Moving Objects in Static Maps, Animation, and the Space-Time Cube

Biadgilgn Demissie Mullaw
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By

Biadgilgn Demissie Mullaw

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Thesis Assessment Board

Chairman: Prof. Dr. M.J. Kraak
External examinoer: Prof. Dr. M.J. Dijst
Supervisor: Ms Dr. C.A. Blok
Second supervisor: Dr. O. Huisman

INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS

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Abstract

Cartographic visualization has undergone considerable developments with the introduction of new computer technologies. As a result of this development, alternative visualization methods are being made available in the cartographic world. As visualization is important for various human activities like navigation, planning, monitoring, and academic accomplishments, the selection of the appropriate visualization method for a particular application is important. It is, however, not always known what 'appropriate' is in a particular context.

Nowadays, there is a lot of interest in studying dynamic spatial phenomena. There are various dynamic phenomena in the world among which moving objects are worth exemplifying. Recently, moving objects are getting attention in database applications and in visualization. Moving objects are of two categories: individual moving objects and group moving objects.

This research is concerned with individual moving objects and their movement behaviour. The research focused on visualization of the trajectory movement characteristics of these individual moving objects. The main goal of this research is to find the optimal representation for visualizing moving objects (more precisely: walking people). Four representations are considered in this research: the single static map, multiple static maps, animation, and the space-time cube. The study is conducted by considering four movement characteristics (or aspects of moving objects): *speed change*, *returns*, *stops*, and *path* of movement. The ability of users to perceive and understand these aspects from the four representation methods is studied. To achieve the goal, a user test is conducted using the questionnaire method (the users performing tasks). The visualizations were prepared on three levels of complexity - the complexity varying in the number of objects represented and the geometry of the trajectory along which they move.

A prediction about suitability was made based on theory, cartographic knowledge, and common sense. The prediction shows that animation is better than the other methods for visualizing *returns* and *speed change* at all levels, and *path* at Level 2. In the other aspects and levels of complexity animation had equal suitability with the other methods. However, the prediction is not enough to make selection of the best method for a particular use. Thus, user test is needed. The result of the suitability after test illustrates that users perceive and understand the movement characteristics better in an animation than in the other representations, at different levels of complexity. Animation is most suitable for *stops* at Level 1, for *returns* at Level 3, and for *speed change* at Level 1. In the rest animation has equal suitability with one or more of the other methods, except for *path* at Level 2 where the space-time cube is most suitable. In the overall result therefore animation is found to be the optimal representation for moving objects (walking people).

Key terms and phrases: change, movement, moving objects, visualization, static map, multiple static maps, animation, space-time cube

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1. Introduction

1.1. General background

Visualization through graphic representations has been an effective way to communicate both abstract and concrete ideas and its application is expanding in many disciplines of science, engineering and medicine. The use of graphics makes communication and analysis easy. In a geo-visualization environment, graphics (like maps) help to visually understand relationships, patterns, trends, and movements in a number of ways, for instance using multiple representations without constraints (Kraak and Ormeling 2003). The representation of spatiotemporal phenomena consists of three important components: time, space, and attribute. Kraak & Ormeling (2003) attested that the representation of time is receiving increasing attention in geo-visualization environments; without it the study of spatiotemporal process, changes or events cannot be successful. The most commonly used spatiotemporal visualization techniques are static maps (single and multiple), animated maps and the space-time cube (STC).

The use of static maps is one of the earliest applications of geo-visualization. In single static maps, graphic variables (position, form, orientation, colour, size, etc) are used to indicate changes in time or represent an event at a certain time moment. In the temporal representations perspective, small multiples display a set of maps, each for different events in time and change therefore is depicted in successive snapshots (Slocum 1999). In small multiples the temporal sequence is represented by a spatial sequence for the user to perceive the variation in time (Kraak and Ormeling 2003; de By, Georgiadou et al. 2004). Computer animations have become important tools in the cartographic application in recent times. Animations are all about change (in locations, attributes and/or time) (Kraak 1999). They show relationships and correlations between geographic phenomena and time (Karl 1992; Ogao 2002). Animations are conceived to be important, e.g. in monitoring activities, in account of detection of change and perception of spatiotemporal patterns and trends of the represented dynamic object (Blok 2005). An important concept in Time-Geography is also the space-time cube where space is represented along the x and y axis and time is represented along the z axis (Kraak and Koussoulakou 2004). It is a 3D representation of movement, or paths where the user can visualize changes, durations, and other aspects of paths in time of, for example, people, cars, or animals. The classical the space-time cube studies deal with the behaviour of humans considering certain activities of individuals like following a path through space and time (Xia and Kraak 2005). Kraak & Koussoulakou (2004) stated that a better exploration and understanding of temporal events in the geo-world requires the integration of geo-visualization with the space-time cube.

As regards the relative effectiveness of representation of spatiotemporal geographic objects and acquiring knowledge about these objects from static maps, animation, and the space-time cube, experts have significantly different views. Blok (2005), among others, has raised a question as to whether animations are effective media for visualization. Some argue that animated maps might be better than static maps and others contend to the contrary based on the use context. Cartographic animations show process directly; and static maps hardly show dynamic aspects of reality (Karl 1992). To show changes in time and space, multiple still images can be placed on a page but they may become too small and consequently, difficult to compare (Dorling and Openshaw 1994). Dorling & Openshaw (1994) deducted that changes and patterns can be shown on a page in a sequence of static maps on condition that the dynamic information is extremely simple. Temporal animation has fascinating advantages over temporal static maps (series) particularly in depicting real world process and trends, and explaining spatial relationship (Kraak and Ormeling 2003).

On the other hand, Tversky & Morrison et al. (2002) contended that the recently undertaken experiments failed to show the effectiveness of animations over static maps for learning on the reason that animations lack equivalent and comparable contents. They also mentioned that complexity of the content in (non-interactive) animations challenges comprehension. According to Kim & Yoon (2007), animations are not more effective than equivalent static graphics in learning for low cognition (comprehension) related learners. Fabrikant (2005) mentioned that experimental researches in many fields have shown that static graphics facilitate comprehension and communication of complex phenomena.

Moreover, earlier geo-visualization studies argue that the space-time cube representation is powerful in revealing complex spatiotemporal patterns of moving objects. They argue based on the fact that time and spatial information are displayed simultaneously. Kraak (Kraak 2003) explained that the space-time cube is most suitable for the display and analysis of paths of phenomena where time is represented in the third dimension. It can also be applicable for real time monitoring, for example, running races. Kristensson et al (2007), however, argue that the actual usefulness of the space-time cube representation in revealing complex spatiotemporal patterns has not been empirically validated. They further asserted in their investigation by comparing the space-time cube and baseline 2D representations that the space-time cube is at least worth further investigation, for example by varying data density (complexity), choice of maps, domains or level of expertise.

1.2. Problem description

There are significant researches done on animations and their effectiveness in representing dynamic phenomena in various fields (Dorling and Openshaw 1994; McEachren and Fraser Taylor 1994; Tversky, Morrison et al. 2002; Blok 2005; Fabrikant 2005; Fabrikant and Goldsberry 2005; Opach 2007). However, there are contradictions and doubts as to the suitability of static maps, animations, and/or the space-time cube in terms of understanding, communication, and geographic knowledge acquisition in general. Evaluation of static maps, animations, and/or the space-time cube could best be carried out based on the purpose, user tasks, and characteristics of the data. The possibility of *extracting relevant information* and *discovering geospatial knowledge* can be important measures of effectiveness of animations in learning (Blok 2005). The degree users detect and comprehend change, understand spatiotemporal patterns, identify important geospatial objects and their attributes explain the effectiveness of cartographic representations. The problem is that there is hardly clearly established knowledge (but many doubts and questions) as to whether static maps, animation, and/or the space-time cube is/are optimal in the visualization of dynamic phenomena. To fill this gap of knowledge (Kumar 2005), some researchers come up with results that make animations superior to the other cartographic representations, while there are arguments otherwise as well. The question addressed here is which representation (single static map, multiple static maps, animation, and/or the space-time cube) can be considered optimal in the visualization of moving objects?

These issues form the prime impetus for this research. This research aims at narrowing the gap in knowledge by representing moving objects in single static map, animation, and the space-time cube to find which method is optimal for moving objects (with an application involving walking people). The research is conducted at different levels of complexity (in terms of number of objects and the geometry of the trajectory) of the objects represented (see 4.2). Speed change, returns, stops and path of movement are subject for investigation (questions like: why moving objects and why only these aspects are explained in 4.2). The ability of the users to perceive and understand these aspects from different levels of complexity is the consideration on which the assessment is undertaken. It will be of assistance, in addition to determining the optimal representation method, in terms of illustrating the influence of level of complexity in the visualization of moving objects.

1.3. Objectives

The main goal of this research is to find the optimal cartographic representation (s) for moving individual objects (for the application of walking people). The research studies this by representing some movement characteristics of walking people in static maps, animation, and the space-time cube, at various levels of complexity.

Specific objectives:

- To identify the types of movement of moving objects;
- To identify the aspects of a moving object that can in theory best be represented by static maps, animation, the space-time cube at different levels of complexity;
- To identify spatiotemporal user questions about visualization of moving objects;
- To represent some aspects of a moving object in animation, static maps and the space-time cube, at different levels of complexity; and
- To assess which representation method is optimal to represent moving objects and for which aspect at what level of complexity.

The results will give insight into the suitability of static maps, animation, and the space-time cube. Results are supposed to present a basis for different users to select one or a combination of these representations for their own particular application related to moving objects, while taking into account the aspects and the level of complexity of the object to be represented. After accomplishment, this research will also give Geo-visualization researchers a ground to further investigate the suitability of the representations in other use contexts.

1.4. Questions that need answers to achieve the objectives

- What are the different types of movements of objects?
- What are the aspects of moving objects that can be visualized in static maps, animation, and the space-time cube?
- What are the strengths and weaknesses of static maps, animation, and the space-time cube so far investigated in other researches in representing dynamic phenomena.
- What are the spatiotemporal questions users can in theory ask about moving objects (walking people)?
- How can the aspects of moving objects be represented in single static map, multiple static maps, animation, and the space-time cube?
- How can be the suitability of static maps, animation, and the space-time cube be assessed to find the optimal representation for moving objects?
- Which representation method is optimal in terms of visualizing moving objects (and their movement characteristics) at different levels of complexity?

1.5. Methodological approach

Conceptual basics

Before staggering to the design and implementation phases of the research, a theoretical framework is developed. Input is gained by focusing on literatures about cartographic visualization in general, and static maps, animation, and the space-time cube representations in particular. In spatiotemporal representations, there are issues like time, space, change, movement, cognition, and so on which are addressed extensively. These concepts are summarized from the literature. Literature about the aspects of moving objects that can in theory be represented by static maps, animation, and the space-time cube in line with the aforementioned notions are important collections that answered the first, second, third, and fourth research questions: *"what are the different types of movements of objects?", "what are the aspects of moving objects that can be visualized in static maps, animation, and the space-time cube?", "what are the strengths and weaknesses of static maps, animation, and the space-time cube so far investigated in other researches in representing dynamic phenomena?" and "what are the spatiotemporal questions users can in theory ask about moving objects (walking people)?"* .

The output of this phase is a conceptual framework containing expected suitability of the single static map, multiple static map, animation, and the space-time cube based on the theoretical considerations of the strengths and weaknesses of each representation, cartographic knowledge, and user questions obtained from the study of the conceptual literature.

Case study design and implementation

The investigation of the suitability of visualizations to represent moving objects demands a clear and explainable methodological structure. To achieve the objectives, definition and determination of factors that affect the representation techniques is important. The geographic object to be represented and the design of the representations should be decided in order to make effective investigation of the optimal representation. In this research walking people are represented. Their movement characteristics are determined. The design is undertaken in such a way that makes clear (as much as possible) the movement characteristics of the objects. The representations are designed without interactive interface, but a minimum interactive environment is given to animation and the video version of the space-time cube.

Data are prepared fictitiously. They are prepared in such a way that they would maintain the movement characteristics determined to be represented, and suit the design of the representations and the purpose of this research.

This phase is dedicated to answer the fifth question: *"How can the aspects of moving objects be represented in single static map, multiple static maps, animation, and space-time?"*

The following tasks are accomplished in this phase:
Assessment and selection of tools that will be used to develop the static maps (single and multiple), animation, and the space-time cube. Develop the representations. They are prepared at different levels of complexity of the moving objects. The outputs of this phase are single static map, multiple static maps, animation, and the space-time cube.

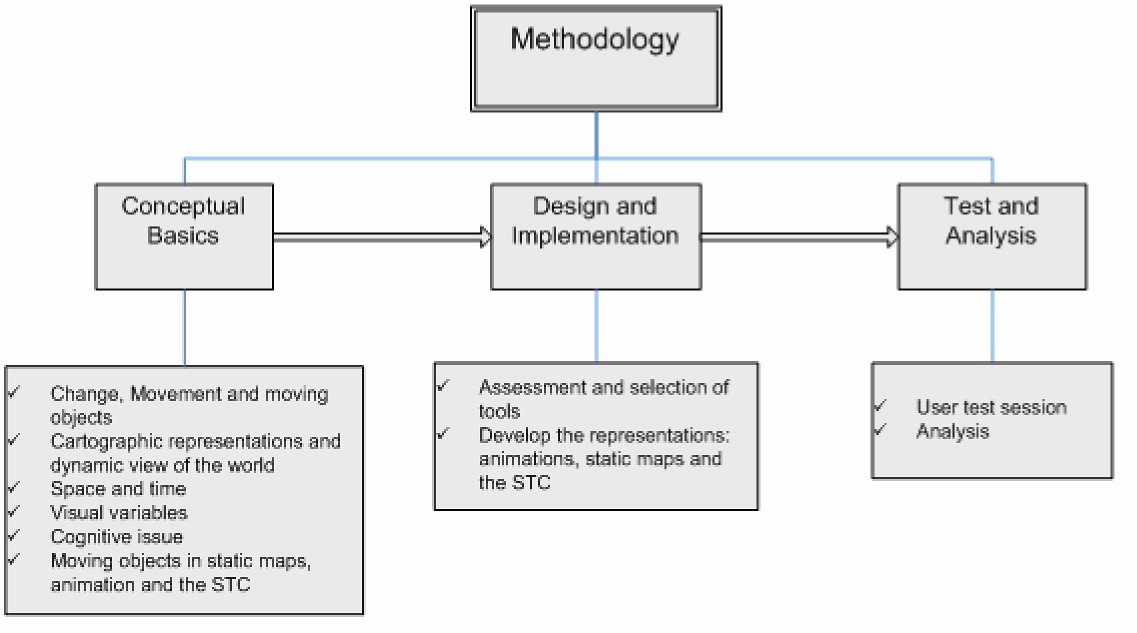

Figure 1.1 Methods followed in the research

Test and analysis

In this phase a user test is conducted to evaluate the suitability of static maps, animation, and the space-time cube in different levels of complexity.

The sixth and seventh questions, "*how can the suitability of static maps, animation, and the space-time cube be assessed to find the optimal one for moving objects?*", and " *which representation method is optimal in terms of visualizing moving objects (and their movement characteristics) at different levels of complexity?*" are answered at this level. In this phase statistical analysis is employed to analyze the responses of the users.

The output of this phase is an adjusted conceptual framework of the output of the first phase (an expected conceptual framework) based on the test results of the evaluation.

Finally, based on the analysis at this phase and the knowledge acquired from the previous phases, conclusions are drawn and recommendations are given.

1.6. Organization of the thesis

This thesis is organized in seven chapters. Chapter 2 discusses about the concepts of change, movement and moving objects. In this chapter the aspects of moving objects represented in the visualizations are identified. Chapter 3 is about cartographic visualization. It discusses about the cartographic representations in the context of representing dynamic phenomena. Cartographic visualization in the context of moving objects is discussed in chapter 4. In this chapter, the strengths and weaknesses of static maps, animation, and the space-time cube investigated in other researches are addressed. Finally, a conceptual framework about the suitability (prediction) of these representations is developed. Chapter 5 is about the design and implementation of the visualizations. It explains the design decisions and the actual implementation of the representations with the aspects of moving objects identified in chapter 2. Chapter 6 describes the test and analysis. It describes the evaluation methods used and the results from the test. Finally, chapter 7 discusses the conclusions and recommendations of the thesis.

