indicate that for answering those nine questions, timeline shows, overall, both high effectiveness and efficiency. This meets the expectation of the performance of alternative timeline representation. However, as we can see from **Figure 5.7**, the high correctness is not always from timeline group. STC group sometimes got higher correctness (e.g. question 1, 9) and sometimes they had equal correctness or STC had only one correct answer less (e.g. question 3, 4, 8). This phenomenon suggests that for some specific questions (demands), timeline may not always perform better than STC. And, the time shown in **Figure 5.8** is the calculated average time cost for each question. This kind of data processing may lead some specified information loss. In order to investigate for answering which kind of question the alternative timeline is much appropriate, therefore, detailed analysis for each question based on think-aloud records and eye-tracking data is going to be done.

5.5.2. Further evaluation based on performance data, thinking-aloud records and eye-tracking data

The performance data is discussed along with thinking-aloud data and eye-tracking data in this stage. For the thinking-aloud data it is possible to reply the video recorded in the test, and check participants' words when they answer particular question. For eye-tracking data it is necessary to visualize the eye movement on gaze plot. In **Figure 5.9**, the gaze plot displays movement sequence, order and duration of gaze fixation. The gaze points of each participant are represented as circles; the size indicates how long the point was fixed; the line between every two circles represents the path of the eye movement and the number in circles shows the order of gaze point. Since the eye movement datasets are always large so when the data amount increases the overlaps of gaze points may lead misunderstanding of that area. It is possible to segment the large dataset to smaller one, for example, producing gaze plot for each test question and set transparency or numbering the fixation points to solve the overlap problem. In addition, it is useful to reply the gaze fixation process in Tobii Studio, which is better to understand the whole process of eye movement while participant answer questions.

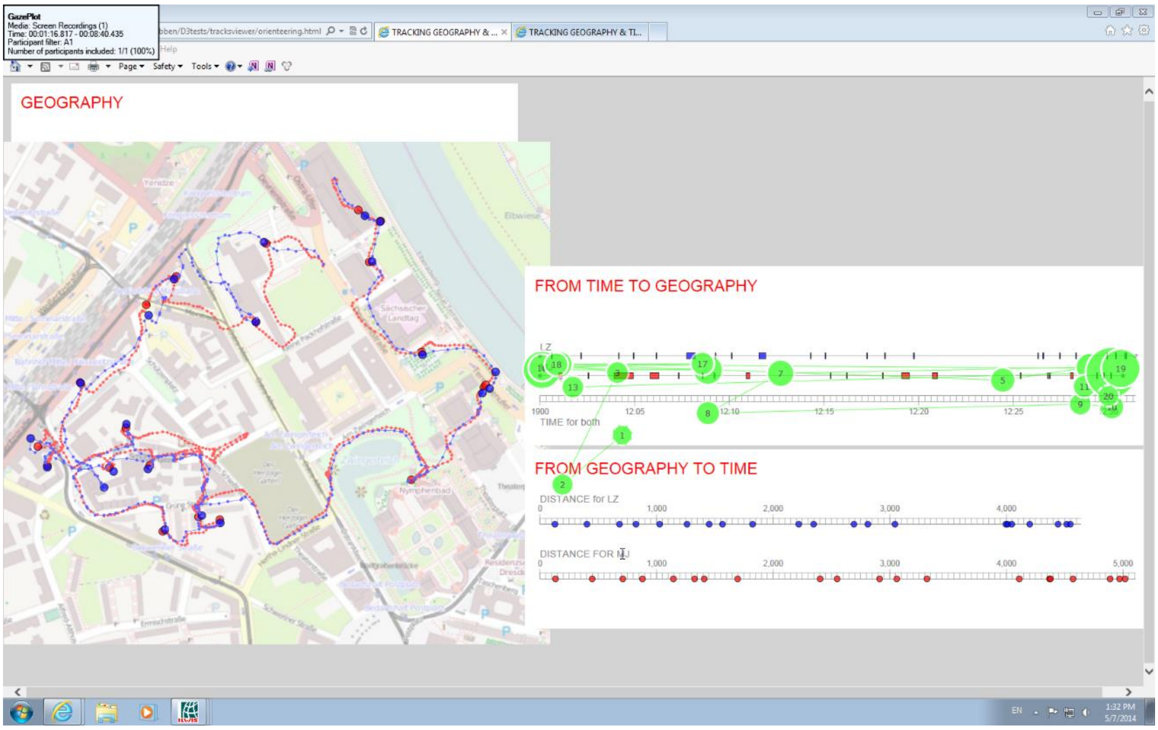
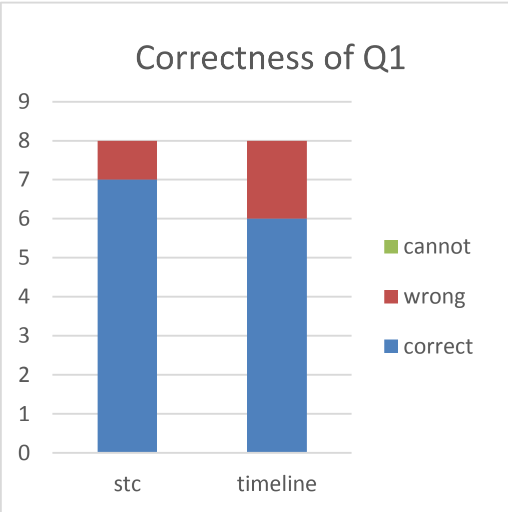
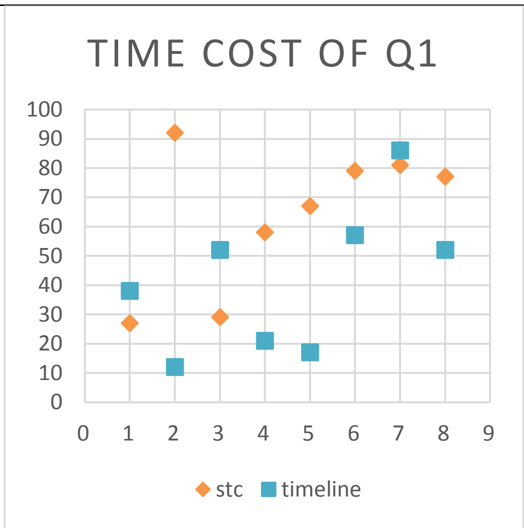
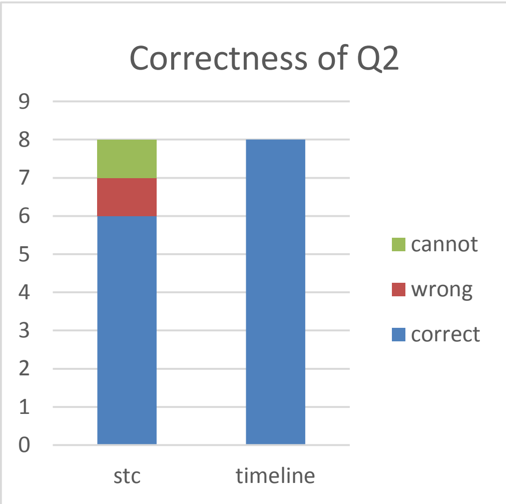
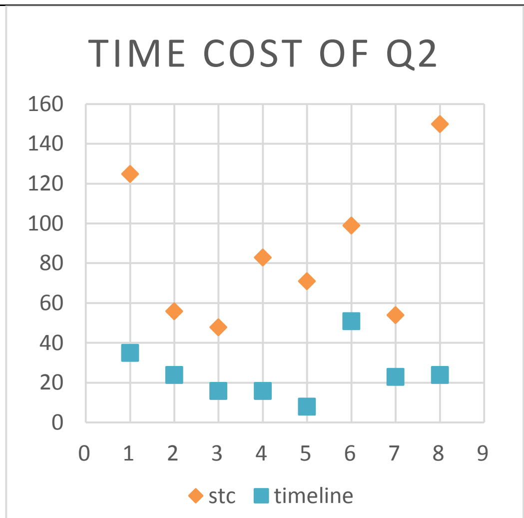


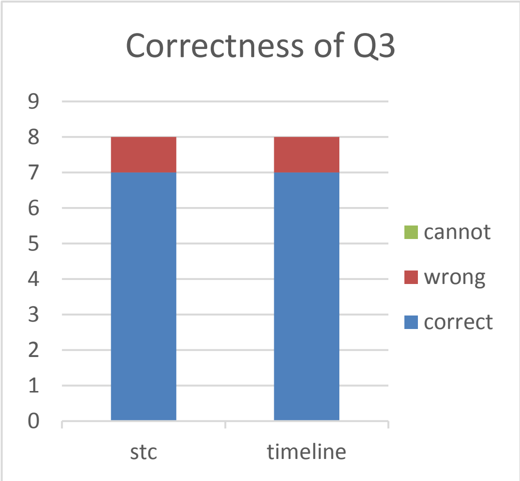
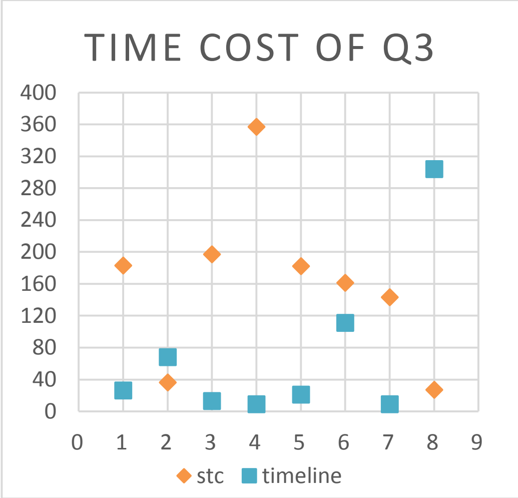
Figure 5.9 Gaze plot produced in Tobii Studio