2. Moving objects and spatiotemporal change

2.1. Introduction

The concept of change in space and time is not a new concept. It has been an issue of discussion and research (also in the context of GIS representation) in different areas like geology (by studying geological events), demography (by studying the growth of population), and economics (by studying the trend of economic growth). As Claramunt and Jiang (2000) have explained, nowadays the representation and understanding of movement in time is an active research issue in many sciences related to the representation of geographic phenomena. The concepts related to moving objects, however, are complicated and are new areas of concern in different fields of studies like visualization and database applications. The identification of moving objects and conceptualizing their movement in space and time is indispensable for various applications (for example, tracking the path of individuals for management and political needs, vehicles for traffic control, ships for naval purposes, military vehicles for military analysis).

In this chapter, the concepts of change in a geospatial context (2.2), movement, and moving objects are discussed (2.3). This chapter summarized the focus of the study with a schema. Finally, it closes with a summary.

2.2. Geospatial concepts of change

2.2.1. Conceptual approach

The concept of change has a wide range of meanings. It might mean transformation (change of something by improving in appearance or usefulness) or modification (making minor changes in the sense of improvement) over time (Rensink 2002). It might also mean change in some aspects (alteration) or change in character, form or function (conversion). It can also be explained as a shift in position or direction as well as a variation within a given range of possibilities. The meanings of change associated with geospatial objects are important here and will be discussed below.

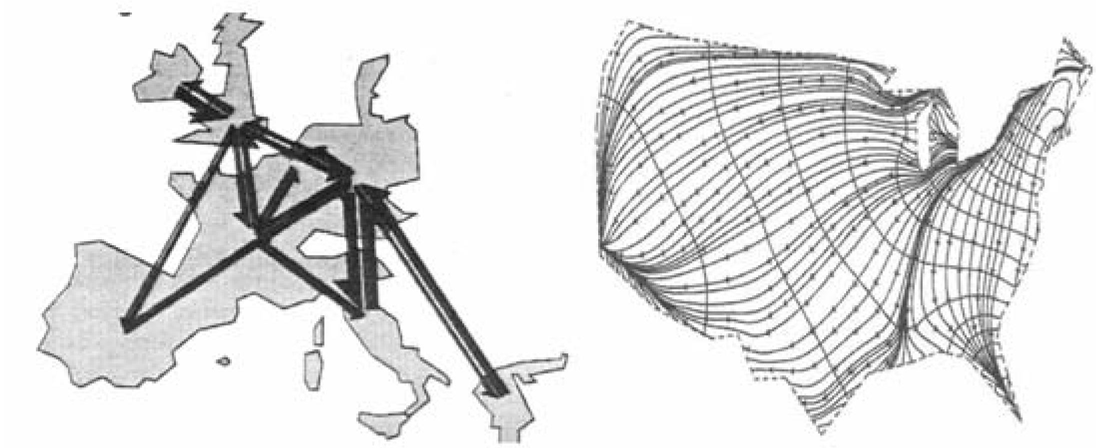

Figure 2.1 Discrete (left) and continuous (right) flow maps (Andrienko and Andrienko, 2007; pp. 121).

The real world has many different objects that exhibit spatiotemporal characteristics. There can be made a distinction between continuous change (e.g. change in location of moving vehicles, flying birds, or stream discharge) and discrete change (e.g. merging of two parcels of land, the change in space from the origin to the destination of the migrant people/animals, or demolition of a building) (Harrower 2002; Pfoser and Theodoridis 2003). Eschenbach (1998) terms the discrete and continuous conceptions of changes as event view and processes view. The event view in case of movement relates the starting position and the final position of a moving object. The process view, on the other hand, emphasizes the path or trajectory and the process of change along it. Harrower proposed four basic kinds of geographic changes within the two types of changes: location, shape/size/extent, attribute, and state/existence. Harrower has further grouped the location, and shape/size/extent as relative and self-referential respectively. Change in location of one object requires another object as a reference to articulate that the object has changed its location. Change in shape/size/extent, however, does not need an external spatial referent. Change in shape/size/extent is not a relative expression; it can be expressed by the object on its own (by measuring its geometry or describing the extent using map coordinates). Change in attributes needs no motion of the object (it is not positional shift). Change in existence refers to appearance or disappearance and is measured at a nominal level. Table 2.1 gives these changes with examples and their level of measurement.

Table 2.1 Types of geographic change (Harrower, 2002; pp. 32)

Change in…	Example	Level of measurement
Location	The path of a hurricane	Ratio
Shape/Size/Extent	The areal extent and shape of a hurricane	Ratio
Attribute	Decreasing wind speed	Ratio
State/Existence	Downgraded to tropical storm	Nominal

Harrower was concerned about how these changes in geographic phenomena can be represented simultaneously in a cartographic representation. In this research all the changes in geographic phenomena will not be represented. Some changes are represented (see 2.2.2, last paragraph).

Drummond (2007) has illustrated three primary change classes as attribute change, shape change, and movement. Attribute change is a non-spatial change and the rest are forms of spatial change. For the spatial change further sub-classification is made. The shape change includes expansion (regular or irregular), contraction (regular or irregular), and deformation (under the constraint that area remains constant). The sub-types of movement are translation and rotation transformations. The attributes of movement are identified to be azimuth/direction, speed, and rate of change in speed (acceleration or deceleration).

2.2.2. Change in a visual analysis point of view

Blok (2005) has developed a framework of general linguistic expressions needed to characterise changes that are relevant for monitoring and that can (at least in theory) be discovered by visual exploration. Four main categories are distinguished in the framework: concepts to describe change in the spatial domain, in the temporal domain, overall spatiotemporal patterns over longer series, and relative similarity in comparisons. The main categories are related to visual exploration tasks and to the focus of attention of the viewer of the representations. In the spatial domain Blok (2005) proposed three main classes to characterize change (Figure 2.2): Appearance /disappearance (existence or non-existence of an object; Mutation (refers to change in the thematic, not geometric, attribute of an object), which further is classified as mutation at the nominal level of measurement and mutation at a higher than nominal level, mainly in terms of increase/decrease; and *Movement*, which is about change in spatial location or geometry of an object. Movement is sub-classified as movement along a trajectory and boundary shift; the former refers to a phenomenon that changes its position following a certain path. Change in geometry is possible in the process of movement, for example, a tornado and pollution in river water. Boundary shift refers to a movement in location of part of a phenomenon (for example, jet streams).

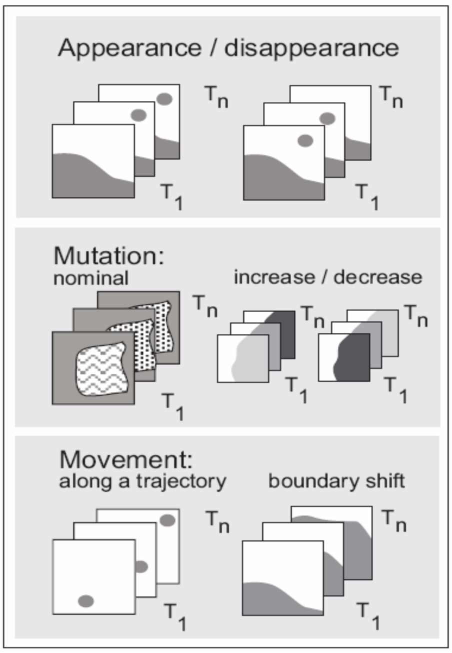

Figure 2.2 Characteristics of change in the spatial domain (Blok (2000); pp. 23)

In the temporal domain, Blok has distinguished different characteristics of change (Figure 2.3). These include moment in time, sequence, duration, pace, and frequency. By aggregating changes over relatively short periods, she has identified two spatiotemporal characteristics over long periods that are relevant for many applications: cycle (periodical return) and trend (structured non-cyclical pattern). An example for the cyclic spatiotemporal change could be seasonal migration of birds attributed to seasonal weather change. Another example is the positional change by season of the Inter-Tropical Convergence Zone (ITCZ), or seasonal prevalence of hurricanes and tornados. A spatiotemporal trend can be exemplified by the gradual expansion of desertification (for example in the “Sahel” region), or a structured change (increase or decrease) in the amount of rainfall influenced by terrain/location (such as from lowland to highlands or from tropical to temperate zones).

Finally, for the purpose of comparison of changes for exploration tasks (based on the application), Blok (2005) has given two concepts: comparison of recent changes (relatively short periods), and comparison of relatively long periods. The definition of a short or long period depends on the application. For example, for a moving person a short period might be measured in minutes/hours, and a long period in weeks/months/years. For the comparisons in relatively short periods, two ways of comparison are distinguished: same or different. These distinctions refer to changes that are comparable/non-comparable (particularly in the locational and/or the thematic data components). With regard to the comparison in relatively long periods, she has identified the following concepts: 1) same/opposite/difference to indicate comparable (proportionally or inversed) and incomparable changes. Here there are positive correlation (same), negative correlation (opposite) and anomalies (different). 2) In phase (synchronous)/phase difference to indicate to simultaneousness of pattern developments. Patterns are in phase when their start and end is at the same time. However, if there is a time lag between patterns (same or different), it is a phase difference.

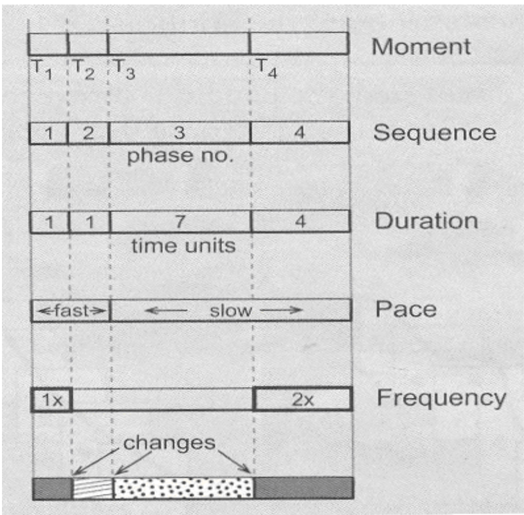

Figure 2.3 Characteristics of changes in the temporal domain where changes are marked by orthogonal lines into the time bar (Blok, 2005; pp. 57)

It is possible to summarize the concepts of change in 2.2.1 and 2.2.2 in a geospatial context to this research as: existence, locational change, geometric change, attribute change, and identity change (see Table 2.2).

Table 2.2 The types of change and their respective characteristics in a geospatial context.

Changes	Characteristics	Examples
Existence/ non-existence	Appearance/ disappearance	The very existence of a man and his death
Locational	movement	Trajectory movement of people
Geometric	Expansion/contraction/ deformation	Change in shape/size/extent of a region- change in the boundary of a forest area
Attribute	Increase/decrease	Change in speed of a vehicle
Identity	Transformation	Change from one type to another, e.g.: forest to grassland

The existence or non-existence of an abject influences the occurrence of the other types of change. We cannot talk about other changes unless the object exists. Locational change is characterized by movement. Movement in this context refers to change in the location of all parts of an object (this doesn't include the change in location of a part of an object). For example, a moving vehicle, a hurricane, etc. The geometric type of change encompasses expansion, contraction, or deformation of an object (e.g., an expanding agricultural land, a reducing forest area, or merge of two parcels of land). Attribute and Identity changes are equivalent to what Blok (2005) has termed "Mutation". A separation (as attribute and identity) can be made to make it clearer. Attribute change is characterized by increase/decrease of some attributes of an object (e.g., increase or decrease in the temperature of a water body); and change in identity connotes change from one state of being to another state of being. In identity change the nature of the object is changed. For example, changes from water to gaseous state or from forest area to agricultural land.

Since the topic of this research is about moving objects, the interest of the study will focus on changes in the location of these objects, i.e., "movement". It will be discussed in the next part of this chapter.

2.3. Movement and moving objects

2.3.1. Determinants of movement behaviour

The movements of phenomena on the surface of the earth have some cause. Before going to a deeper discussion about movement and behaviours of movement, some important factors that determine the behaviours of movement of phenomena are summarized below.

Andrienko and Andrienko (2007) have identified four factors that affect the characteristics and behaviours of movement of objects: properties of space; properties of time; properties and activities of the moving entities; and various spatial, temporal, and spatiotemporal phenomena. Each factor is outlined and explained below.

1. Properties of space: This comprises of different categories of factors, such as terrain (elevation, slope, aspect), accessibility (distance, availability of roads), physical surface conditions (forest, water, land), objects at a given location (trees, buildings, other moving objects), mode of use (agriculture, industry, service), and meaning of a place for a moving entity (home, work place, recreational place).

2. Properties of time: includes temporal cycles (daily, weakly, monthly), physical characteristics (presence, intensity, and duration of daylight), and meaning in terms of typical activities (working day against weekend, day against night).
3. Properties and activities of the moving object: This may refer to properties of individuals (gender, age, marital status, occupation, and educational level), way of movement (constrained or free, by air, by water), means of movement (vehicles, animals), purpose and/or causes of movement, and activities performed during movement.
4. Various spatial, temporal, and spatiotemporal phenomena: these include rush hours (from work or schools), climate and weather, traffic incidents, and so on.

Discussion of the factors that influence the behaviour of movement of objects is important in terms of giving awareness of what caused certain movement behaviours.

2.3.2. Movement and classes of movement based on spatial structure

Yattaw (1999) mentions some aspects of the spatiotemporal change in a phenomenon that are subject to geographic analysis (for example, what type of change it is, how the change happens, what causes it, how to represent it, and so on). She points out that geographic analysis is concerned with the direct investigation of movement of objects in space (e.g., daily trip pattern studies where personal use of time and space in an urban environment are examined). She added that investigating the dynamics of a phenomenon (such as a moving object) over space and time is crucial in geographical understanding and is the concern of various disciplines like geography, cartography, visualization. In many geographical analyses, movement is receiving increasing attention particularly in investigations involving geographic information systems, visualization, and cartography.

We can make a distinction between *change* and *movement*. These two concepts might be mutually inclusive (but not necessarily) giving account to situations like the nature of the object (moving object or static object), the type of change (locational or non-locational), or the geometric characteristics of the object (point object or region). In other words, if there is a movement of an object, there is a change in the location of the object. Any change in an object may not, however, involve movement in the geospatial context. There may be a change in other aspects of the object but its location. For example, the demolition and reconstruction of a building doesn't involve movement but there is a change in the other attributes or nature of the building. But if there is movement of an object, it makes obvious the presence of change. This research will see only the change in location of objects which in geospatial context is termed as movement. The changes in an object in the course of movement or otherwise will not be subjects of discussion and investigation.

Movement is defined by Blok (2005) as a change in the spatial location or geometry of an object. The change in spatial location denotes change in geographic location of an object while change in geometry might mean expansion, contraction, bulging, etc. of an object (the change in spatial location and geometry of an object are categorized in separate classes in Table 2.2, however). The object could be a moving object (like tornado which may in the course of movement change its geometry) or it could maintain at least part of its location (expansion of a rangeland). However, a separation is also made (in part 2.2.2-Table 2.2) between movement and change in geometry. Movement defined as change in location of the whole parts of an object.