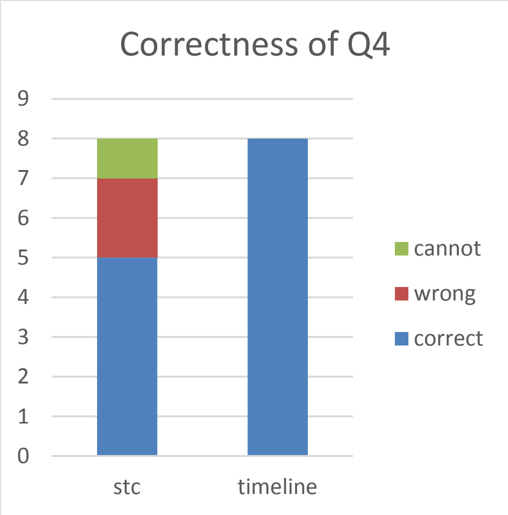
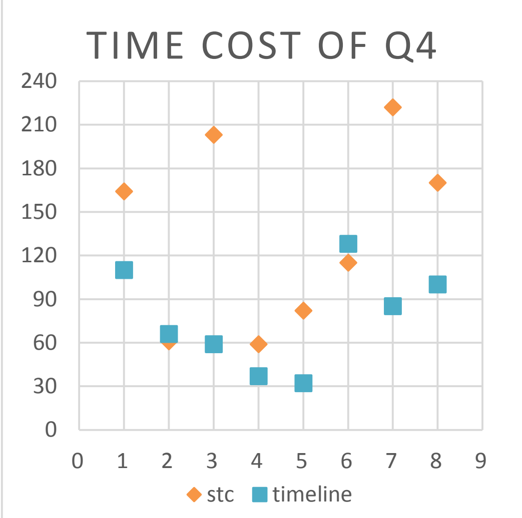
Since each question reflects the particular information can be conveyed from visualization, the analysis is structured by questions and the analysis result is shown in following tables and graphs. In bar chart shows the correctness of answers from 8 test participants from each group. The x-axis shows different groups while y-axis refers to participants. The scatter plot shows the length of time that each participant from each group spent on answering questions. The x-axis refers to participants while y-axis shows the time for answering questions. “Q1” in graphs refers to the test “Question 1” and so on.

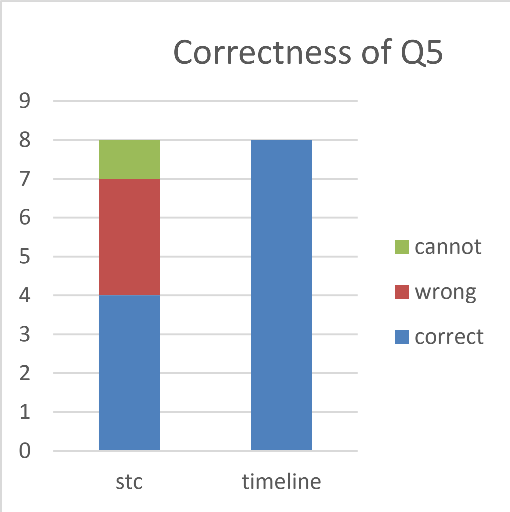
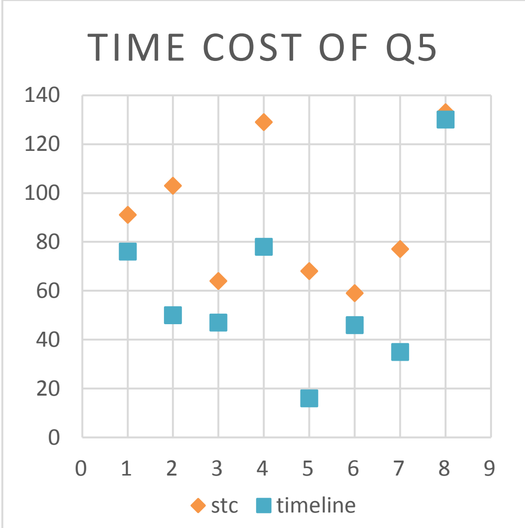
The text under graph not only describe the correctness and time cost for each question, but also explain why this result happened by the aid of thinking-aloud records.

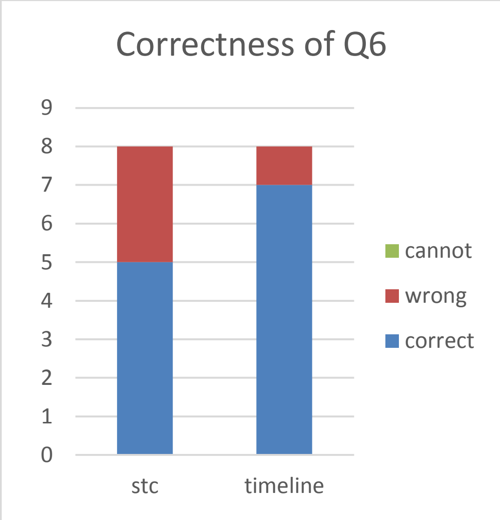
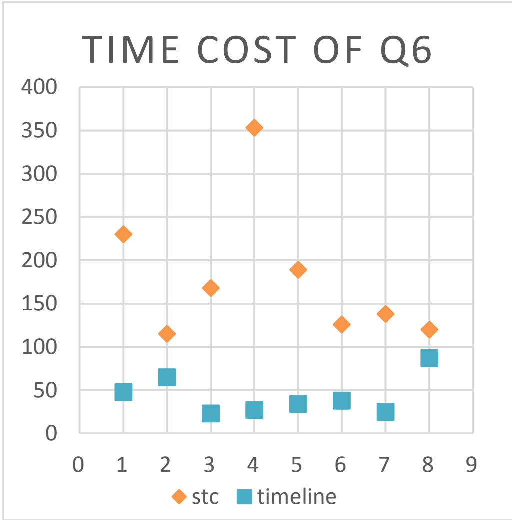
<table>
<tr><td colspan="2">Question 1: did the two competitors follow the same path from target 1 to target 2?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Most participants find the answer to Q1, both in STC and timeline, and they did not feel difficult to answer this question. Although there is no geographic information shown timeline, but from the geography view people can easily find there is a track shown with an open street map. One reason why some people get wrong answer because they are not clear with the question, two participants treat the “same” in question as “similar”, and one is from STC group another is from timeline group.</td><td>For this question participants always start from finding right target (target 1 and target 2), some participants in STC group feel a little confused when they try to figure out which side the event starts, for example, bottom or top, so it costs them several time. After they find the target they also need spend some time on rotate the cube to a suitable perspective to see the path. For the participants in timeline group, it is easier for them to find target because the order is displayed on timeline and through the interactive function, they can easily find those two target on geography view. However, it still cost some time.</td></tr>
</table>

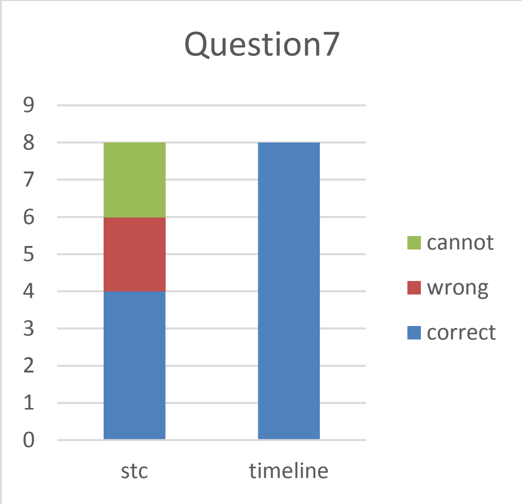
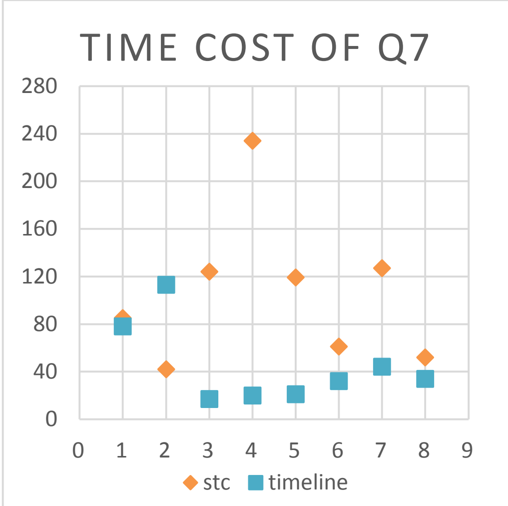
<table>
<tr><td colspan="2">Question 2: which competitor ran the longest distance during the event?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Most participants working with STC feel difficult to know the information related to distance, and these is also no tool in Ilwis for users to measure the length of path line so most of them felt this is a really difficult question. Finally some participants give answers by using their observation without any exact evidence so are not sure with their answers. But participants using timeline feel much easier on this question, and most of them got the right answer from the distance bar in GT view.</td><td>Since participants working with STC all feel difficult to answer this distance related question, they spent lots of time to compare the path both competitor passed in the cube and still not sure with their answers. But the situation in timeline is different, most participant understand what the length of distance bar in GT view represents, so the spent less time than participants in STC group and get the right answer.</td></tr>
</table>

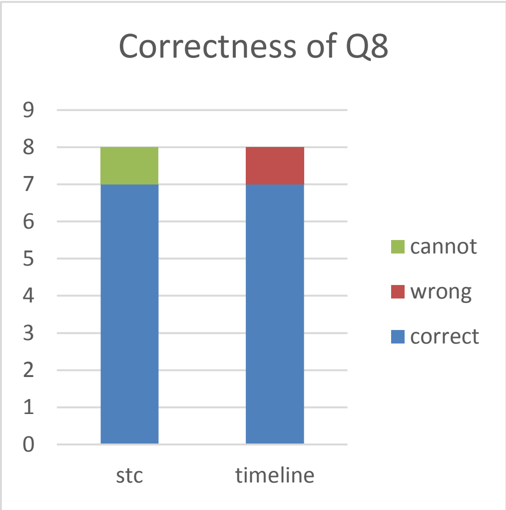
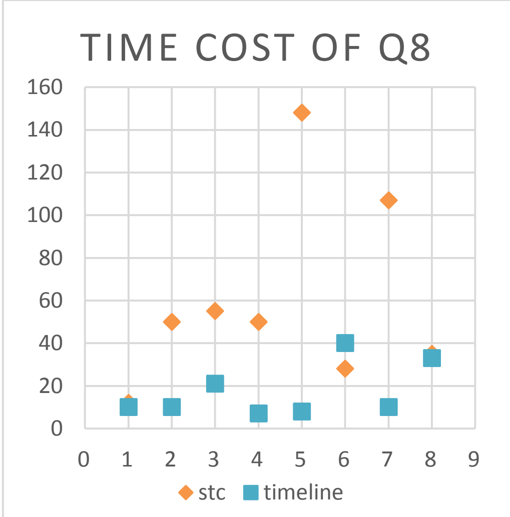
<table>
<tr><td colspan="2">Question 3: which competitor took most time for the event?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Most participants in both group all get right answer. In stc group, since there is no information about event duration so participants need to move the background map up and down to check the exact time of start and end for each competitor, then make a calculation. However, One possible risk exists in this process. For example, one participant make mistake when he calculates the time difference so finally he got wrong answer. For participants using timeline, it is easy to compare the length of time bar in TG view and most of them get right answer. But if people mix up the different meaning of length of bar in different view, they may got a wrong answer. The one give wrong answer in timeline group because he forget this function of timeline.</td><td>Since the duration does not directly displayed in stc, participants need to find start and finish first and make some notes about time, then do some calculations to get the answer. This process often takes a certain while, as it can be seen from the above graph, 7 participants took more than 2 minutes. For the people using timeline, if they are clear about the meaning of the length of bar in GT view they can easily get answer, 5 participant only took less than 40 seconds to find answer. But if people do not understand the timeline well, they may get trouble and spent lots of time in finding the answer with reading other parts of timeline application, for example, the last participant.</td></tr>
</table>

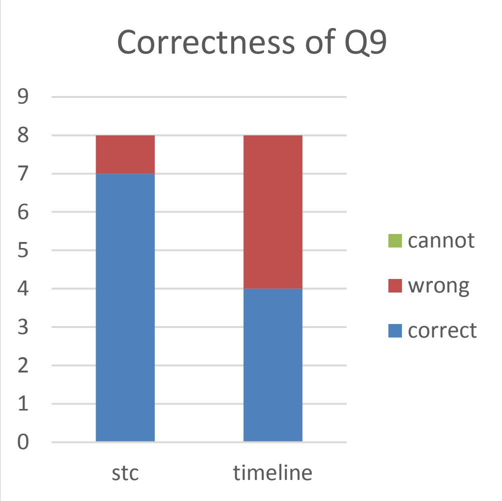
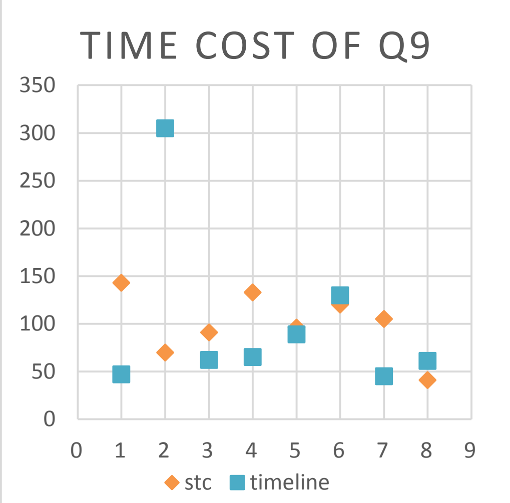
<table>
<tr><td colspan="2">Question 4: who was the first to reach target 2? When did he arrive and departure again?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Majority participants in stc group understand that time goes from bottom to top in stc so they got the right answer, the competitor whose intersection with ‘station’ pipe is lower is the first to reach that target. But some people are not familiar with this principle so they cannot find answer. And another difficulty is find the arrival and departure time. Most participants complain that the thickness of path and pipe make them confused to find the exact moment. For timeline group, since the arrival and departure time are already shown in the yellow pop-up, so it is easy answer the second part of question. The only challenge is to find the 2nd target, some participants get this from geography view and others find it in TG view, both methods are not difficult for participants and they all get right answer.</td><td>For the first part of question, participants using stc do not take too much time but for the second part, most people feel difficult to determine the exact arrival and departure time, so this process took a while and two participants even spent more than 3 minutes. In the timeline group, people spent more time on determine which target is the second one. Some people start searching from geography view, some from TG view. Since there is a pop-up for each stop on target, once participant determine the right target they can directly get answer from the pop-up, so second part of question does not took a long time for the people using timeline.</td></tr>
</table>

<table>
<tr><td colspan="2">Question 5: who ran a longer distance between target 3 to target 4?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>In this question, participants in two groups both need to find target 3 and 4 first, and most of them use counting target from the start. The possibility of making mistakes while they are counting increases when the target number we ask increases, this effect is more obvious in timeline because there is no identifier for each target. But for 3rd and 4th target, most participants feel not too much difficult. In timeline group, participant can get answer by using distance bar in GT view or calculate distance difference by using information shown in pop-up, these tasks are not easy for them and all of them get right answer. But for participants using stc, similar with Q2, there is no exact distance information shown in the cube so people could only compare it by observation and assumption, which is the reason why only half of participants get the right answer.</td><td>Since the distance is difficult to compare in stc so most of participant in this group spent lots of time on this comparison process. Things are much better in timeline group because there are lots of method to compare distance. Some participant can directly get answer by comparing the length of two distance bar in GT view so they only need few seconds; some participant use the distance information shown in pop-up in any view, although they need to calculate the distance difference but this is not so difficult and does not take too much time.</td></tr>
</table>

<table>
<tr><td colspan="2">Question 6: who spent more time between target 2 to target 3?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Similar with Q3, participant using stc need to make some notes about the departure time of last target and arrival time of next target, then calculate the time difference. They may make mistake in the calculating process, which result in a wrong answer. This question to participants in timeline group is much easier because the length of two bars (which represents time) in TG view is easy to compare and get the right answer.</td><td>Since participants using stc need to make notes and do calculations, which is very time-consuming and half of participants spent more than 2 minutes and half to get the answer. But in timeline group, the length is easy to compare and the result is very obvious, so majority of participants only spent less than 50 seconds to get the answer.</td></tr>
</table>

Question 7: who was faster when running from the start to target 1?	
Effectiveness	Efficiency
	
For the "faster" in question, most of participants understand this question is related to speed. In stc group, only several participants understand the slope of path line in cube indicates speed, but they still cannot get answer because slope for two path is similar and the path is complex, they feel difficult to compare. Most of participants want to use the equation $speed = \frac{distance}{duration}$, but as mentioned before the exact distance value is not presented in stc so it is still difficult for participants to get answer, which result in only half participants get the right answer finally. But in timeline, it is obvious to find the distance of both competitors are almost the same, but one took much longer time so it is easy to get the answer the other competitor has a higher speed.	Although most participant in stc group know the speed is related to both time duration and distance, but the difficulty of distance recognition increases the time cost. Another situation is that participants understand what slope of path represents, but the two path are almost parallel so they are need some time to compare and try to get result from several tiny difference. But for timeline, the distance and duration information is clearly displayed, participants can get this information easily so 5 participants get right answer within 1 minutes.