Eschenbach (1998) has distinguished two types of movement of phenomena based on their spatial structure. The first one is movement along a path or trajectory (see also Blok 2005). Movement of people from home to work or otherwise and movement of the earth around the sun are exemplified. The trajectories of moving objects are commonly conceived as linear paths. And since it is easy to linearize the movement of individual objects through space, the individual locations in the course of movement are points in space. As a result, the individual locations of moving object along their path are represented as points in space. Point objects can only move by changing their location completely because points do not have different parts in space. Trajectories are spatially embedded linear structures and the movement along them is continuous (but on condition that the trajectory is spatially continuous and the spatial sequence of the movement is respected) (Eschenbach, Habel et al. 1998). In other words, object movement along a trajectory is continuous but represented discretely (constrained by the acquisition, storage and processing technology) (Meratnia and de By 2004). Eschenbach et al. explained that *trajectories of moving objects have the following properties in space: they are connected, have shape, do not branch and are directed*. However, the trajectories may not necessarily be connected or directed. We also have an isolated trajectory, trajectories that make branches, and trajectories which are not directed (trajectories may have a number of destinations). (See also Pfoser and Theodoridis 2003). These properties are important considerations when indicating moving objects in cartographic representations. This research will give emphasis to these properties in the design phase and will take them into account to test the perception or understanding of users.

The second type of movement distinguished by Eschenbach (1998) is pure internal movement. The main characteristic of pure internal movement (unlike movement along trajectory) is that the locations occupied by the body in the course of the movement exhibit an overlapping behaviour. This is prevalent in situations where in the course of movement certain spatial region is occupied throughout or during the process. Changes of the positions of parts of the objects (that can exhibit trajectories) and changes of the orientation of internally constituted spatial reference frames are responsible for defining (identifying/categorizing) internal movement (Eschenbach 1998). Eschenbach added that this category of movement shall include rotations of disks and spheres as well as the motion of fluids in a closed system or bodily movement such that the movement meant not only movement of the whole body of an object but also parts thereto. The class of movements that keep some parts of space constant can further be subdivided. These classes are growth and shrinkage, movement of parts, internal rotation, and short movements that can constitute trajectory movement but are too short to end in a complete shift in position. In this thesis, trajectory movement is the subject of concern. It is discussed in the following section.

2.3.3. Behaviours and characteristics of the movement of objects along a trajectory

As explained above moving objects exhibit various behaviours along their course of movement. For the purpose of this thesis, the movement behaviour is relevant because it can be good grounds to study which cartographic representation (s) is/are optimal for visualizing moving objects. Behaviours of objects other than those moving along a trajectory are not important here and will not be subject of this study.

According to Andrienko and Andrienko (2007), movement data can be seen as a function of matching pairs of entity (object) and moment in time on the one hand and positions in space on the other. From each location of an entity (object) at a time moment other movement characteristics can be derived:

speed, direction, acceleration (speed change), turn (change of direction), which are called derivative movement characteristics. Stop along the course of movement is another important movement characteristic. Thus, change in location and derivative movement characteristics describe the *individual* movement behaviour (IMB) of a moving object (see figure 2.4 – left). This behaviour thus has its own characteristics, for example, the path (trajectory) travelled by the object, the distance travelled, the direction from start to end, the changes in speed and direction in a given time duration, etc.

Andrienko and Andrienko also defined movement characteristics for *a collection of entities (objects)* (which they called the momentary collective behaviour (MCB) when it is for behaviours of the collection at a certain time moment (shown in figure 2.4 - right), and dynamic collective behaviour (DCB) for a certain time period). The former has some characteristics, such as distribution of the entities (objects) in space, spatial variation of the derivative movement characteristics, and the statistical distribution of the derivative characteristics over the set of entities (objects). These can be used to compare similarities and differences between the momentary collective behaviours at different time moments or between momentary collective behaviours of different groups of entities (objects) depending on the applications and the purpose under consideration (use case). They assumed that dynamic collective behaviour is needed when there is a need to analyse and describe movement data in a given period of time.

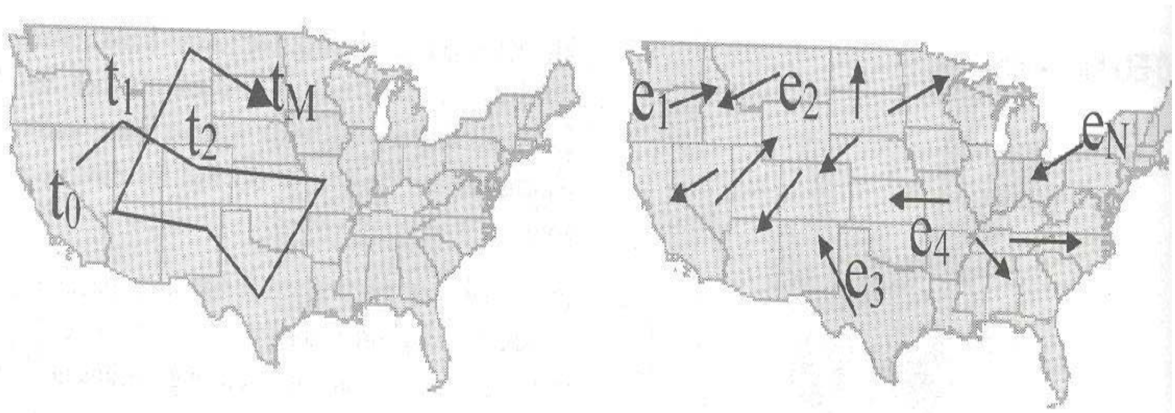

Figure 2.4 An illustration of the notions of individual movement behaviour (IMB) of a selected object (left) from t_0 to t_M and momentary collective behaviour (MCB) (objects e_1 to e_N at a selected moment (right) at a one moment of time (Andrienko and Andrienko, 2007; pp. 122).

For the purpose of this thesis, the individual movement behaviour is more important. Thus, the focus will be on the characteristics of individual movement behaviour of objects moving along a trajectory.

2.3.4. Moving objects

The universe consists of moving objects from the level of galaxies, through planets, crustal plates, water bodies, vehicles, animals (including people), and cells to atomic particles. Some behave according to observed physical rules (e.g., planets in orbit, cells in a human body, etc). Some move in patterns (e.g., vehicles along defined network of roads/rail-lines) and some are more chaotic (such as some movements of animals).

In every dimension of life we encounter dynamic phenomena varying in size, shape, location, behaviour, and other attributes. Dynamics of objects are affected by different respective causes, which could embrace natural and human factors. People being dynamic things, they are motivated by various activities, such as work, shopping, and in-door activities which drive their dynamics (Huisman and Forer 2005). For example, their movement is driven by desire (like the need for interaction), survival (such as the need to get things), psychic force (such as the need for recreation), and coercions (for instance, migration caused by occurrence of natural disasters). Among the dynamic characteristics of phenomena, locational change (movement) is the most prevalent. The movements we conceptualize in our environment exhibit different behaviours subject to, among others, the nature of the object. This section focuses on moving objects, and their movement characteristics will be dealt.

Moving objects refer to a wide range of phenomena, such as animals and their migration in habitat, the migration of whales, vehicles in a traffic environment, soccer players and foot ball players, and hurricanes (Guting and Schneider 2005; Laube, Imfeld et al. 2005). Moving objects are studied in many applications, like in human movement analysis, traffic planning, animal behaviour science, and sports scene analysis (Bogaert, Weghe et al. 2006). Moving objects might have zero dimensions (e.g., birds), one dimension (e.g., stream flow), two dimension (e.g., expanding forests), or three dimension (e.g., the Earth). Because most applications are interested in the locational change rather than the shape of the moving objects, objects are commonly represented as point objects (Bogaert, Weghe et al. 2006). And all these moving point objects share movements that can be represented as geospatial lifelines (a series of observations consisting of a three dimensional location and time (Laube, Imfeld et al. 2005). Moving point objects are defined as points that change their location over time (Erwig and Schneider 2002). The representation of these moving objects is crucial for migration studies, simulation activities, traffic controlling, and path tracking (e.g. in monitoring activities). In this thesis the interest is moving point objects.

Moreira, Ribeiro et al (1999) have identified two kinds of moving objects: *objects that have a completely free trajectory and objects that have a constrained trajectory*. The former ones are constrained only by the dynamics of the object itself, for example a bird flying through the sky. The bird is free to fly in any direction and position without being limited to have a defined position, path, or direction. Their movement (in this context) is determined by their dynamics (which, however, might be determined by the need for food, interaction etc.). The moving objects that have a constrained trajectory move in defined trajectory. For example, a train on a railway track moves along the given path. These categories of moving objects have no freedom of movement out of the defined route. However, we should be aware of the fact that the constraints might also be naturally defined. For example, vehicles (such as military cars for military strategy) can move away from constructed roads, but will be constrained by the terrain. But this issue doesn't seem to be considered in the concept of "*trajectory*" which Moreira, Ribeiro et al. have explained. The role of perception in restricting free movement is also an important issue in the discussion of free trajectory. Perception of movement is a process through which humans and other animals orient themselves to their own or others' physical movements. For instance, the flying birds, mentioned above, should perceive their movements to balance themselves and to move effectively (in the life process of looking for food, interaction with others, and to protect themselves from external dangers among others). Otherwise their survival will be challenged.

2.3.5. The need to study moving objects

We might ask questions like "*Why do we need to identify moving objects?*" "*Why do we need to visualize moving objects?*" Prior studies have given negligible attention to positional data of moving objects (Jae Du 2002). Most researches in moving objects give attention to their representations in databases. For example, Meratnia and de By (2004) researched in techniques for compression of data of moving objects for the purpose of storing, transmission, and computing. Jae Du (2002) attempted to identify the temporal pattern of moving objects in database applications to serve and give a location based service. Erwig and Schneider (2002) developed a framework of spatiotemporal relationships of moving objects described by spatiotemporal predicates to assist the development of spatiotemporal databases (STDB).

Our world is filled with mobile inhabitants which results in "traffic" that exhibits patterns (as a result of its behaviour) observable at various scales (Meratnia and de By 2004). The identification of locations of moving objects can be used in various applications. Jae Du (2002) studied the use of information about individuals' locations for the purpose of rendering more personalized mobile services. The services can be applicable to sectors which have varying locations over time (using a PDA, mobile telephone, cars, airplanes, or trains, etc.). Meratnia and de By aimed at providing tools to study, analyse and understand the patterns of traffic in general. To exemplify, commuters in urban areas, a truck fleet at the continental scale, pedestrians in shopping malls, airports or railway stations, shopping carts in a supermarket, pieces of luggage in airport logistics, and/or migratory animals are important spheres of real life application. Real time applications for detecting vehicle location for instance are also worth mentioning (Vazirgiannis and Wolfson 2001).

The visualization of moving objects is important for monitoring and analysis activities by answering, for instance, specific questions like - are the planes approaching to collision? In which location do the animals stop frequently? Which roads are usually busy in traffic? Which one is the regular direction of animals in search of their food? Which tourist sites do have high flow of visitors? Moreover, visualizing moving objects will be of assistance for exploration and understanding of temporal events taking place in our geo-world. For instance, the use of the space-time cube for sports, such as to get an insight into rugby team work (Moore, Whigham et al. 2003) and archaeological events in which we can display and analyze the path of individuals, groups, or other objects moving through space (Kraak and Koussoulakou 2004). Getting insight into a movement activities like goal oriented team sport The conceptualization of the path of human movements through space and time, for instance in space time prisms, are functional for various applications, such as tourism flow analysis among others (Huisman and Forer 2005). We can also understand and analyze the occurrence of hurricanes (where they start, how they move – speed and path, and where they end using various visualizations).

2.4. Schema of the aspects of moving objects to be represented

To show which aspects of moving objects are going to be represented in static maps, animation, the space-time cube, a schema is developed (see Figure 2.5). The schema starts with the characteristics of change that are the focus of this thesis and ends with the aspects of the moving objects to be represented in the four cartographic representations under consideration. Emphasis is on *movement* which the trajectory movement of individual objects is the main issue. Stops, returns, speed change, and path are the specific aspects that are going to be represented. The properties of the trajectories can also be depicted in the representations.

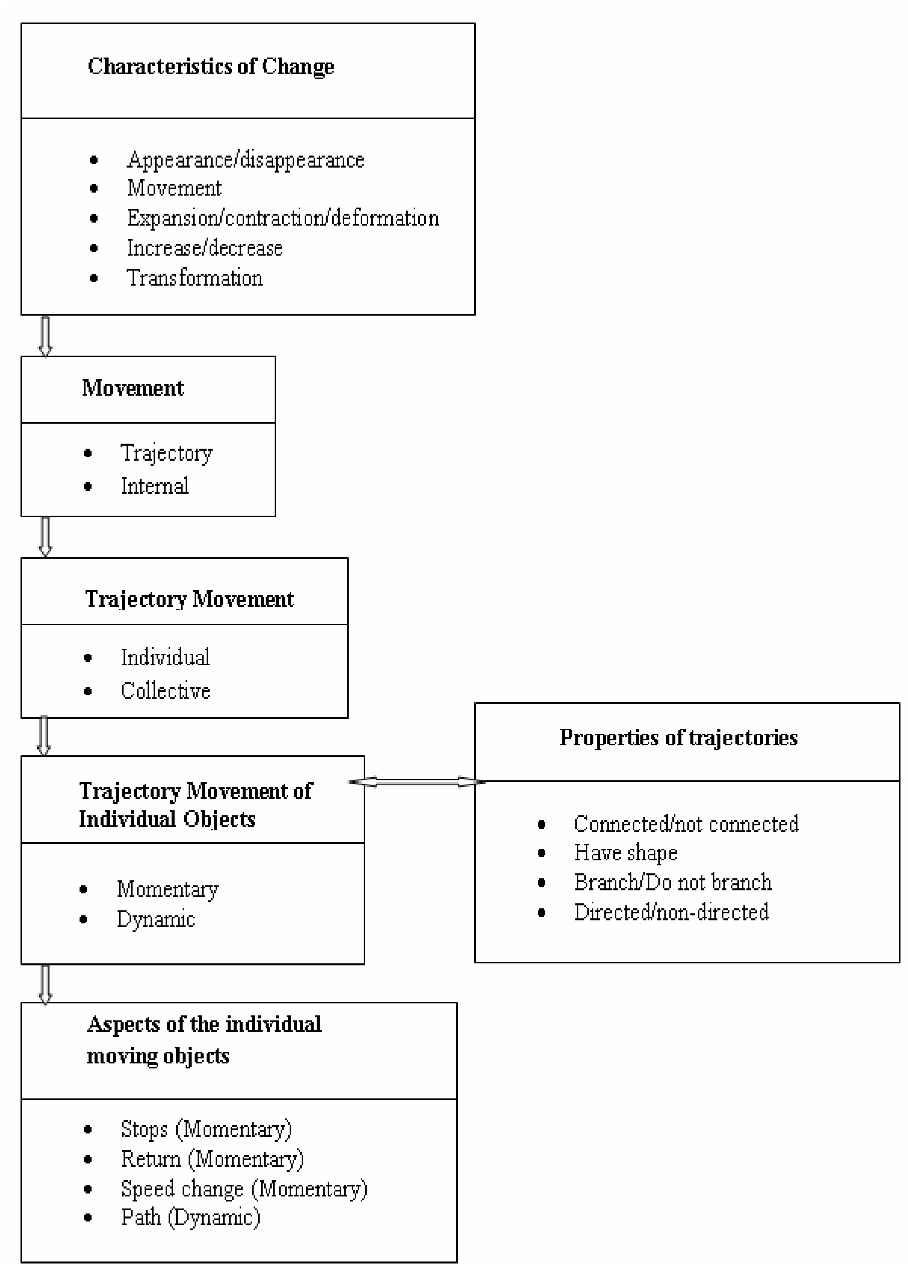

Figure 2.5 Schema of the aspects of the moving objects to be represented in static maps, animation, and the space-time cube. The schema goes down deducting from the characteristics of change to the aspects of the objects to be represented.

2.5. Summary

In this chapter concepts about change, movement and moving objects are discussed. Changes are also classified as spatial and temporal. The spatial changes are characterized by appearance /disappearance (existence or non-existence of an object; Mutation (which refers to change in the thematic, not geometric, attribute of an object), and movement. The temporal changes on the other hand are characterized by moment in time, sequence, duration, pace, and frequency. Movement is made out as either movement along a trajectory or pure internal movement. In the trajectory movement, moving objects are seen as those that move in a free and constrained trajectory. Internal movement reflects the changes (movements) in the parts of an object not the entire object. Movement behaviours can be seen as individual and/or collective that would be exposed at a certain moment of time (momentary) or a give period of time (dynamic). Moving objects are objects that change their location with time. Their movement could be along a free trajectory or a constrained trajectory. Moving objects refer to, for example, walking man, migrating animals, moving vehicles, hurricanes. This thesis will focus on individual moving objects represented as points changing their spatial location. Since it is not possible to cover all aspects moving objects, four have been selected for investigation in this thesis. The aspects considered are stops, returns, speed change, and path of movement.

3. Cartographic visualization

3.1. Introduction

The previous chapter is all about the concepts of change, movement and moving objects. The chapter narrows from the concept of change via movement to moving point objects. Some classes and behaviours of movement are discussed. The trajectory of moving point objects can be represented by cartographic representations. Thus, this chapter is about cartographic visualization. The chapter provides a brief discussion of cartographic visualization by giving an insight into how the dynamics of the world are represented, the concept of time, the visual variables that should be in use in the visualizations, and visual cognitive issues. In section 3.2, the notion of a dynamic view of the world is discussed. Section 3.3 discusses about time and space. It explains how time can be visualized in cartographic representations. Section 3.4 is dedicated to the visual variables. It discusses the two types of visual variables: graphic variables and dynamic visualization variables. The ability of users to notice or not to notice changes is discussed in section 3.5. An extended schema of the schema in chapter 2 is presented in section 3.6. Finally the chapter closes with a summary in section 3.7.

3.2. Dynamic view of the world

Our world is highly dynamic. This dynamics is manifested by the changes that take place in geospatial phenomena over time. For instance, moving objects are highly dynamic phenomena at least in terms of change in their spatial location. Owing to the high dynamics of the world, scientists' interest in the static world is minimal. However, in the old times, cartographic representation tools were able to depict the static world using static display techniques. Recently, there is some attention to depict the dynamic nature of the world in maps. Static maps have got significant problems for the fact that it is not easy to set time and space on a static page (Hearnshaw and Unwin 1994). It indicates that the use of static maps to visualize spatiotemporal phenomena (such as moving objects) and the behaviour of their dynamics is not an easy task. However, (Yattaw 1999) described that development of new and more powerful visualization tools such as computer animation and three-dimensional modelling provides geographers and other researchers with tools to better understand the change in space and time of dynamic phenomena by making use of movement, perspective shading, and shadows in the representations.

Dynamic representations denote the displays that change continuously regardless of the control by the user (Slocum, Blok et al. 2001). They make direct use of time to depict some data, and demonstrate a temporal behaviour in general and dynamics of phenomena and process (Muller and Schumann 2003). Animation is a dynamic representation which, Slocum, Blok et al (2001) argue, is natural because of the fact that it depicts the temporal data by relating world time with display time. Animation is a powerful visualization tool for cartography that transcends the potential of the printed map (Karl 1992). It has got a great potential to relate time with space for the reason that it adds a new cartographic dimension (which is display time) that can portray dynamic processes in an intuitive way and therefore increases the possibilities of data exploration and analysis (Hearnshaw and Unwin 1994). Hearnshaw and Unwin stated that an animation depicts change in the geospatial data components: *location, thematic attributes and time*. It allows the creation of map sequences that can show spatial information dynamically. Slocum, Blok et al. (2001) explained also that it is possible to provide an exploratory animation environment for geospatial data, although in most applications animations are designed with minimal interaction.

The most commonly known three dimensional representation (or dynamic view) of geospatial phenomena is the Hägerstrands's Space-Time-Cube (Kraak 2003; Kraak and Ormeling 2003; Kraak and Koussoulakou 2004). It places time in the third dimension. Some additional techniques (which are not the focus of this thesis) to view dynamics are time-tracks and linked views: Time-Tracks are commonly used for Air Force and Navy commands and control systems to show on a map surface the trails of moving entities (Shuping and Wright 2005). Linked views are used to support multivariate analysis, including time series data in one view, and a map in another. They enable users to rapidly explore complex information, dynamically mix it, and correlate it visually (Kraak and Ormeling 2003; Shuping and Wright 2005). In this research, static maps, animation, and the space-time cube are taken since the purpose of the research is to find the optimal representation among these representations in visualizing moving objects.

3.3. Space and time

3.3.1. Broad-spectrum

Space and time are important in various disciplines like geography, physics, geology, and cartography. The world is of course full of "spaces"- physical, mathematical, geographical, cartographic, social, economic and today, even cyberspace. The world is also full of "times"- geologic, astrological, seasonal, and so on (Peuquet 2002). Time therefore is important in a wide range of sciences in studies about spatial and temporal processes. The movement of things is managed by time. In this research the conception of time and space from a cartographic point of view (see below) will be the emphasis.

3.3.2. Time in cartographic representations

The conception and treatment of time in cartography may depend on applications from different disciplines. For example, the conception of time in geology might be on evolution of the physical earth. And in physics it might be a question of geometry. The goal of time in cartography is to distil from reality the most important elements of time and represent them in such a way that it suits to cartographic application (Langran 1992). Important questions in cartographic time are thus what components of time are important to represent and how to represent them. These questions have to be answered in this research about moving objects.

Cartographic representations play a role to understand changing geospatial patterns and relationships. To be successful in this regard, cartographic representations should include time since events (changes) happen as time goes by (Kraak and Ormeling 2003). Time is regarded as the fourth dimension in cartographic representations in the sense that thematic attributes are taken as the third dimension while the space acquires two dimensions. Langran (1992), however, argues that attributes are statistical surfaces (which do not give a solid three dimensional representation) and it seems more accurate to consider time as the third dimension.

What is important temporal information represented by maps? Wood & Keller (1996) identified five categories of temporal information represented by many maps: 1) Moments: the dating of an event in space; 2) Duration: the continuance of an occurrence in space; 3) Structured time: the organization or standardization of space by time (standardization is needed for large groups of people to synchronize their time measurement system, e.g., the classification of space into different time zones); 4) Time as distance: the use of time as a measure of distance (e.g., we can measure the distance between two points by the time it takes from the one to the other); and 5) Space as clock: spatial relations are used as a measure of time (for example, measuring time based on the location of the sun on a day). Frequency and order are also important temporal aspects. In so far as the representation of moving objects in this thesis is concerned, moments, duration, frequency, and order are important temporal aspects that need due emphasis. With respect to symbolizing these temporal information (as is illustrated in Figure 3.1 in the context of their application for moving objects), moment, duration and order can be considered as directly related to measurement of time. Frequency is a repetition of events, included in order.

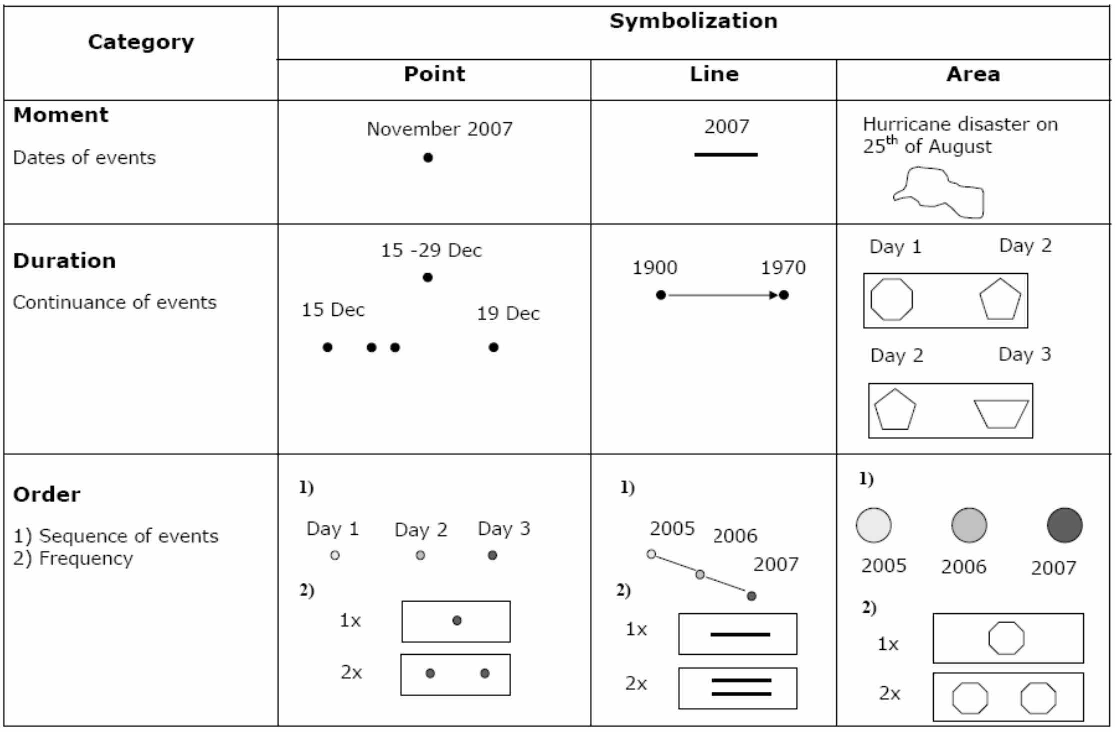

Figure 3.1 Point and line symbols used to represent temporal information. In this regard Moments, Durations and Order (frequency included in order) are symbolized (after Wood and Keller 1996; pp. 145).

Time (as explained above) can be mapped in various ways in the cartographic environment. The most prominent and commonly used cartographic tools are static maps (single and multiple), animation, and space time cube (Kraak and Ormeling 2003). In temporal animation, change in time is perceived in a single display area by depicting several snapshots sequentially, each snapshot represents an event on that display time and conveys real movement in the maps (Kraak and Ormeling 2003; Blok 2005). Representing time in static displays is not an easy task. In single static maps, graphic variables like location, size, and value (Blok 2005) can be used to show changes in time. We can symbolize these variables by, for example, point symbols to show the moment of time a certain event occurs, or lines and arrows to indicate the passage of time (Monmonier 1993; Kraak and Ormeling 2003). Small multiple single maps represent snapshots of time and together the maps make up an event (Silva and

Catarci 2002). The temporal sequence in this case is represented by the sequence of the process in space (Slocum 1999; Peuquet 2002; Kraak and Ormeling 2003). In small multiples, each repeated frame captures an incremental moment in time (Silva and Catarci 2002; Shuping and Wright 2005). Among the most suggestive concepts of spatiotemporality is Hägerstrand's space-time cube that depicts time in the third dimension. (Langran 1992; Kraak 2003; Kraak and Ormeling 2003; Kapler and Wright 2004; Kraak and Koussoulakou 2004; Shuping and Wright 2005). More discussion about these three cartographic representations (in the context of presenting *"moving objects"*) will be made in the next chapter.

3.4. Representing data: visual variables

In the discussion above, cartographic representations and cartographic time have been the focus. For the user to perceive and understand the meanings of these cartographic representations, *representation variables* play paramount importance. Blok (2005) has defined representation variables in a geodata context as: "changeable signs or signals that can be used to symbolize aspects of the data in perceptual form" pp. 61. Representation variables, she meant to comprise visual variables, haptic variables, sound variables, etc. Representation variables are used to help the process of visual perception and/or sensory perception of users to understand maps. In this research, only the visual variables are utilized because the research makes use of these variables to assess the effectiveness of animation vis-à-vis static maps and the space-time cube.

Slocum (1999) described visual variables as *"visual variables are commonly used to describe the various perceived differences in map symbols that are used to represent spatial phenomena"* pp. 22. Slocum has tried to classify visual variables into three categories: visual variables for static maps, visual variables for animated maps, and visual variables for depiction data quality. In this research the first two categories of visual variables will be addressed because this research is about representing moving objects in static maps, animation, and the space-time cube (data quality is not an issue of concern). The visual variables for static maps and animated maps have been identified as graphic variables and dynamic visualization variables respectively by Blok (2005). According to Blok, the graphic variables are visible within the two or three spatial dimensions used to represent geographic data whereas dynamic visual variables are observed in the temporal dimension (display time) of an animated map.

3.4.1. Graphic variables

Bertin is the first author to introduce graphic variables and to emphasize their role in map understanding. Bertin recognized two kinds of variables (namely, retinal variables and locational variables) (Bertin 1983). The latter refers to the (x, y) axes of two dimensional data graphs and maps (that is the location variable). The retinal variables are topics of symbolization. Thus, he introduced six retinal variables which are in this context known as graphic or static visual variables. These include size, (colour) value, texture, (colour) hue, orientation, and shape. Later Morrison (1974 - cited in MacEachren 1995) introduced more variables – colour saturation, and arrangement. MacEachren (1995) (amongst others) also proposed more variables, like crispness, resolution, and transparency.

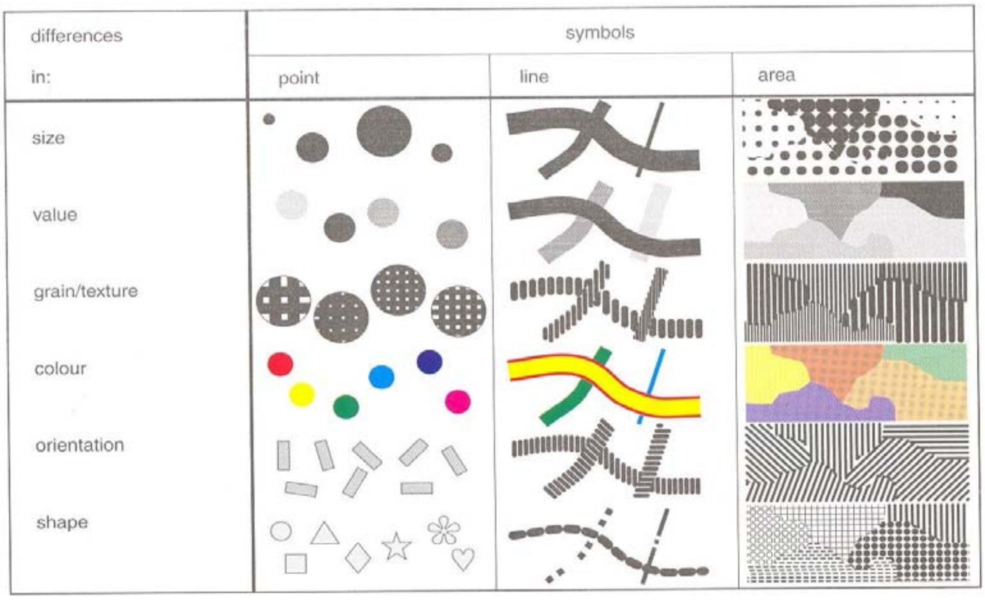

Figure 3.2 Graphic variables and their representation in cartographic symbols (Kraak and Ormeling 2003; pp. 111).

The graphic variables have dimensions which should be worth considering in map design. In this respect there are three types of graphic variable dimensions explained by Monmonier (1993). These are point symbols, line symbols, and area symbols. They represent zero, one, and/or two dimensional features based on the scale and degree of generalization of the features. Moving objects deemed as point objects are the subjects of this research, however. Point and line symbols are to be used.

3.4.2. Dynamic visual variables

Dynamic visual variables are variables applicable to dynamic displays (animated maps). Bertin (1983), in his definition of the graphic variables asserted that they are not applicable to dynamic displays. He argued that movement introduces one additional variable which, he believed, is an overwhelming one severely limiting attention adversely affecting the meaning of the other variables. However, others argue otherwise. For example, MacEachren (1995) argues that movement is a powerful map 'variable' for the fact that it combines the two important dimensions – time and space. It is most likely true that in animation, things that change take more attention than things that do not; and things that move take more attention than things that do not change in place. MacEachren therefore maintained that the use of time gives the map designer a powerful new graphic dimension that should be explored in detail rather than to exclude it from consideration.