<table>
<tr><td colspan="2">Question 8: who spent more time while staying at target 3?</td></tr>
<tr><td>Effectiveness</td><td>Efficiency</td></tr>
<tr><td>
</td><td>
</td></tr>
<tr><td>Most of participants in stc group said this is an easy question for them because compared to former question, this one does not have any distance information involved and time information is easy to know in cube. Since from the path one competitor seems cross around a ‘station’ for a while, most participant believe that is the one stay longer on target 3. However, there is still one participant think from the complex path he cannot get answer. For the participants working with timeline, they can get answer by comparing the length of rectangle (which represents the duration on stop) in TG view, or use the information in pop-up (the exact arrival and departure time is presented in it). Both way are easy to lead them get right answer.</td><td>Most of participant spent less than one minute to answer this question. One reason could be the different of path in stc is clear enough for participant to make their decision. For the participants working with timeline, most of them understand that the length of rectangle in TG view represent the duration on stop so they get their answer very fast, for example, 5 participants answer this question within 10 seconds. And the arrival and departure moment is also presented in pop-up so they can also easily find this information without spent too much time.</td></tr>
</table>

Question 9: did the two competitor visit all the target?	
Effectiveness	Efficiency
	
All the participants in stc group are clear that they need to check whether there is an intersection between path and target pipe. Most of them find one path does not intersect with all the pipes and get the right answer. But most participants working with timeline feel difficult to answer this question, because they are confused about how to judge "visit" or not. There is neither clear mark of target in geography view nor identifier in pop-up, which increase the difficulty to answer this question. For the reason listed above, only half of participants get the right answer.	This question took a relatively longer time for all the participants, because it is a synoptic question and people need to derive lots of information from both visualization to support them get answer. In stc group, participants need to examine all the target pipe about the intersection with each path. In timeline, it is time-consuming to compare every target for each competitor, for example, sometimes people need move their eye among three views (geography view, GT view, TG view), which result in the time cost increased.

Seeing from above analysis, the performance of alternative timeline representation can be split up into three levels, much better than STC, more or less equal and no better than STC.

1. Much better than STC (more than two correct answers).

Question 2, 5, 6, and 7 belong to this group. There are several reasons that explain why for these questions timeline performed much better than STC, which are also merits of alternative timeline representation.

- Distance information is clearly indicated in timeline representation but not STC.
- Time duration of both moving and stop parts are demonstrated on timeline, but in STC the way of finding out time duration for moving and stop is to move the base map to get a rough moment of departure and arrival of each stop.
- The speed between each two stops is clearly presented on timeline, but in STC the only thing that somehow relates to speed is the slop of trajectories.
- Timeline representation utilizing straight line to abstractly represent movement events, but STC using the actual shape of trajectories, which is different to compare the characteristics of multiple movements.

2. More of less equal with STC (more/less than one correct answers).
   Questions 1, 3, 4, and 8 belong to this group. Explanation of why they equally performed is that for this kind of questions, both timeline and STC can provide desired information somehow with equal difficulties. Specifically,

   - The overall pattern of movements can be got from both representations (for timeline, it is acquired from trajectories on the base map).
   - The overall time of movements can be acquired from the length of timeline of TG representation, and from start and end time on STC respectively.
   - The duration for staying at stops can be got by directly measure the length of stop duration block on timeline and the length of perpendicular part of trajectories overlay the stop pillars on STC respectively.

3. No better than STC (less than two correct answers).
   Question 9 is the only one, on which the timeline played obviously worse than STC, which was expected to perform better than STC. It is because the timeline representation did not demonstrate that all the stops on the line are orienteering targets, which made subjects confused and thought no targets information on timeline representation.

Consequently, for detailed movement characteristics extraction, alternative timeline representation played better than or at least equal to the STC, which convinced the conclusion that the effectiveness of timeline is higher. By contrast, for the overall pattern identification, both timeline and STC played somehow equally well. In addition, the efficiency analysis of each question also shows that except for the question 9, time spent for answering questions were apparently shorter when using timeline than while using STC, which means the timeline is much efficient when using it to answer movement detailed information related questions.

Thus far, whether to accept or reject first two proposed hypothesis can be answered. Based on the analysis of usability evaluation result, the first two hypotheses are accepted because both time duration on stops and moving speed are clearly demonstrated and can be simply and quickly acquired from alternative timeline representation.

5.5.3. Satisfaction evaluation based on interview result

The interview is structured by several satisfaction related questions:

- Do you think this prototype is easy to understand and what is difficulty when you work with it?
- Do you think the prototype is designed properly?
- Do you like this visualization and what do you like about it?

And finally the test participants were asked to give some open comments and suggestions.

The STC was perceived as “creative”, “interesting”, “nice tool for visualizing the path or movement”. Two participant stated that they like the color used in STC, which made the two path is clear to recognize. All the participants stated that the STC concept is easy for them to understand, but several participants complained that the STC in ILWIS is a little difficult to operate.

The timeline was perceived as “easy to understand temporal information”, “easy to use”, “interesting approach” and “very useful”. All the participants stated the timeline is easy to understand, which is on the premise that a detailed introduction was given to the participants. One participant stated that the TG view is difficult to understand for him but GT view works well, because it is difficult to understand the temporal information from a one-division bar. One participant did not use the geography view and he also consider the information in pop-up is not that useful because all the test questions can be answered by two alternative timelines.

Since participants had only experienced one representation and the above-list issues are all their subjective opinions, it is difficult to judge which representation has a higher satisfaction level. However, the information collect from their open comments describes the difficulties when they work with the particular prototype and suggestions for that prototype (see Table). This information is useful for author to improve the design and implementation. The third hypothesis cannot be fully tested.

Table 5.1 Difficulties and suggestions from participants experience STC

		Difficulties	Suggestions
STC	Tp1	NA	• Time information should be shown more obviously
	Tp2	• Cannot get information related to exact time and distance	• It is better to show some labels about distance between each stop
	Tp3	• Lots of calculation for duration • When the stations are closed to each other feel difficult to know the order of target • Difficult to define the arrival and departure • Path is too thick	• The path can be thinner • Label the duration of time
	Tp4	• Difficult to zoom in/out • Not sure whether competitor visit that target or not, and also for arrival/departure	• Easier to zoom in/out • measure time on scroll bar
	Tp5	• not sure whether the path intersect with the pipe of not • no specific distance shown	• provide more detailed information
	Tp6	• difficult to interact with • not sure about the order of target • no exact value of distance	• make the time label in cube more clear
	Tp7	• Not sure for arrival/departure • calculation	• add clear label for time • add function of distance calculation
	Tp8	• difficult to establish a criteria of defining visit or not • pattern of base map make him confused	• remove or change the transparency of base map

Table 5.2 Difficulties and suggestions from participants experience Timeline

		Difficulties	Suggestions
Timeline	Tp1	• no id for target • length on two bas are difficult to compare	• add identifier of target • draw vertical line when circle on bar is highlighted
	Tp2	• the circle represents stop on target is overlapped • difficult to define whether people visit the target or not because lack of mark for target	• map can be zoomed in/out • add identifier of target
	Tp3	• not sure about the order of target	• add identifier of target • add labels for start, target and finish on the map
	Tp4	• the name for timeline is too long and too academic to understand	• give alternative timeline shorter name, at least easy to understand for users
	Tp5	NA	• add identifier of target
	Tp6	• only see stop but not sure about where is the target, target is not clear	• add signs for target
	Tp7	• no clear sign for start on map	• add clear label for target and start/finish • zoom in/out for map could be helpful
	Tp8	• circles represent stops are overlapped on map • no clear label	• map can be zoomed in/out • add clear label for start & finish on the map and also pup-up on timeline

As shown in table5.2, the suggestion are most frequently mentioned is "add target identifier", another highly focused suggestion is that "show the location of pre-defined target on map". Several people suggest that it is better to make the map in geography view can be zoomed in/out, which is helpful for people to understand what happens when the track is complex and targets are closed. One participant mentioned an interesting issue, when visualizing a larger amount movements the tracks on map could be overlapped heavily, but if the track can be selectively hidden and shown as a layer it make much sense for users. For example, if there are ten tracks in total but user only need to analyze two tracks, they can switch off other track layers.

5.6. Discussion

5.6.1. Test result

To correctly answer usability evaluation questions, subjects are supposed to follow an expected routine through each view. For instance, to answer distance related questions, subjects are expected to check map view and then GT representation of timeline view sequentially. Then abnormal routine of answering questions might indicate that subjects did not use the appropriate tool, or did not understand questions correctly. It might also explain the occurrence of unexpected answer or the aberrant time for answering questions.