Table 3.1 Dynamic visual variables and their definition used in cartographic animation (Blok 2005; pp. 65)

Dynamic visualization variables	Definition
Moment of display	Position of a state or a change in the representation in display time.
Order	Structured sequence of states or changes in the representation in display time.
Duration	Length in display time of a state or change in the representation.
Frequency	Repetition or number of identical states or changes in the representation per unit of display time.

Albeit Bertin argued that movement adds one additional variable (time-which actually is not a dynamic variable), DiBiase et al. and MacEachren proposed six dynamic visual variables. These include: duration, rate of change, and order (DiBiase et al., 1992 cited in MacEachren, 1995); and display date, frequency, and synchronization (MacEachren 1995). Display date (also called moment of display – Blok, 2005) is the time at which some display change is initiated. It can be linked directly to a temporal location. Duration refers to the length of time between two identifiable states. Order is the sequence of frames or scenes. Although time is inherently ordered, the representation of change over time is depicted sequentially. Rate of change denotes magnitude of change per unit of time in a sequence of frames or scenes. The number of identifiable states per unit of time is frequency (which is also called temporal texture). Finally, synchronization (also called phase correspondence) refers to the correspondence of two or more time series in time (for example, matching chronological dates of two or more data sets precisely). Blok (2005), however, has cast off rate of change and synchronization as representation variables. She argued that they are derived from the rest of the representation variables; and are the effect of changes in the data and the interactions that take place with the other variables.

In this research, the visual variables will be given regard in the design phase where their application is important to efficiently represent moving objects (i.e., how the visual variables are going to be used in representing some aspects of moving objects).

3.5. To notice or not to notice changes

The task in this research is (as is mentioned in chapter one) to study the suitability of cartographic visualization methods (static maps, animation, and the space-time cube) to find which one is an optimal representation for moving objects. The users' perception and comprehension of changes of relevant aspects of moving objects is an important issue because noticing changes in animation might be difficult. Changes in the scene or objects in the scene may pass unnoticed. The responsible visual perception phenomena are change blindness and inattentional blindness (Rensink, O'Regan et al. 1997; Blok 2005).

Change blindness occurs in cases where we fail to notice even large changes. It could be because they occur simultaneously with some visual disruption, caused by an eye movement, a flicker, a blink, or a camera cut in a film sequence (O'Regan, Rensink et al. 1999). For example, large changes can take place unnoticed when few small but high contrast shapes are splashed over a picture. Inattentional blindness is the inability to detect unexpected changes regardless of the position of the changes and the focus of the observers, because they are working on other tasks (Rensink 1999; Blok 2005). Observers fail to notice changes (such as appearance, disappearance) of an unexpected object. Thus, this is a failure to see unattended items. Is there a relationship between change blindness and inattentional blindness? Rensink (1999) has given a good explanation of the relationship between these phenomena. To begin with, it is important to keep in mind that the phenomenon of change blindness shows only that we are blind to *changes* made in the scene while having no idea about the ability of the observer to notice or not to notice the scene itself. Inattentional blindness contrarily is concerned about the observer's perception of the *scene*. That is, inattentional blindness is silent on the issue of perception of change in the scene. It might be, for example, that we could see attended items but not be able to see them change. Change blindness refers to the dynamic aspect and inattentional blindness to the static aspect of the world.

What do we need to see and perceive changes? Attention is needed to see changes (Rensink, O'Regan et al. 1997). In order to see trends, patterns, paths, speeds (and variation in speed), etc. in geospatial data such as moving objects, attention should be employed. Attention affects the speed of transmission of information in the visual system (Stelmach and Herdman 1999). Since change blindness occurs when more than a few items are present, attention to a limited number of items (4-5) is important (Rensink 2002). Attention can be of two types: distributed attention and focused attention. When the attention of the observer is not directed to a certain object or group of objects, it is known as *distributed attention*. Distributed attention facilitates the perception of object presence not the perception of change. To see and perceive changes we need *focused attention* (Rensink, O'Regan et al. 2000). Rensink, O'Regan et al. (2000) and Simons and Rensink (2005) explained that changes to semantically central items are noticed and perceived faster than changes elsewhere irrespective of the physical salience of the changes. This implies that changes to objects which get special attention can easily and quickly be seen and encoded. This is what they called *focused attention.* Focused attention facilitates the perception of changes in the absence of which the visual memory is overwritten by the subsequent stimuli (Rensink 2002). In such cases reasoning or visual processing will be difficult.

What draws attention? Owing to the limited capacity of the visual processing system, a number of different objects in a scene cannot visually be processed concurrently. Visual attention therefore undertakes the selection of behaviourally relevant information (Kastner, Pinsk et al. 1999). For example, if attention is directed to a particular location in the visual field, it ensures easy seeing of changes and quick visual processing in the attended location while the unattended ones are suppressed. Attention is, according to (Kahneman, Treisman & Gibbs 1992 cited in Rensink 1999) drawn by the motion signal in the visual input by pulling attention towards its location such that it can easily be seen. Thus, it seems that changes to moving objects are more easily detectable than to stationary ones (Rensink 2002). Expectation of what changes are going to take place also draws attention.

So far in the discussion about our perception of change, it has been asserted that observers' ability to notice change in animation is limited. It is not possible to detect all changes to objects in a scene simultaneously though it would be possible to see their presence. Thus, to notice changes a focused attention is rudimentary. Focused attention facilitates observers' ability to notice change and the quick visual processing of these changes. In the case of the representation of moving objects in cartographic representations (especially, animation), it might be important to orient the focus of the observers to anticipate changes of some aspects of the objects such that they can easily see and perceive these changes. The users will be made aware what changes (aspects) they are supposed to see in the moving objects. The number of objects to be observed will also range 1 to 4, so that the attention of the users will be only to these objects.

3.6. Extended schema

In chapter two the schema gives the types of movement and movement characteristics that are subjects for representation for the purpose of this research. The aspects of individual moving objects identified are indicated to be represented in single static maps, multiple static maps, animation, and the space-time cube in Figure 3.5. The spatial, thematic, and temporal components of map are important. Visual variables are used to represent the movement characteristics and time as well. How the moving objects are represented determines (in addition to psychological constructs) whether or not users can notice changes.

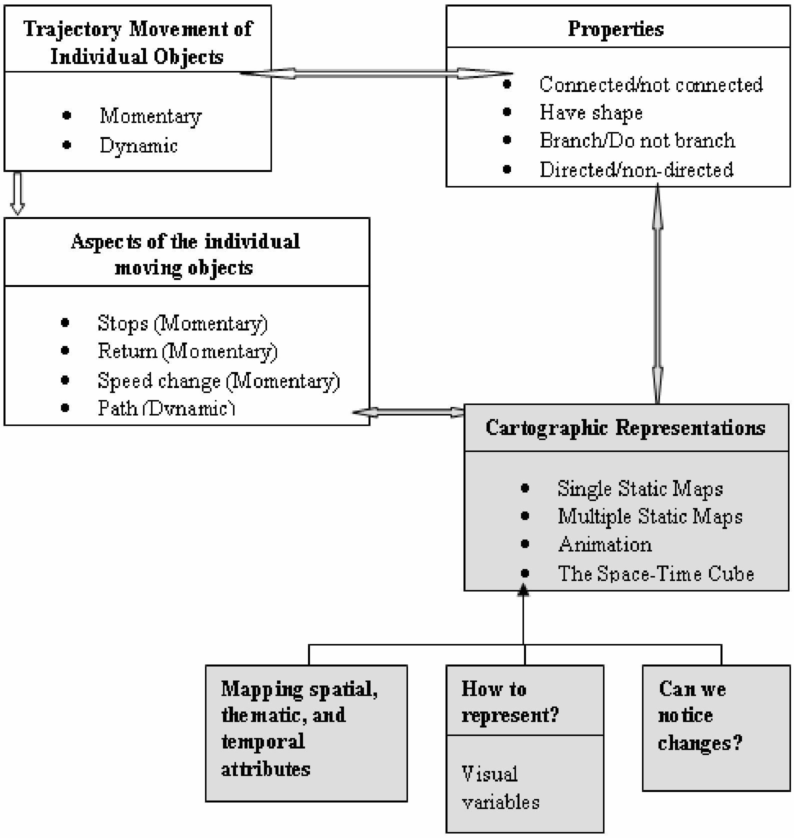

Figure 3.3 Extension of the schema in chapter two which shows aspects of moving objects to be represented in static maps, animation, and the space-time cube.

3.7. Summary

Cartographic visualization helps to understand and analyze some data characteristics such as pattern, relationship, trend, etc. Static maps (both single and multiple), animation, and the space-time cube are the common representations, which are also the media going to be used in the representation of moving point objects in this research. The representation of time in cartography is important because geospatial phenomena and processes are the constructs of time. Visual variables are also indispensable in the representation of geographic phenomena. We can perceive and understand the dynamics of objects through the utterances of these variables. With respect to the cognitive issues, change blindness and inattentional blindness are the two phenomena thought to be responsible for the failure of observers to notice changes. Change blindness occurs when changes are failed to be observed regardless of the expectation of the observers, the size of the change etc. Inattentional blindness is about the failure to notice unexpected changes. To see changes, focused attention is needed. In the design the number of objects in which the users have to see movement characteristics will be limited. In the task users will be made aware of what changes they have to see.

4. Visualizations: moving objects context

4.1. Introduction

After addressing the concepts related to moving objects in chapter 2 and cartographic visualization and cognitive issues in chapter 3, this chapter discusses the capability of static maps, animation, and the space-time cube in describing characteristics of movement and the users' presupposed ability to perceive and comprehend some aspects of the moving objects represented. Since the intention in this study is to find the optimal representation for moving objects, some aspects (stops, returns, speed change, and path) at different levels of complexity are subject for investigation. These aspects are selected for two reasons: 1) Time constraint: In order to accomplish the study effectively with the given time period, the study is limited to these aspects; 2) They are thought to be strong points by which the optimal representation for walking people (either single static map, multiple static maps, animation, or the space-time cube) can be assessed. These are important points because if we want to represent these aspects, they may not be equally well represented in animation and in the other representations, or it may be difficult to represent them in either of these representations. For example, it is difficult to portray *stops* in single static maps; that is why this aspect is not tested for single static maps in this research.

In section 4.2 of this chapter, the issue of comparability of animation and the other representations is discussed. Section 4.3 is about the strengths and weaknesses of static maps, animation, and the space-time cube in presenting dynamic geospatial phenomena (such as moving objects). User questions related to the aspects to be represented and the associated levels of reading are discussed in section 4.4. Section 4.5 explains the conceptual framework containing the expected suitability of each representation for the aspects of moving objects under consideration at different levels of complexity. In section 4.6, the chapter closes with summary.

4.2. Comparability

In the course of comparison of animation with static maps and the space-time cube, there are some concerns raised by Tversky, Morrison et al. (2002) that these representations might not be comparable in terms of content and procedure. Even though they appear comparable at first instance, Tversky, Morrison et al.(2002) contend that animations present details of the micro-steps between the larger steps of dynamic phenomena that are visible in static representations (i.e., animations show more information than their static counterparts). Moreover, as regards the procedure, in some studies the animation is prepared in such a way that it provides an interactive environment while the static displays lack this environment. In such situations it will be very tricky to assess the facilitatory power of animation in learning in comparison to static maps.

The non-comparability might be related to the way these representations are constructed, perceived, and conceptualized (Chan and Black 2005). Their concern is that animation may be too complex or fast to be perceived and conceptualized. Thus, they proposed that to develop effective animation we need to consider the users' limited working memory capacity; the perceptual and cognitive demands that animation may impose on them; and easy construction of animation to understand relationships of components in a complex system. In complex processes, it is possible for animations to be accompanied by other representations (based on the use) but this doesn't mean animations are not effective in depicting complex processes. Whether animations are too fast or not depends, amongst others, on the dynamics of the object or process represented. Animations can have the same speed as the object or process, or can even be prepared in a slower speed if, for example, it is needed for analysis or other purposes of the object or the process in the course of dynamics.

The comparability issue is challenged by Blok (2005). Blok argues that whether or not the visualization methods are comparable is not so important. In so far as they are different media, they have different potential of data representation. Their potential depends mainly on the nature of the data they represent and the purpose of use. For a particular use one of the media may be best while the other might be a best choice for another use. For example, considering the concern of Tversky et al., if micro steps are needed for a particular application, the choice will be animation. Conversely, in applications where micro steps are not important other representations might be a better choice (but not necessarily). This doesn't mean that the strength of animation is only when micro steps are needed, however. Animation might also be a best choice in applications without the need for micro steps: the use context matters. Blok further explains that adding interactive controls to animation should be provided if the use demands it (which actually happens in most cases).

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Given particular aspects to be represented and a particular use, what then is the visualization method that best fits? To answer this question, the methods of representation are assessed to discover their possible potential for the visualization of walking people. For example, the user can even have interactive control of animations (the minimum controls) if it is really important for extracting visual information about the represented aspects. Why moving objects? Moving objects are simpler than other dynamic phenomena (e.g., flow of water, expansion of agricultural lands, etc) in that they can be represented by points and their dynamics (in terms of spatial location) is along a trajectory. Their movement can be easily followed and perceived (Rensink 2002). With other phenomena, the changes might take place in different directions (distributed) which might challenge the ability of the observers to notice these changes (Rensink, O'Regan et al. 1997). Moreover, the flexibility of moving objects in terms of complexity is high. They can be represented from the very low level of complexity (such as one object along a simple linear trajectory) to high complexity (such as many moving objects along complex geometry of trajectories). Specifically, walking people have complex but flexible movement behaviour. The number of objects and the complexity of the geometry of the trajectory have impact on the perception and understanding of map users (Tversky, Morrison et al. 2002; Opach 2007). When the number of objects increases, it challenges the ability of users to notice changes in (the aspects of) each object. The attention may be taken to one object and in effect miss the other objects. The same happens when the trajectory varies from simple to complex. Following a simple linear trajectory doesn't equally challenge the perception of users like a non-linear trajectory.

4.3. Strengths and weaknesses in visualizing dynamics

It is mentioned above in 4.1 that cartographic visualizations may not be effective representations in all situations (such as in representing aspects of moving objects). Thus, in this section the strengths and weaknesses of each cartographic representation in terms of visualizing dynamic geospatial phenomena are assessed.

4.3.1. Static maps

It is evident that two-dimensional still images are a very good way (if not the only way) of showing two-dimensional still information (Dorling and Openshaw 1994). Cartography has in its long history been successful in representing dynamic spatiotemporal phenomena with static, spatial representations in a two dimensional form (Bertin 1983; Köbben and Yaman 1995; Fabrikant 2005). Single static displays make the dynamic reality comprehensive and dictate the essential facts and relationships of a dynamic process (Monmonier 1993); they are relatively effective in giving an overview of the patterns of, for example, the trajectory movements of objects. Fabrikant (2005) reviewed that according to a number of experimental researches conducted, static displays have a good potential to facilitate comprehension, learning, and communication of complex phenomena. The depiction of dynamic states of the world doesn't strictly necessitate the use of cartographic dynamic displays. This assertion sounds unrealistic for the reason that if there is the option for the dynamic reality to be represented realistically, it wouldn't be static maps (see 4.3.2). That is, the main problem associated with the static maps (both single and multiple) is that the dynamism of the phenomena is not maintained (Turdukulov and Kraak 2005).

Tufte (1997) has expressed his appreciation of the use of small multiples in various paradigms as: small multiples reveal repetition and change; directly depict comparisons; help analyze, compare, differentiate phenomena; Tversky, Morrison et al. (2002) also put that small multiples have the power to make possible the comparison and re-inspection of the details of the components of the phenomena represented. However, the time component as well as the complexity of the relationships of the phenomena should also be taken into account. With large time periods and complex relationships, small multiples might fail in supporting information extraction and reinspection. This might be because their visualization is restricted by a limited number of small time slices (Turdukulov and Kraak 2005) and their potential to represent complex phenomena and processes is limited. They may also become too small to make comparisons (Dorling and Openshaw 1994).

In the context of representing moving objects, single static maps have problems in depicting repeated bidirectional movements (e.g., a repeated movement along the same trajectory), and in depicting stays for some time at one location. Multiple static maps might also experience these problems. The display page might be intensely crowded if there is a repeated long time bidirectional movement as well as stops for a long time. Movement along a trajectory is a continuous scenario. Small multiples however are discontinuous spatial representations of this continuous scenario. The users therefore are left with the task of interpolating between images of the multiples to perceive the continuity of the movement. In this case space takes the place of time as the sequencing dimension (Tufte 1997). Static maps therefore are successful only when the dynamic phenomena and processes are simple with few occurrences of events.

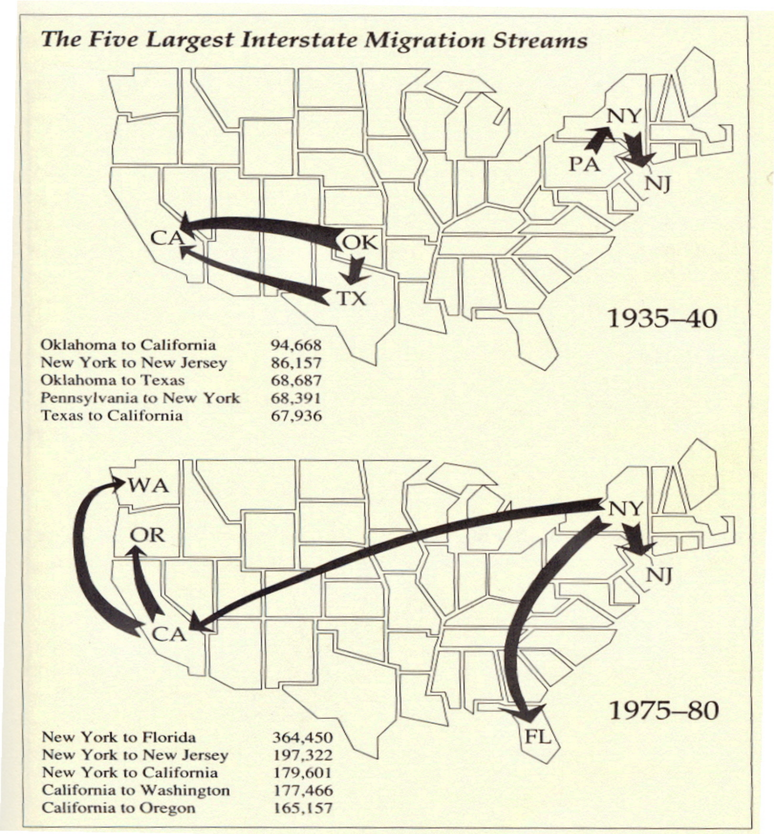


Figure 4.1 Single static maps depicting the movement of people (migration) from an origin to the destination showing also the path of their movement with straight and curved arrows (Monmonier 1993; pp. 191).

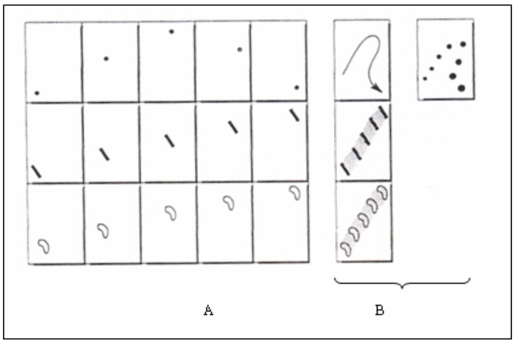


Figure 4.2 Dynamics in position of objects depicted on static maps. A) Series of maps showing change in time (such as movement) by displaying a position at a certain moment in time on a single map. B) Single static maps showing the path and direction of movement (Koussoulakou and Kraak 1992; pp. 102).

4.3.2. Animation

Animations are powerful with respect to showing trends and dynamic processes (Kraak 1999). See Figure 4.3. Users of maps perceive a spatiotemporal phenomenon/process more quickly and more easily from animated maps than from static displays (Koussoulakou and Kraak 1992). This is because animations make direct use of time to depict the dynamic phenomena and the process (Muller and Schumann 2003). Griffin, MacEachren, et al. (2006) have undertaken an investigation to compare the effectiveness of animated cartographic displays with static small multiples. They studied the ability of users of these cartographic representations in terms of identifying clusters that move over space and through time. They discovered that more participants of the experiment identified patterns correctly using the animation than the small multiples. This seems contrary to the arguments and findings of Tversky, Morrison et al (2002) that the extra cognitive load required to perceive and understand animations (compared to static maps) challenges the ability to efficiently extract information from them. Tversky et al. argue that animated displays have problems when re-inspection is needed because they are fleeting and they disappear. It will not even be easy, in the process of reinvestigation, to conceive changes that take place in minutes or seconds. However, there are ways by which animation can be made more suitable. One is that animation can be placed in a loop, so that it can be reviewed. Another is that animation can be displayed at least in a minimum interactive environment, with some media player controls (Blok 2005) to give users control over playing backward and forward. From the perspective of moving individual objects, for example, movement can also be followed from a visualized path (see Figure 4.3); so that users can easily review the routes of the objects (it will not be fleeting and doesn't disappear).

Monmonier (1993) argues that in what ever way an animated map is prepared, it will only be truly effective if it is accompanied by one or two static displays. He believes that animated maps are truthful and intriguing, but they are not easy to comprehend. Slocum (1999) also added that small multiples are necessary complements to animations. Thus, according to their argument, we cannot assert that animation is effective in showing dynamic reality unless it is accompanied by static maps. This contention, however, seems to disregard the potential of animation in dynamic data representation. It is contended here that if animation is constructed (taking into account the characteristics of the data and the purpose) in such a way that it would give a good environment to extract information, there is no reason why animation wouldn't be powerful because it shows real dynamics better than other representations. But, if the use demands, animations can of course be accompanied by other representations (see the discussion in section 4.2).

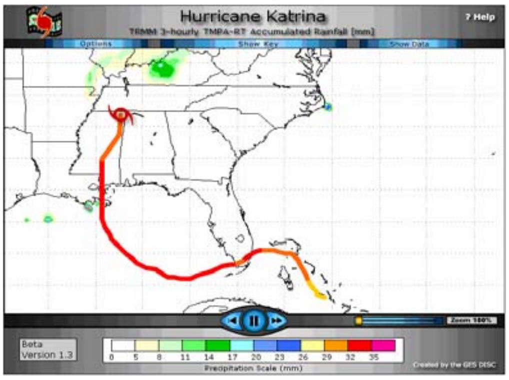


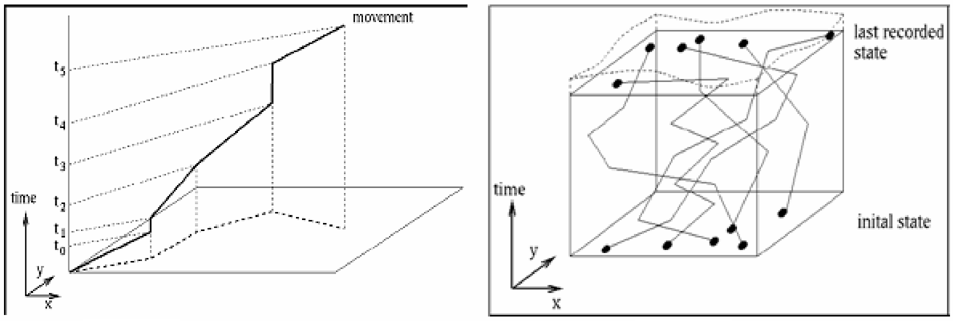
Figure 4.3 Animated display of hurricane Katrina in 2005. It shows the path, speed and direction of the hurricane (taken from <http://disc.gsfc.nasa.gov/hurricane/2005/Katrina/katrina.html>)

We can also raise our concern about the effect of the level of complexity. Tversky, Morrison et al. (2002) pointed out that complexity in all situations challenges comprehension in animation. (Opach 2007) investigated the effectiveness of animation in representing moving objects (clouds) by analyzing the perception and response of the map users at different level of complexity (complexity in terms of the number of the clouds depicted). Though he tried to test the effectiveness of animation without comparing it with other cartographic representations, he revealed that with an increase in the level of complexity the ability of the users to draw the routes of the moving clouds and to identify the location where acceleration/deceleration takes place decreases. This, however, doesn't tell how optimal animation is for a particular use in comparison to other representations and how level of complexity affects a choice for a representation level. In this regard, Andrienko and Andrienko (2007), by comparing animation and the space-time cube, have found out that the upper limit (in terms of the number of the objects represented and ease of extraction of information from the display) is higher for animation than the space-time cube. They further explained that few numbers of objects and shorter time periods keep the utility of animation higher than the space-time cube. The level of complexity could have also been seen in terms of the complexity of the geometry of the trajectory along which the objects move (explained in section 4.2). Since the geometry of the trajectory would affect the movement characteristics, it will have an impact on the extraction of information from an animation.

4.3.3. The space-time cube

What makes the space-time cube (see Figure 4.4) special compared to the other cartographic representations is that it displays both all time and spatial information simultaneously. The space-time cube is suitable for depicting as well as analysis of paths of individual or group trajectory movement of objects (Kraak 2003). In their investigation of the spatiotemporal interaction between two moving objects along a road network, Weghe, Cohn, et al. (2004) have tried to depict the path of moving objects in the space-time cube. They, however, indicated that undertaking visual analysis on the movement as well as the interaction between the moving objects in the space-time cube is difficult because it portrays a three dimensional view (time as a third dimension). They prefer representations using snapshots and transitions. The snapshots show the interaction of both objects at a time moment (t_i) (location of the object is given, along with the shortest path between both objects at that moment in time). The transitions show the movement from t_0 – t_1 up to t_{n-1} - t_n. In this regard it is good to complement one representation by another when it is difficult to utilize it for a specific use. But this shouldn't lead to the generic assertion that one representation method is totally ineffective or always less effective than the other.

Kristensson, Dahlback, et al. (2007) compared the space time cube and baseline 2D representations (static maps) using the error rates and response time. They found that users benefit more from the space-time cube than from static displays when analyzing complex spatiotemporal patterns. Contrarily, Andrienko and Andrienko (2007) have explained that the length of time, the complexity of the geometry of the trajectories, and the number of the objects represented influence the effectiveness of the space-time cube to extract useful information. The impact of high number of objects and high complexity in the geometry of the trajectories make the space-time cube like a bowl of spaghetti which makes extracting information difficult. The contradiction between the findings is attributed to some factors: the aim of the study and the characteristics of the data. For example, Andrienko and Andrienko aimed at defining visual analytics tools suitable for massive collections of movement data for detecting patterns, while Kristensson worked on human walking traces.



(a) (b)

Figure 4.4 Moving point objects: (a) a trajectory and (b) several trajectories in 3D (space and time) framework. The dashed line in (a) shows the projection of the movement on a two dimensional space. In both (a) and (b) space (x- and y- axis) and time (t-axis) are combined to form the three dimensional framework (from Tryfona and Pfoser (2001); pp. 3).

4.3.4. Summary of the findings

The findings and comments given by different authors as to the strengths and weaknesses of the representation methods are summarized in Table 4.1. Overall, the table shows that for all the representation methods the level of complexity of the phenomena represented and associated characteristics influence their effectiveness. With static maps having many events to be visualized challenge their effectiveness. With increase in complexity of the phenomena or processes, for example, in animation, information extraction is difficult; the space-time cube appears a bowl of spaghetti when the number of the objects increases. Different results and comments are given by the authors; some findings have contradictions (see the discussion in section 4.3).

Table 4.1 Summary of the findings of different authors about the strengths and weaknesses of static maps, animation, and the space-time cube in the representation of dynamic phenomena.

Methods	**Authors**						
	Dorling and Openshaw (1994	Tufte (1997)	Monmonier (1997)	Tversky, Morrison et al. (2002)	Fabrikant (2005)	Turdukulov and Kraak (2005)	
Single static maps			- Make the dynamic reality comprehensive and dictate the essential facts and relationships of a dynamic process - Give an overview of patterns		Facilitate comprehension, learning, and communication of complex phenomena.	Their visualization is limited to small time slices and the dynamism of the phenomena is not maintained	
Multiple static maps	They may become too small and consequently, difficult to compare	Reveal repetition and change		Make possible comparison and re-inspection			
	Koussoulakou and Kraak (1992)	Monmonier (1993)	Tversky, Morrison et al. (2002)	Blok (2005)	Griffin, MacEachren, et al. (2006)	Andrienko and Andrienko (2007)	Opach (2007)
Animation	- Complexity challenges comprehension - Problems when re-inspection is needed	Difficult to draw routes and identify where speed change takes place with an increase in the level of complexity	Users perceive a spatiotemporal object /process (esp. movement) quickly and easily	Adding interactive controls helps to overcome some of the limitations.	Increase in the number of objects and a longer time period constrain extracting information	Better than small multiples and STC in depicting patterns correctly	Truthful and intriguing, but not easy to comprehend
	Kraak (2003)	Weghe, Cohn et al. (2004)	Kristensson, Dahlback, et al. (2007)	Andrienko and Andrienko (2007)			
The space-time cube	Suitable for depicting as well as analysis of paths of individual or group trajectory movement	Difficult for visual analysis on the movement as well as the interaction between the objects.	Better than static displays in analyzing complex spatiotemporal patterns	High number of objects and high complexity of geometry of the trajectories make the STC like a bowl of spaghetti			

4.4. User questions and associated levels of reading

A number of questions can be raised by users of maps that refer to all components (spatial, thematic and temporal) of geospatial data (Koussoulakou and Kraak 1992; Blok 2005). Some questions in the context of analyzing cartographic visualizations walking people related to some aspects (stops, returns, speed change, and path) are listed below.

- Where and when are important changes (like speed changes) happening?
- Does the same person visit the same place more than once?
- Do the persons stay for some time in one place?
- Is there a relationship between moving objects (e.g.: walking people being simultaneously at the same place)?
- What are the main characteristics of the geometry of the trajectories (simple or complex)?

User questions arising during map use have been categorized into three reading levels, both in the spatial (Bertin 1983) and temporal (Koussoulakou and Kraak 1992; Blok 2005) domains: elementary, intermediate, and over all reading levels. In the visualization of walking people in different representations in this research, both the spatial and temporal levels of interest are important.

The reading levels are:

- Elementary level: questions pertaining to a single element at a certain location in space and / or time.
- Intermediate level: questions pertaining to a group of elements in space and / or time.
- Overall level: questions pertaining to all the elements on the map in space and / or time.

The questions listed above can be asked at different levels of reading. For the purpose of this research questions will be asked at a variety of levels, to avoid an evaluation that is biased by specific levels only. Elementary and intermediate spatial levels will be combined with intermediate and overall temporal levels.

Awareness of strengths and weaknesses of the different methods, and questions that users might ask help to develop the conceptual framework about the suitability of the cartographic representation methods for visualizing moving objects (see 4.5), and for the design phase in chapter 5.

4.5. Conceptual framework: suitability

So far in this thesis, attempts have been made to discuss and identify the concepts of movement (types and behaviours), moving objects; and the strengths and weaknesses of the cartographic representations in depicting dynamic phenomena. A conceptual frame work is designed to show the suitability of single static map, multiple static maps, animation, and the space-time cube in enabling users to perceive and understand some relevant aspects of walking people (stops, returns, speed change, and path) at different levels of complexity.

Table 4.2 Predictions of the suitability of the representations at three levels of complexity: from low (Level 1_ to high (Level 3). The predicted suitability is represented by tints from light (low) to dark (high). Stops are not going to be tested for single static maps. Since the questions related to path needed more than two objects, Level 1 is skipped.

Methods	Stops			Returns			Speed change			Path	
	Complexities										
	L1	L2	L3	L1	L2	L3	L1	L2	L3	L2	L3
Single	NA	NA	NA								
Multiple											
Animation											
STC											

NA: Not Applicable
L1, L2, L3=levels of complexity

Predictions (Table 4.3) are based on the user questions, and strong and weak aspects of each method learned from literature review; cartographic knowledge; and common sense. This led for example to the assumption that in most cases the suitability at level 3 is lower than at complexity level 1 or 1 and 2.