For example, the test question 2 is asking about distance, which is expectedly answered by GT view, because the length of bar represents distance and people could get answer easily by comparing the length difference of two bar. **Figure 5.10** shows the gaze plot of eight participants, as it can be seen from which almost every participant focus their eyes on GT view and the start and finish of distance bar is frequently scanned. However, the eye movement of participant 6 is different from others. He paid the most notice on the TG view and geography view. Combining thinking-aloud record of him we find that he did not notice the distance related information is shown in GT view. Finally he got right answer by check the finish part of twos bar in TG view to compare the cumulative distance shown in pop-up, however, he spent 51 seconds which is quite longer than other participants. In the interview after test he mentioned that he was confused about the function of three views when he answer first several questions so he often use the TG view to find answers, which means he forgot the function of other views. The same situation happened on participant 8 when he answer the 3rd test question. The question 3 is about duration of entire event, where he spent more than 5 minutes on that question and he did not get correct answer. As it is shown in **Figure 5.11**, most participants understand that the answer can be found in TG view because the bar in it indicates the duration of stop and event. The eye movement of them are often switch from start and finish of time bar in TG view. But the gaze plot of participant 8 is total different from others. Combining the thinking-aloud records, this participant total forget the length of bare presents the time duration. Since he forgot the function of TG view he try to find answer in other ways. He check the pop-up for lots of target especially the first and last several targets, but he still not sure when the competitor arrive finish. Finally he said this question is really difficult to answer and gave a wrong answer.

The reason why participant ignore one particular view or forget the function of one view is might because of the background and cognitive level of participant. Another reason might be the complexity of visualization itself. For instance, although most of participants agreed with the understandability of timeline representation, they still thought that they need extra time to get familiar with this visualization representation as they were confused by the function of three views, which is not necessary for the STC group.

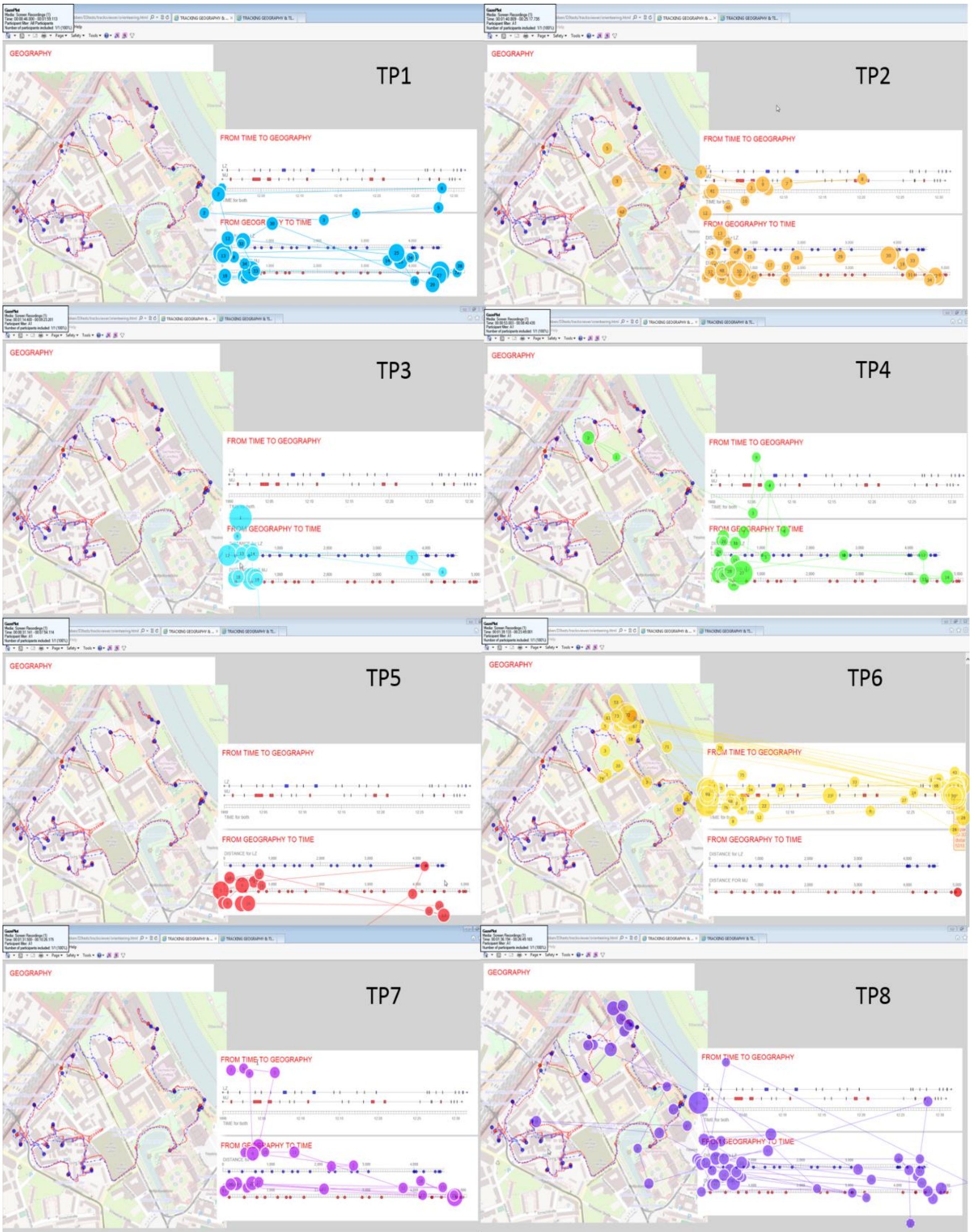


Figure 5.10 Gaze plot of eight test participants of question 2 (Which competitor ran the longest distance during the event?)

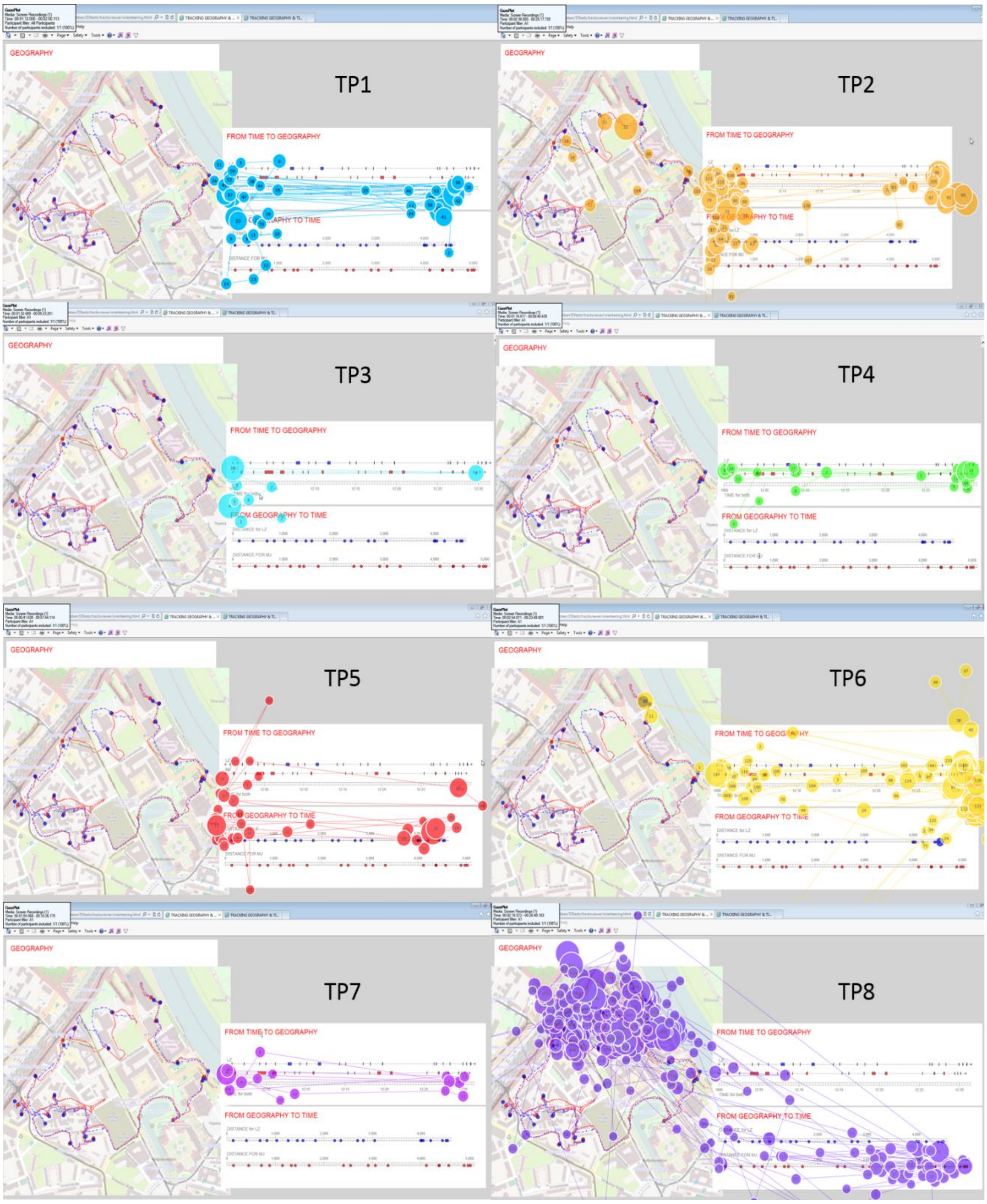


Figure 5.11 Gaze plot of eight test participants in question 3 (Which competitor took most time for the event?)