In the visualization of *stops,* animation and the space-time cube have high suitability at Levels 1 and 2. In animation users can easily see movement and stops from the dynamics. In the space-time cube, it is anticipated that users can easily conceptualize *stops* from the vertical orientation of the paths in the cube. However, when the complexity increases, it will look like a bowl of spaghetti (Andrienko and Andrienko 2007). In the visualization of *returns*, *speed change*, and *path* only animation has high suitability- at levels 1 and 2 for *returns* and *speed change*, and at level 1 for *path*. This is because animations show real dynamics (Chan and Black 2005) from which observers can easily notice the speed change, the back and forth movement, and path (assuming the paths are displayed and not just the locations of the moving objects). However, it is challenged when complexity increases because the movement of many objects in complex trajectories might facilitate delusion due to the flitting behaviour of the movement, impeding the perception of the users. Overall, according to the prediction, animation is the most suitable method for visualizing moving objects (walking people)

As explained above, the predictions are reasonable assumptions based on findings in literature review and cartographic knowledge/common sense. But is that enough to make optimal choices? The answer to this question will be based on a user evaluation in the context of this research (relatively few individually moving objects / walking people).

4.6. Summary

This chapter has raised the issue of comparability in the cartographic representations. It is believed by Tversky, Morrison et al. (2002) that without comparability in content and procedure, it will be tricky to study the relative effectiveness of the cartographic representations in presenting dynamic geospatial phenomena. In this research, however, comparability is not the main issue, it is more about finding the optimal representation in case of moving objects, by investigating some aspects of moving objects (stops, returns, speed change, and path) at different levels of complexity. A review is made about the strengths and weaknesses of static maps (both single and multiple), animation, and the space-time cube. The results from various studies indicated that level of complexity challenges the effectiveness of the cartographic representation methods. Finally, a conceptual framework (Table 4.2) of the expected suitability of the different representations in visualizing moving objects is proposed. This framework will be adjusted later in this research (see chapter 6). In the framework the expected suitability of the representations for different aspects of moving objects (stops, returns, stops, speed change, and path) at three levels of complexity are presented. In this expectation, animation is though to be predominantly suitable to provide a view to all the aspects of the moving objects under consideration.

5. Design and implementation

5.1. Introduction

In chapter 4 discussions as to the strengths and weaknesses of the representations have been given. After identifying and deciding on the movement characteristics subject for this research, a prediction about the suitability of the representation has been made. This chapter deals with the design and implementation of the representations that will be used to verify the predictions. It gives an explanation and description of how data can be represented (with the geographic, thematic and temporal components), how the data are generated and the visualization environment. For the purpose of the design and implementation fictitious data are used. The data are prepared at three levels of complexity.

5.2. Design of the representations

5.2.1. Data representation

Table 5.1 gives an overview of ways to represent the geographic, thematic and temporal components of geographic data using different representations. In this means about moving objects (walking people), the paths of the moving objects (possessing a geographic location) are represented by the graphic variable location. Other graphic variables (and others) are used for thematic components and for the temporal component each representation uses different expressions.

Table 5.1 Graphic transcription of the geographic, thematic, and temporal components of geographic data (after Koussoulakou and Kraak 1992-pp. 103).

Components	Representations			
	Static		Animation	The STC
	Single	Multiple		
Geographic location	plane graphic variable	plane graphic variable	plane graphic variable	plane graphic variable
Thematic	other graphic variables	other graphic variables	other graphic variables	other graphic variables
Temporal	graphic variable	spatial sequence (deduction) of maps	dynamic visual variables in the temporal dimension (display time)	third dimension of the cube

	Visual variables	Representations			
		Static		Animation	the STC
		Single	multiple		
Geographic	Graphic variables				
	Location	●	●	●	●
Thematic	Graphic variables				
	Colour	●	●	●	●
	Shape	●	●	●	●
	Orientation	●	●		
Temporal	Graphic variables				
	Location	●			
	Dynamic visual Variables				
	Moment			●	
	Order			●	
	Duration			●	
	Frequency			●	

Figure 5.1 Visual variables used for the geographic, thematic and temporal components of the data in cartographic representation of moving objects in this research.

The use of potentially suitable visual variables for presenting moving objects in static maps, animation, and the space-time cube is given in more detail in Figure 5.1. Location is inherently found in all cartographic representations (since we are talking about spatial phenomena). Colour, shape and orientation are graphic transcriptions used only for the thematic components in all representations. They are applicable for data at nominal level of measurement. Colour and shape can be used, for instance, to differentiate different moving objects on a display. To show directions of moving objects or the orientation of paths, orientation will be used in single static maps (arrow heads). Location is used to depict the temporal dimension in single static maps: the spacing between points along the path may tell, for example, the speed of objects moving. The dynamic visualization variables are applicable only in animations to represent the temporal component. The dynamic visualization variables considered here are moment, order, duration and frequency. In the representation of moving objects, moment pinpoints change (like speed) in time. Order is used to represent the sequence of changes (position of the moving objects along their trajectory in time). Frequency is involved if a trajectory is followed more than once by a moving object. Finally, duration can show the change in speed of the moving object in time.

5.2.2. How the visualizations work

All the representations are designed to have three levels of complexity, using the same dataset. Level one has one object, level two has two objects and level three is prepared with four objects. The level of complexity (as is defined in chapter 4) not only varies with the number of objects represented, but also with the geometry of the trajectory along which the objects move. Even though the same data are used for all the representations the representation of aspects such as speed changes, or returns might not be the same. For example, it is difficult to represent stops in single static maps.

For distinguishing between the moving objects, they are given different colours. At the first level of complexity, where there is only one object, it is given a green colour. At the second level of complexity, the two objects are coloured red and blue, and at the third level red, blue, green, and yellow. Red, blue, and green are used repeatedly because they are easy to distinguish them on the grey background.

5.2.2.1. Single static maps

In the single static maps the three aspects (speed change, return, and path) are represented in the three levels of complexity (see Figure 5.3- a, b, c). The paths of the movement of each object are displayed by line symbols so that the routes of movement can be easily depicted. To represent speed change, point symbols are used along the path at regular intervals. This will help visualize speed change from the distance travelled in that time interval. To reduce confusion, different symbols are used for start, return and end (see the legend in Figure 5.2). For each object the start time is given to show, for example, which object arrives first at a certain location.

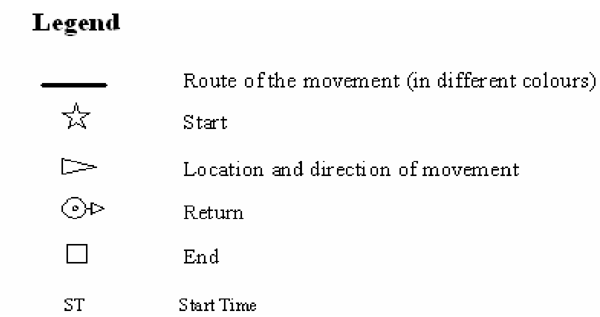


Figure 5.2 Legends used in static maps

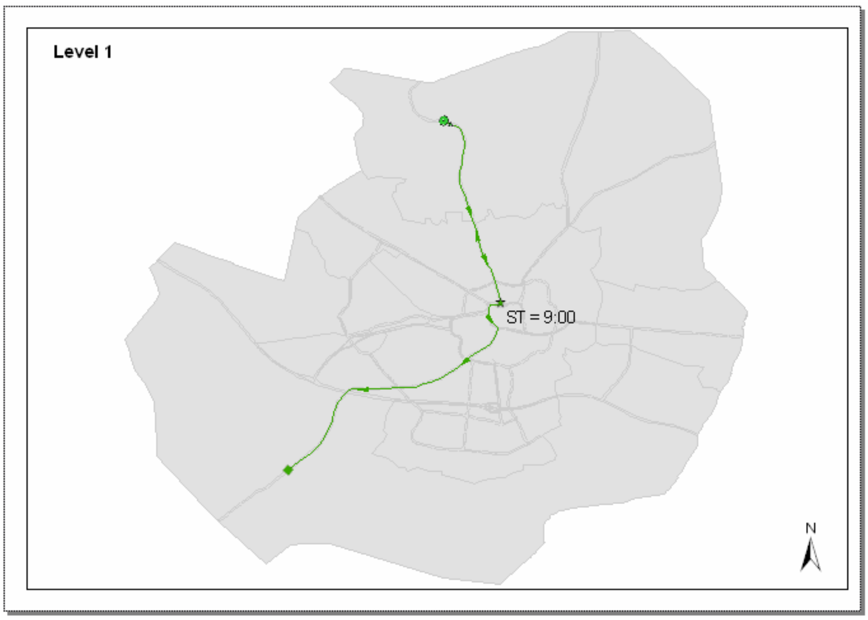


Figure 5.3 Single static maps at different levels of complexity
(a): The first level of complexity for the single static maps with one moving object.

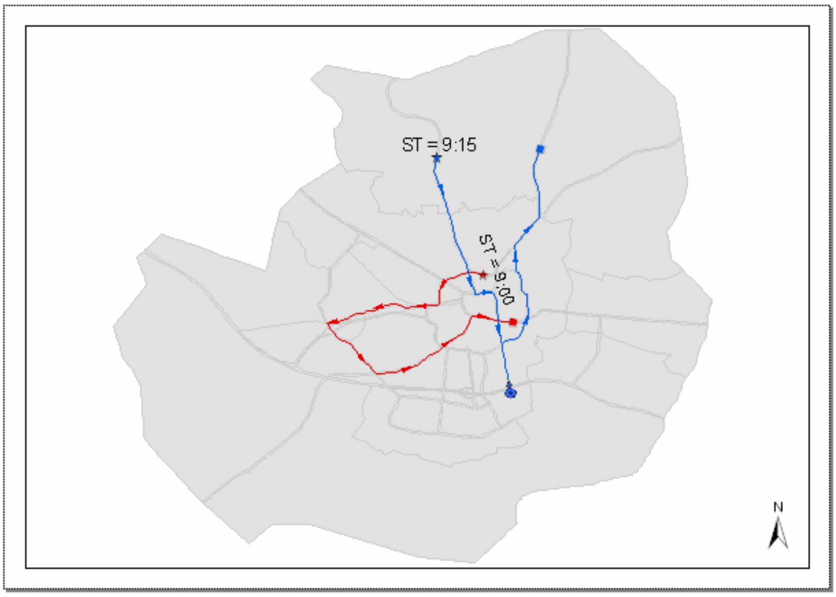


Figure 5.3 (b): The second level of complexity for the single static maps with two moving objects.

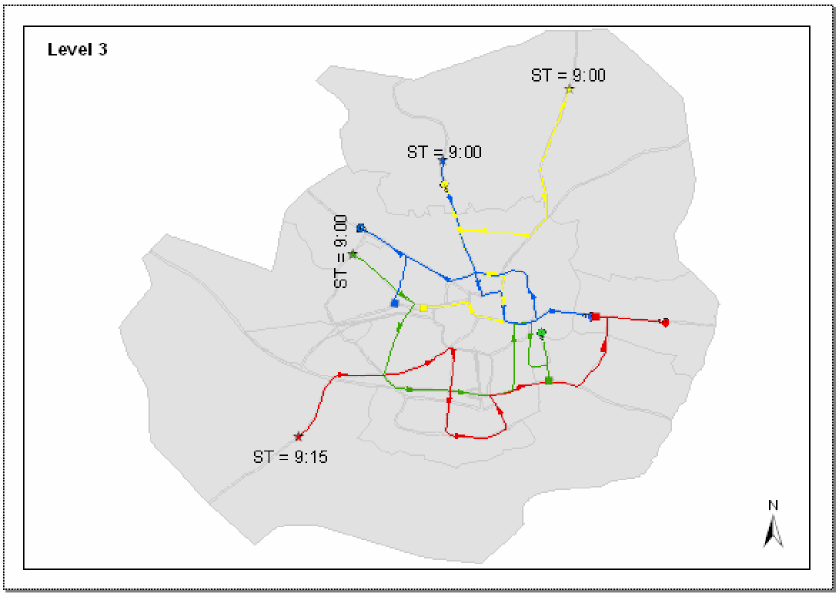


Figure 5.3 (c): The third level of complexity for the single static maps with four moving objects.

5.2.2.2. Multiple static maps

For the multiple static maps, the start and end symbol together with the symbols for location and direction are used. The loop symbol for return is not used because return can be visualized from the previous snapshot. The start time is also given on the first snapshot. In multiple static maps, all the aspects are represented at three levels of complexity (See Figure 5.4-a, b, c). Speed change can be visualized by distance travelled between two snapshots and by comparing with the previous map (similar to the single static maps). Returns can be visualized by the location of the object and the direction indicated by the triangle. Stops can be represented by the location of the object on the same location in more than one snapshot. The trajectories of movement grow from the start up to the end. So on the last snapshot, the total path travelled is displayed.

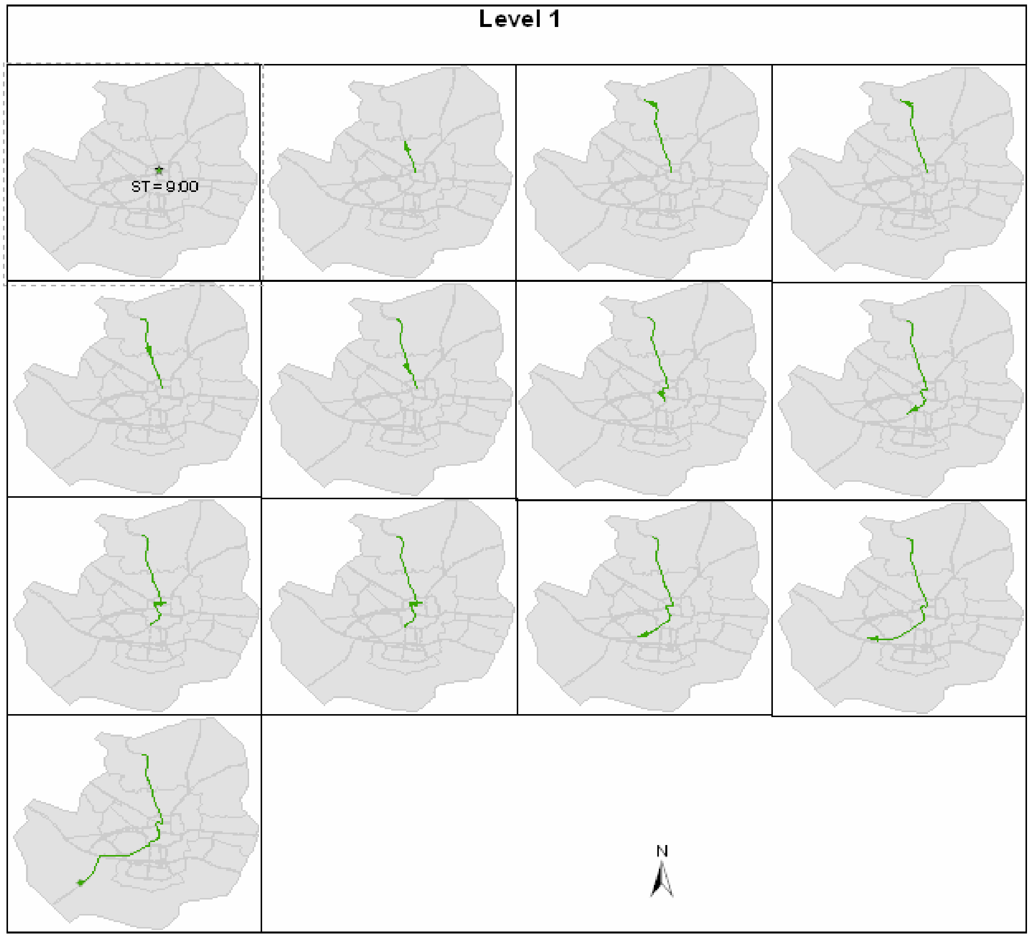


Figure 5.4 Multiple static maps at different levels of complexity
(a): The first level of complexity for the multiple static maps with one moving object.