5.6.2. Test procedure

- **Test questions**

Test questions need to be formulated in a better frame because questions play a very important role in the test. Questions should be related to the information can be delivered by the visualization. The correctness and time cost of each question is a very important aspect for effectiveness and efficiency evaluation. If the test questions are only focus on part of movement characteristics and some questions are more or less repetitive, which results in the information obtained from test is limited. In this test there are 9 test questions, most of them is about comparison of two competitor, which is formulated based on "what + where → who" style. It is better to inquire several questions about when and where, which increases the variety of questions.

- **Test method**

Thinking-aloud is selected to help the evaluator want to get insight into participants' thinking process while they are answering questions. However, in most situations, participants cannot speak whatever came to their mind as we expect. One reason could be that participants are busy with reading visualization manipulating mouse to interact with prototype so that sometimes they ignored the thinking-aloud request. If the participants keep silence, there is no valuable information from participants which increases the difficulty to analysis and find potential problems of prototype. So the evaluator should remind them to speak out what they are thinking or confusing once they stop thinking-aloud. And in this test the gaze data from eye-tracking is also helpful to understand what are participants looking and thinking.

- **Defect in prototype**

From the interview after test, many test participants have more or less complaints about prototype and also some suggestions. For participants using STC, the most common issues are about the thickness of lines (space-time-path) in cube, because if the path lines are too thick the start and finish of the intersection between path line and vertical pipe could be difficult to define, which result in the inaccuracy in time related questions.

6. CONCLUSION AND RECOMMENDATION

1. The timeline based movement visualization representation has been designed, by which most of characteristics of movement introduced in see section 1.1.1 were conceptually visualized in accordance with two use cases. The designed representation successfully integrated fundamental aspects of movement, distance, time, and speed, into one dimensional timeline, which makes the comparison (visually) of multiple movements feasible and much easier than existed solutions. In combination with base maps, the visualization of movement by alternative timeline representation covers spatial (where), temporal (when) and objects (what) aspects, which are the basic components of movement.

   However, the design of alternative timeline is not perfect. Some characteristics of movement cannot be directly visualized, like the instant velocity, acceleration and deceleration etc. Future work could concentrate on the improvement of this design in order to make more movement characteristics be visualized.

2. The conceptual design of alternative timeline representation has been successfully implemented on a representative movement case (orienteering). It indicates that a broad range type of movement can be interactively visualized under alternative timeline concept using computer and GIS techniques.

   Due to time limitation, the prototype of this implementation, thus far, is not functionally robust. It is suggested that future work could deeply develop a Web based application based on the alternative timeline concept. This application is supposed to amend the drawback of the implementation in this study and to supplement new function which can improve the use experience.

3. The performance of the alternative timeline was evaluated to have, for some aspects, higher effectiveness and efficiency than a currently popular visualization method, STC. Although STC performed better on recognizing the overall pattern of movement, the alternative timeline tend to have a lot of merits on visualizing and revealing detail (specific characteristics) of movement. It is also good at differentiating the behaviour of a group of movements.

   Nonetheless, the test strategy might result in the bias and incorrect result, and might make the conclusion of visualization performance not robust. If further evaluation is going to be conducted, it is recommended to improve the evaluation method in a few aspects. For instance, increase the sample size (the number of subjects), in order to statistically analyse the evaluation result, in turn, to get more robust conclusion of usability.

In conclusion, this study successfully designed, implemented and evaluated a timeline based visualization representation. It can visualize characteristics of movement in an understandable way, and can make the visualized information easily comparable. As a supplement to existing methods, the alternative timeline visualization representation would help people get insight into the movement data and its related event.

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APPENDIX

Appendix 1

Test Participants Information Questionnaire

1. Your gender male □ female □
2. What is your nationality? ____________
3. Educational background: ____________
4. Highest degree obtained: BSc □ MSc □ PHD □ Other □ ___________

In which scientific domain did you obtain your degree: ____________
Current Department/Course __________________

5. Do you have any work experience? What kind of job did you do or are you doing?

____

6. Do you have any experience with interactive map products (not static maps), and what kind of experience?

____

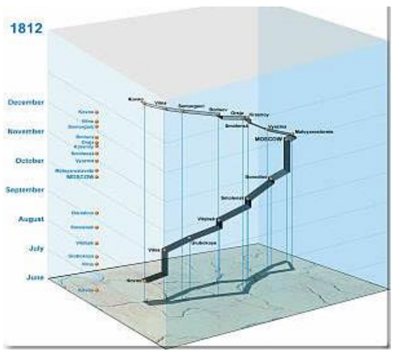
7. Are you familiar with movement data? Do you have any experience in movement data visualization?

____

8. Have you ever dealt with visualization products which are able to present both spatial and temporal information?

____

9. Do you know the so-called "Space-Time-Cube"? Have you ever worked with it?



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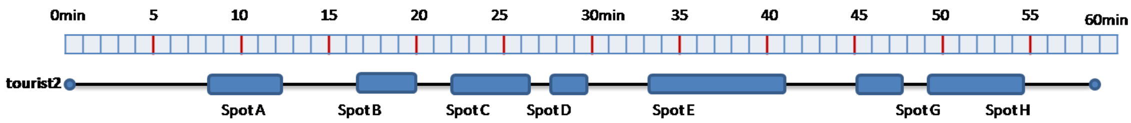
10. Do you know what a "timeline" is? Do you have any experience of working with a visualization product which is designed based on (a) timeline(s)?



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Appendix 2

Test person's information

TP	Gender (F/M)	Nationality	Education background	Highest Degree	Current course
01	F	China	GIS	BSc./ GIS	GFM
02	M	Macedonian	Geodesy	BSc/Cartography	GFM
03	F	China	GIS	BSc/GIS	NRM
04	F	China	Meteorology major	PHD/ Natural geography	GFM
05	M	Ghana	na	MSc/Urban planning	PGM
06	M	China	Software Engineering	BSc/Software Engineering	GFM
07	M	China	Cartography	MSc/Education	GIP
08	M	Pakistan	GIS	MSc	GFM
09	F	China	Ocean remote sensing	BSc/Remote sensing	GFM
10	M	China	GIS	MSc/ Geo-information Science & Earth Observation	NRM
11	F	China	GFM	BSc/Remote sensing	GFM
12	M	Nigeria	Surveying and Geo-informatics	BSc/ Environmental surveying	GFM
13	M	China	Atmospheric Physics	MSc/Atmospheric Physics	GFM
14	F	China	Geography	MSc/geography	GIP
15	M	China	Urban planning	MSc/Urban planning	UPM
16	M	Guatemala	Computer science	BSc/informatics	GFM

TP	Working experience	Experience on				
		Interactive maps	Movement data	s-t information	STC	timeline
01	No	No	No	No	No	no
02	Yes, Geodesy surveying, Road design execution	No	No	No	No	Know the concept, but no experience with it
03	No	No	No	No	No	No
04	20 years, Meteorology	No	No	No	No	No
05	Yes, planning officer	No	No	Yes	No	no
06	Yes, software developer internship	Implemented Eindhoven Event Navigator App (with LBS)	No	Yes	Know it but don't have work experience with it	Know it but don't have work experience with it
07	Yes, editor in Sino Map Press	Yes, web interactive applications, virtual reality techniques, etc.	Yes, but not much experience	Yes	Yes, try to interactive with it to see S-T pattern before	Yes
08	Yes, IT manager related to networking, internet, user data, email management	Yes	No	No	No	No
09	No	Google maps	Yes, GPS	No	Yes, but never use it.	no
10	9 years working experience, about designing and developing GI system	Yes, google maps and self-developed product	A little bit experience	Once, dynamically visualize the path of typhoon in web GIS	No	Yes, but never work with it

11	No	Saw interactive map in lecture	No	No	Have seen it before, but haven't work on it	Have seen it before, but haven't work on it
12	Yes, Field surveys and mapping with GIS	Yes, google earth	A little	Not quite	Know it, haven't work with it	Saw a demo on timeline in lecture, but no experience working it
13	No	No	No	No	Know, but never work with it	No
14	No	No	No	No	Know, but never work with it	Yes know, but never work with it
15	No	Yes, google map	No	No	Yes, but never work with it	Know this idea but do not have any experience to use it
16	Yes Technical support	No	No	No	Recently in actual study	none

Appendix 3

Usability Testing Script

1. Welcome

Meet participant

2. Profile/ agreement (5mins)

- Purpose – testing usability of movement visualization
- Testing visualization solution, NOT you
- Recording you

3. Testing introduction (15mins)

- Introduce Space-time cube (STC) or alternative timeline (depends on which test group the participant belongs to)

  In the meanwhile the hardcopy introduction and implementation on the screen will be shown

  Any question? If so, answering questions.
- You need to answer 3 warm-up questions by working with the provided visual solution.

- Introduce orienteering.

  Any question? If so, answering questions.
- Introduce test procedure (the hardcopy instructions will be given to you also)

  Think aloud (you need to verbalize your thought in the test)
  Eye-tracking (introduce the eye-tracking equipment and software)
  Questionnaire
  Approximately 60 minutes/ person
  Any questions before we start? If so, answering questions.

4. Testing (30mins)

Start Tobbi Studio on the computer and check the project and recording file, and start eye movement calibration.
(Check whether the tp sit comfortable, if not, adjust the chair and screen.)
Let us complete the eye movement calibration first.
If there is no problem with the calibration result, the test will start.
Now I'm going to show you STC in ILWIS (or alternative timeline online). You can browse and interactively play with it. At the same time you are going to answer a few questions. Here is the question list and you can write down the answer below each question when you find the answer. For each question please read it aloud, and continue to tell me what you are thinking when you are trying to figure the answer out!
During the test, if you have any question about the visualization application or any confusion about the question I give to you, you can speak them out. But I cannot response you in this process.
If you complete all the questions, the think-aloud and eye-movement part is done.

5. Questionnaire (10mins)

Now I will give a questionnaire to you, the questions on it are about your feelings when you just worked with the visualization product I gave to you. Do you like it? Do you think it is designed properly? And do you think it is helpful to you when you want to find answers to spatio-temporal questions?
You do not need to write down your answer on this paper, just tell me your opinion and the computer will record it.
When all the questions are answered, press "esc" to stop recording.

6. Thanks

Many thanks for all your work today. You've been really helpful. I hope you enjoyed it!
Show them out

Appendix 4-1

Introduction of the Space-Time-Cube

The STC (Space-Time-Cube) is a visual representation where the cube's horizontal plane (x-axis and y-axis) represents geographic (location) information and the 3D vertical axis represents time. The cube can contain features such as Space Time Paths that represent the spatio-temporal tracks of moving objects, or Stations that represent the stops of static objects.

The figure below is a screen shot of a STC. As shown in the figure, the blue line represents a trajectory of a bus in Dublin. Vertical parts of this line indicate a stop on a specific position and the inclined parts represent the process of movement from one location to another location. The gradient of this inclination reflects the moving speed, the closer the line is to a horizontal plane the faster the speed it has. The red pipes represent the bus stops in the route; if the path intersects with a pipe the object can be considered to be at a bus stop. The open street map is shown on the horizontal plane as a background, and it can be moved up and down by dragging the scrollbar. The time can be labeled along the z-axis and the coordinates along the x- and y-axis. The footprint of this path is projected on the background map also.

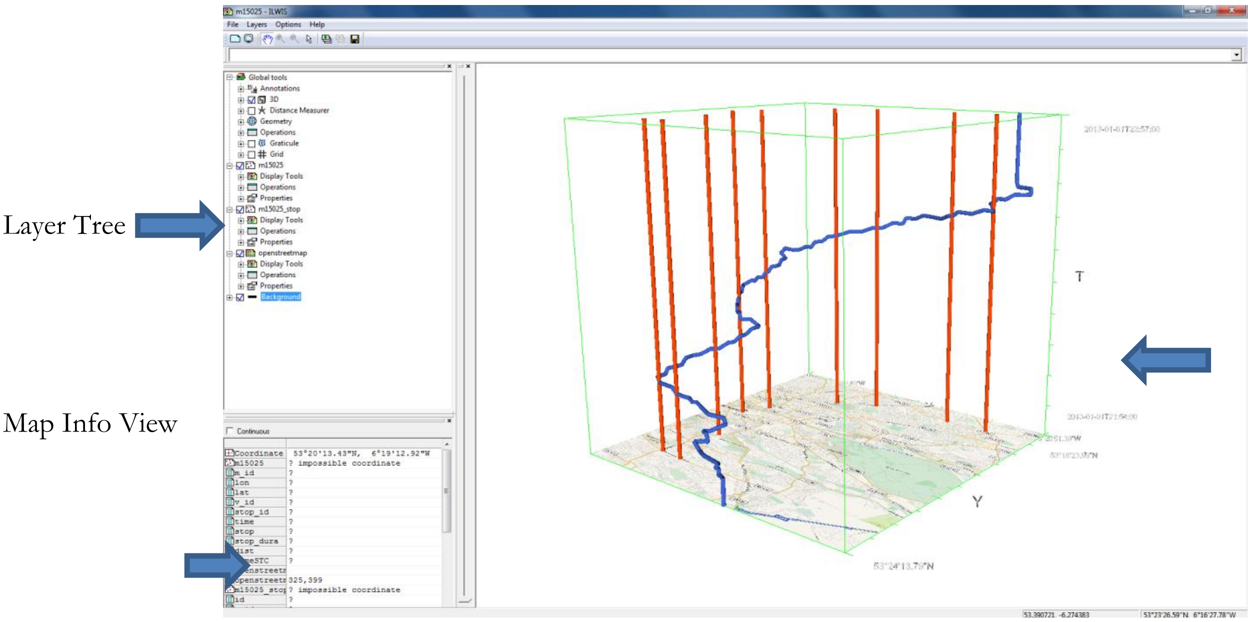

Figure 0.1 STC

The interface of STC consists of three parts, The Layer Tree, the Map Info View and the Map View. The Layer Tree controls all display options of all the items in the Map View. The Map Info View shows extended information about features in the Map View. The Map View displays the spatial data sets. To rotate/move/zoom the cube in the Map View, press 'Ctrl' and drag the mouse using the left button (rotate), right-button (move), middle-button (zoom). When not pressing 'Ctrl', the default mouse function is to identify the object(s) at the mouse-pointer by showing the selected Display Attribute (see Figure2). Alternatively, the "Pan" mode can be entered, by pressing the "Pan" button (the hand on the toolbar of the Map Window). This will change the mouse function to rotate/move/zoom, without requiring the 'Ctrl' button to be pressed. To change the mouse function back to normal mode ("Identify"), press the 'Arrow' button on the toolbar.

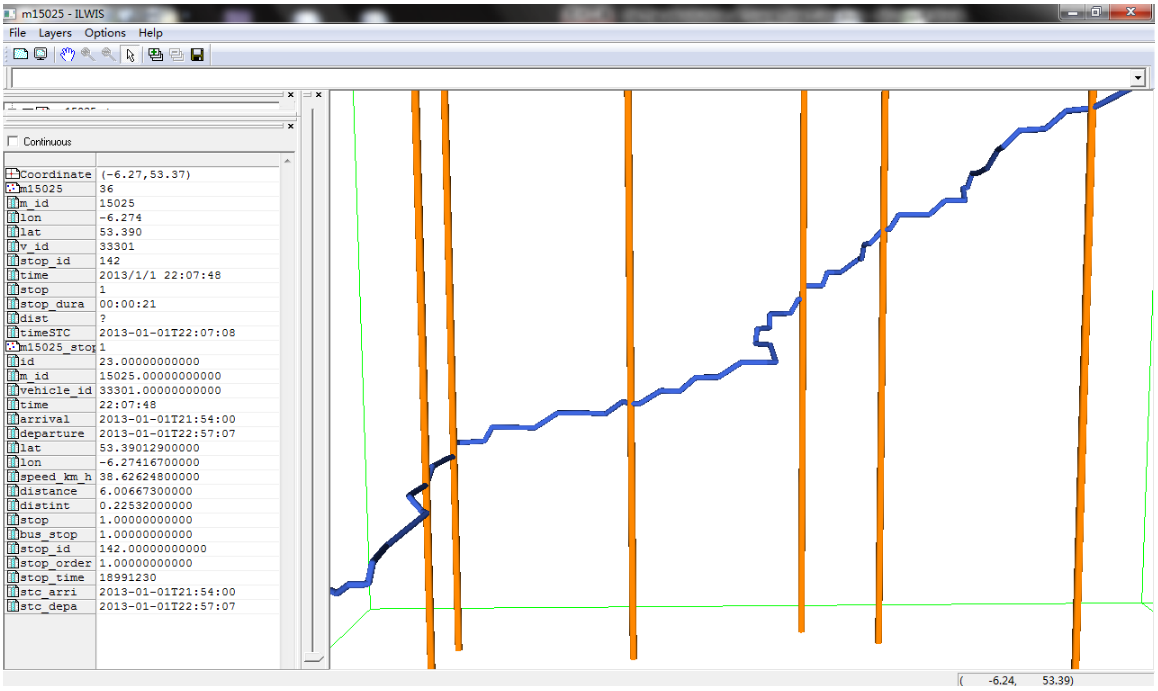

Figure 0.2 attribute of the selected point in STC

Appendix 4-2

Introduction of the timeline application

The designed timelines include three representations (see Figure1):
The most basic one is the "generic representation" at the top. The upper part of it is a linear schematic map, which shows the order of stops of a moving object (the circles represent stops in the movement). The lengths in between every two circles indicate the real distance ratios between stops. The lower part is a timeline which consists of a certain amount of time units; in this example each unit represents one minute. The timeline shows the duration of movement between stops, as well as the duration of every stop. In the representation "from time to geography", the schematic map is stretched on the stops while the other parts (in between the stops) are compressed. So, the length ratios no longer represent the real distance ratios but the time ratios instead. The length of rectangles represents the stop duration at each stop.
In the representation "from geography to time", the schematic map is kept in line with the distance ratios, whereas the timeline is compressed. Actually the duration of the stops is not represented at all. So, only the units representing the moving process are displayed and the size of the units in the timeline indicates the object's average speed in this moving process.

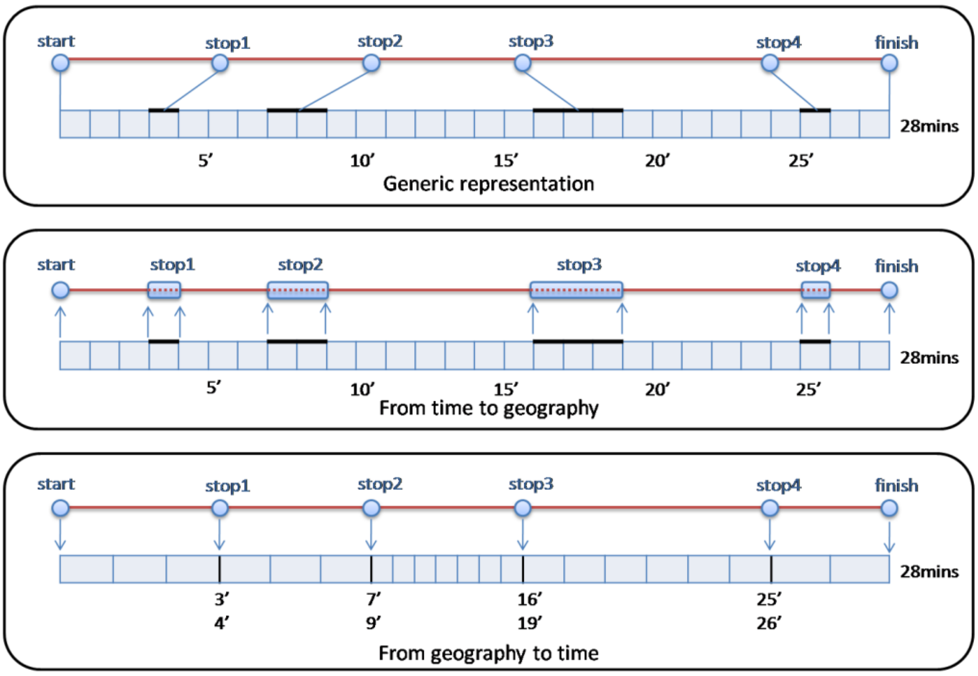

Figure 0.3 Alternative timeline representations

In order to provide the users with a better understanding of the geographic context, a base map with the route is integrated with the timeline representations (see Figure2).

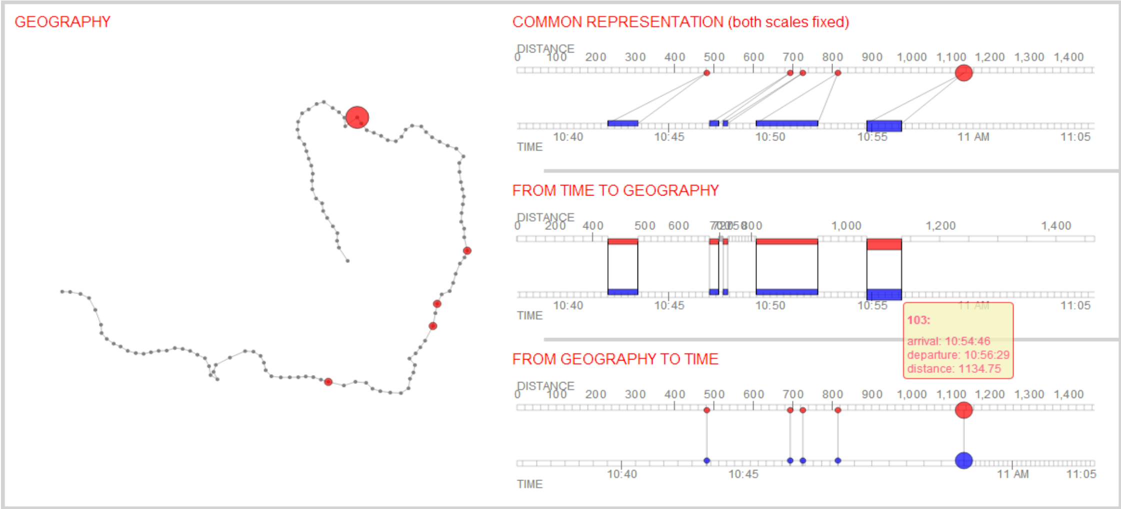

Figure 0.4 Timeline implementation in a web environment (for a single movement)

This timeline implementation contains several interactive functions. All 3 timeline representations are linked to the geography view, so when the mouse moves to a stop on any one view, the stop on other views will be also highlighted and some stop related information will be shown, such as arrival time, departure time and cumulative distance to that point.

When visualizing multiple movements, only 'from time to geography' and 'from geography to time' representation is kept. As we mainly focus on comparing the relative behavior of two movements and the relative value of their characteristics, the timeline of two movements are normalized to have the same start time, which is 00:00:00. The links that represented by the connection line are not visualized, which will not increase the difficulty of interpreting the movement behavior as the line of links are always perpendicular.

Appendix 5

Warm-up questions

Warm-up questions (stc):

When did this object arrive at 1^{st} stop?	
How long did this object stay at 4^{th} stop?	

Warm-up questions (timeline):

When did this object leave the 3^{rd} stop?	
Which part this object move faster, 1^{st} stop→2^{nd} stop or 4^{th} stop→5^{th} stop?	

Appendix 6-1

Introduction to the test process & for thinking-aloud

The test consists of two parts, the first part is "thinking-aloud", then followed by an interview.

In the "think-aloud" session, you will be shown alternative timeline representations which visualize the movements of two orienteering competitors. You will be asked a number of questions, which are designed for the purpose of testing whether you can understand these two visualized orienteering movements. You are suggested to complete those questions when interpreting the visualization product.

You need to think aloud through the whole test process. This will help us to understand better which parts of the application are working well and which parts create problems.

Thinking aloud means that you need to speak out all the thoughts that come to your mind during the test process. For example, which part you are looking at when you try to find the answer and what is the point that makes you take your decision.

You are also encouraged to speak out any questions you may have when you are interacting with the visualization and answering the given questions. Just being an observer, I will not respond to your questions. The questions can be like: "I'm wondering if…"; "I'm confused about…, and should I…" ; and "I'm not sure about…, and should I…" etc.

Once you find the answer, you can write it on the paper. The answers are suggested to be written in a relatively simple way. You need to start each question by saying, for example, now I'm starting with Question 1.

When you feel tired, we can take a break. Whenever you want to suspend the test, we will stop.

After you complete all the questions, the think-aloud session is finished. An interview related to your feelings when you work with the alternative timelines goes after. Several satisfactions related questions will be answered by the evaluator. You are free to speak out your opinions for each question. Some question related to the special things that evaluator noted during the think aloud session could be also asked. In the end, open comments or suggestions for the visualization product are also welcome.

Appendix 6-2

Introduction to the test process & for thinking-aloud

The test consists of two parts, the first part is "thinking-aloud", then followed by an interview.

In the "think-aloud" session, you will be shown Space-Time-Cube which visualizes the movements of two orienteering competitors. You will be asked a number of questions, which are designed for the purpose of testing whether you can understand these two visualized orienteering movements. You are suggested to complete those questions when interpreting the visualization product.

You need to think aloud through the whole test process. This will help us to understand better which parts of the application are working well and which parts create problems.

Thinking aloud means that you need to speak out all the thoughts that come to your mind during the test process. For example, which part you are looking at when you try to find the answer and what is the point that makes you take your decision.

You are also encouraged to speak out any questions you may have when you are interacting with the visualization and answering the given questions. Just being an observer, I will not respond to your questions. The questions can be like: "I'm wondering if…"; "I'm confused about…, and should I…" ; and "I'm not sure about…, and should I…" etc.

Once you find the answer, you can write it on the paper. The answers are suggested to be written in a relatively simple way. You need to start each question by saying, for example, now I'm starting with Question 1.

When you feel tired, we can take a break. Whenever you want to suspend the test, we will stop.

After you complete all the questions, the think-aloud session is finished. An interview related to your feelings when you work with the STC goes after. Several satisfactions related questions will be answered by the evaluator. You are free to speak out your opinions for each question. Some question related to the special things that evaluator noted during the think aloud session could be also asked. In the end, open comments or suggestions for the visualization product are also welcome.