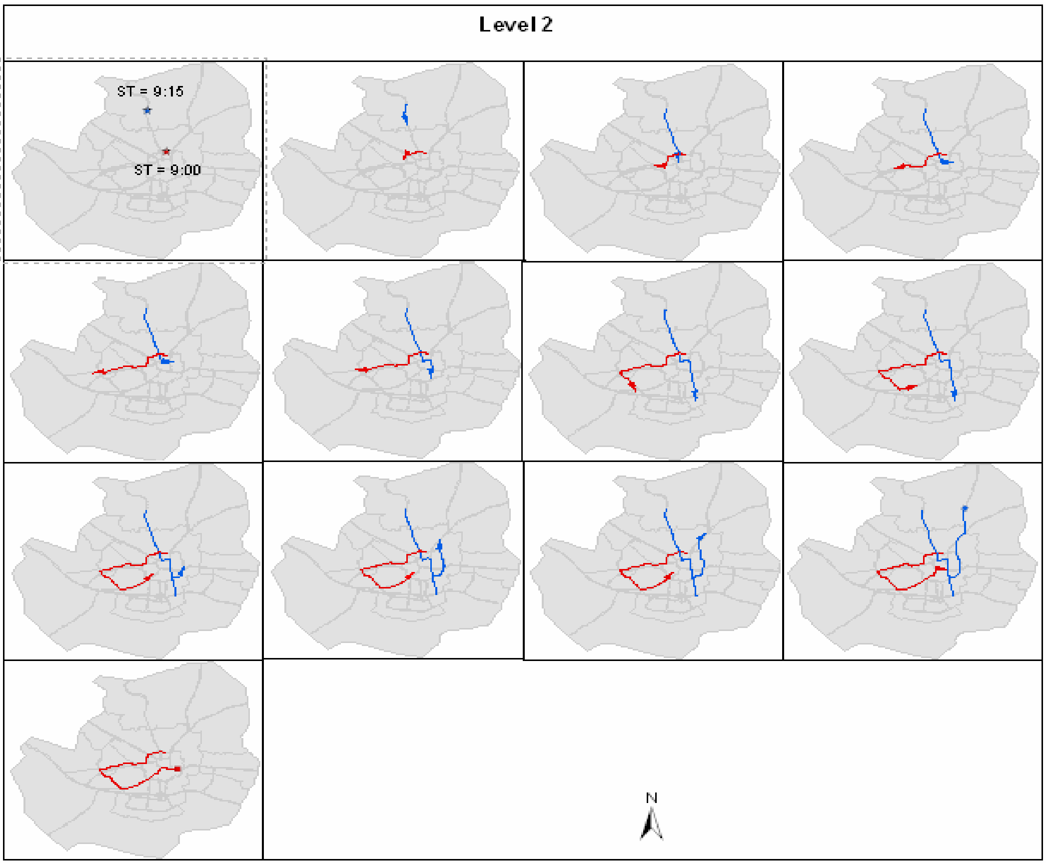


Figure 5.4 (b): The second level of complexity for the multiple static maps with two moving objects.

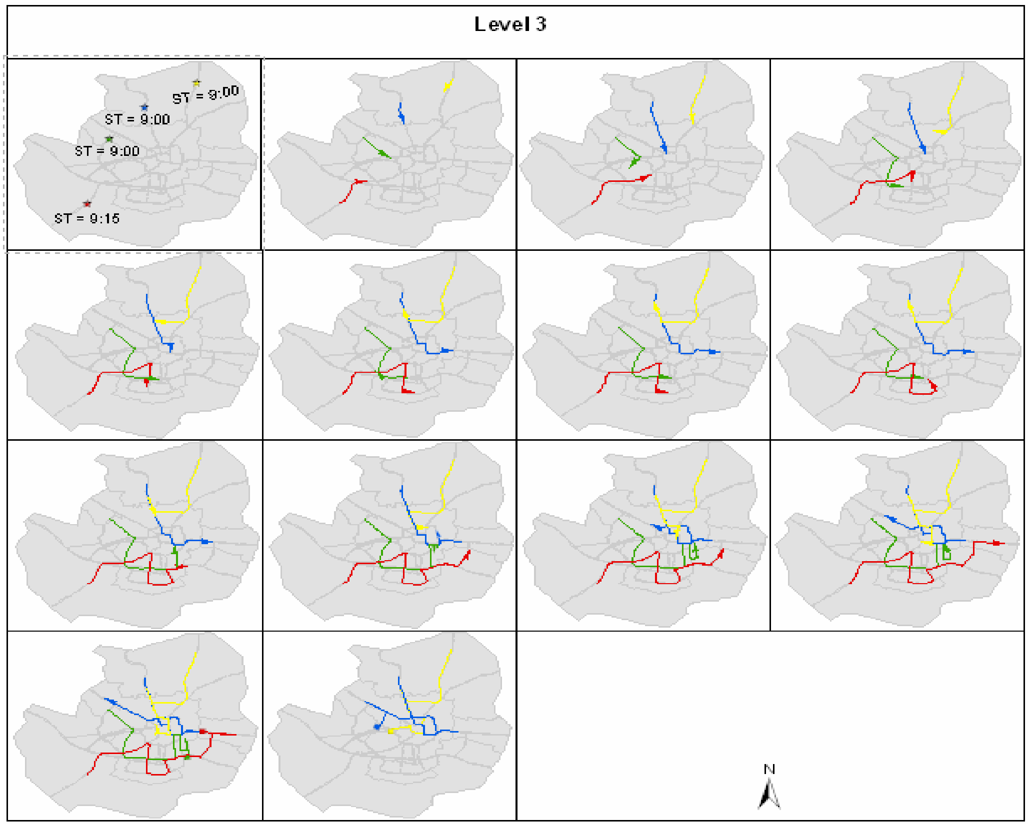


Figure 5.4 (c): The third level of complexity for the multiple static maps with four moving objects.

5.2.2.3. Animation

Like the single static and the multiple static maps, the animation is designed at three levels of complexity (see Figure 5.5-a, b, c). The figures below show the display at the end of each animation. The animations have both the moving point and moving lines together. The lines show the path of the movement throughout the whole display. The point symbol for location used here is "dot" in stead of an arrow. The minimum interaction environment is given (stop, pause, and rewind).

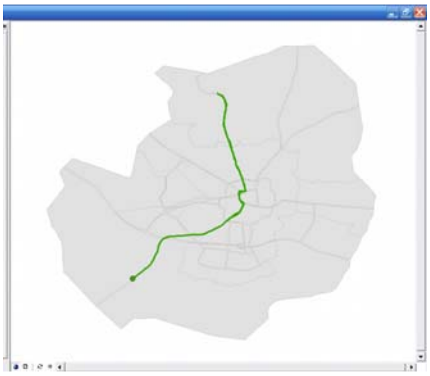


Figure 5.5 Animation at different levels of complexity
(a): The first level of complexity of the animation with one moving object.

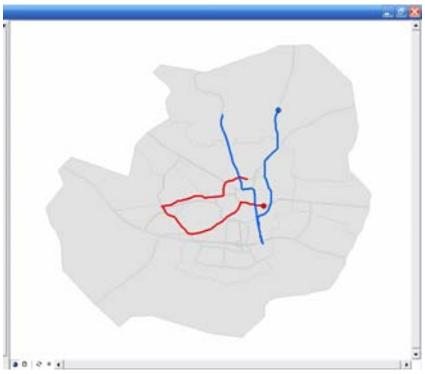


Figure 5.5 (b): The second level of complexity of the animation with two moving objects.

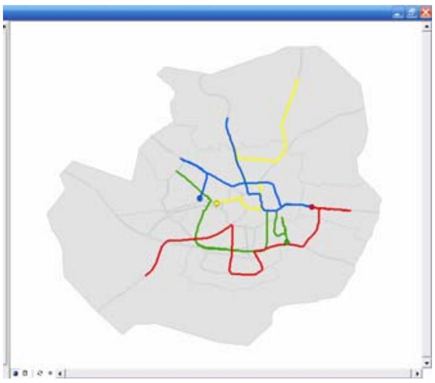


Figure 5.5 (c): The third level of complexity of the animation with four moving objects.

5.2.2.4. The space-time cube

Like all other representations, the space-time cube is designed in three levels of complexity. The background colour of the space time cube is kept grey in order to have contrast with the objects (especially the main paths that move up ward with time). The spatial coverage of the base map is shown on the (X, Y) axis while the time attribute is represented by the vertical axis (T). To clearly depict the path of movement, the foot print is displayed on the map. It shows the trajectory in space. Time is represented by the upward movement of the path from the start. Vertical lines that divide the space of the cube and horizontal lines across at every 15 minutes intervals are displayed as reference to locate objects in space and time.

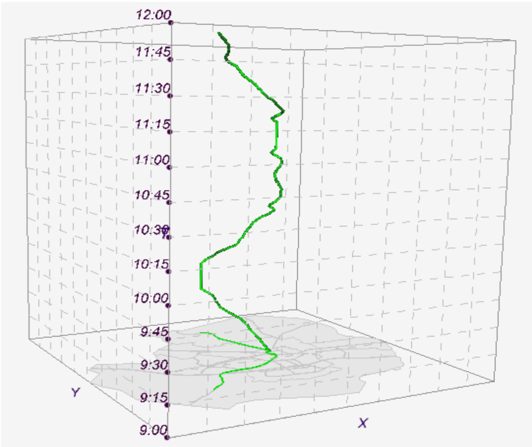


Figure 5.6 The space-time cube at different levels of complexity
(a): The first level of complexity for the space-time cube with one moving object.

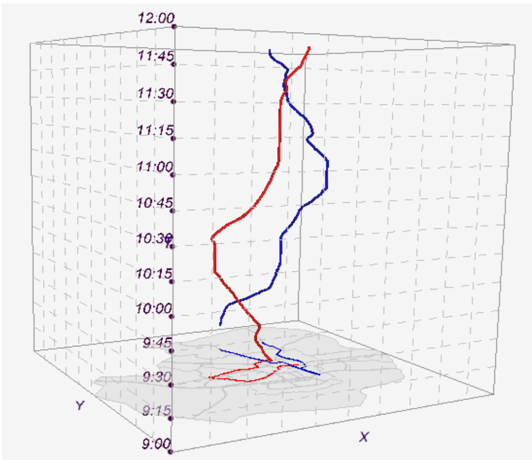


Figure 5.6 (b): The second level of complexity for the space-time cube with two moving objects.

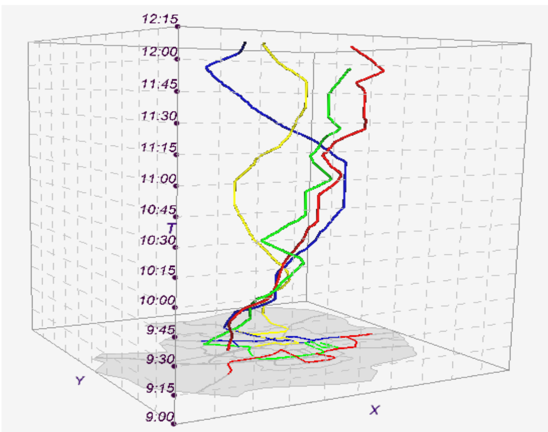


Figure 5.6 (c): The third level of complexity for the space-time cube with four moving objects.

5.3. Implementation

This section gives a description of the software and programs used to generate the data and to produce the representations. It also gives a description about how the data are developed and implemented in the software and programs used in this research.

5.3.1. Software and programs

Software programs used for the implementation include ArcMap/ArcCatalog, ILWIS, the Udig plugin for the space-time cube, BB FlashBack, SnagIt 6, and a Java Program.

ArcMap/ArcCatalog: ArcCatalog is used for creating a point shape file and giving attributes and geographic coordinates to the shape file. Arc Map is used to develop point data by digitizing on a base map containing the district and main road layers of Enschede, The Netherlands (see Appendix 4, Schema A). The Time Slider extension of Arc Map (see Figure 5.7) is used to animate the point as well as line data (as shape files).

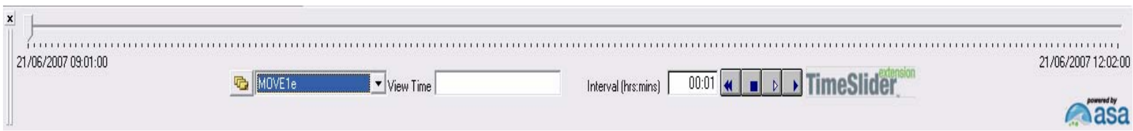


Figure 5.7 The bar of the Time Slider extension for Arc Map

Java Program: This program converts point data with .pts format to .smt format from which the segments can be developed (see Appendix 4, Schema B).

ILWIS: ILWIS is used to create series of segments by making use of the Java program (See Appendix 4, Schema B). The .smt data developed by the Java program are imported to ILWIS and then exported as shape files. These segments are used to generate growing paths for the moving points in the animation.

Udig plugin for STC: This plugin is used to develop the space-time cube needed for the research. This plugin has functionalities for interaction as well as exploration of geodata. For this research the time-space paths with the footprints are used to show the movements along trajectories.

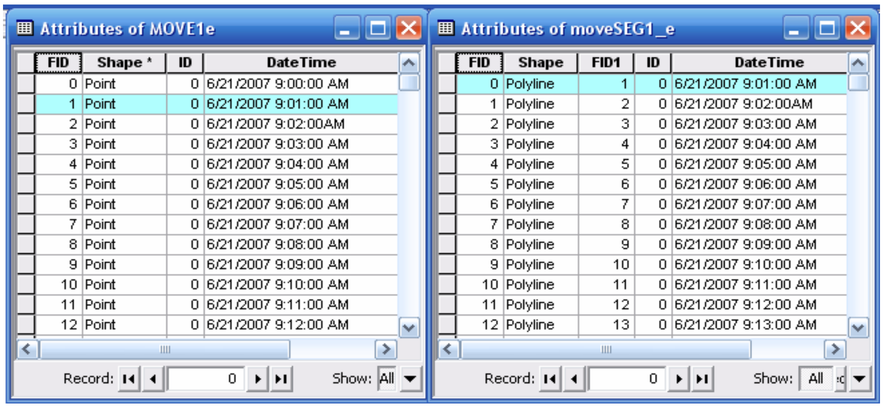
BB FlashBack: Since ArcMap, in the Time Slider extension, has no functionality to export the animations to video, flash, or other formats, the BB FlashBack software is used to extract the animation. It is powerful software which extracts the animation with a good quality. Different export formats can be used: AVI, WMV, Flash, Stand Alone EXE, and Power Point.

SnagIt 6: This is screen catch software which is used to create the video version of the space-time cube. BB FlashBack cannot do this from Udig.

5.3.2. Data

The point data are developed in such ways that have the movement characteristics walking people (stops, returns, speed change, and path) (see Appendix 4, schema A). A series of segments is needed for the moving objects in the animation to show the development of the paths over time. This is done to enrich animation in visualizing the movement characteristics. The series of segments are created directly from the digitized point features. Points and segments are used both for building the animation. For the paths of the single static maps other line data are developed. The procedure for developing the segments for the animation is illustrated in Appendix 4, schema B.

The time attribute is important since movement is a spatiotemporal phenomenon (see chapter 2). A time attribute should be added to both the point and the segment data (see Appendix 4, schema C). The time for the segment data should start one step after the time of the point data because time is assigned to the end point of each segment (see Figure 5.8). The time attribute of the line shape file is needed for the animation only. For the space-time cube the point data are used. For the animation, since both the point and segment data have time attributes, they are animated in the Time Slider extension of ArcMap. For the space-time cube they are imported to Udig plugin for the space-time cube.



Attributes of MOVE1e

FID	Shape *	ID	DateTime
0	Point	0	6/21/2007 9:00:00 AM
1	Point	0	6/21/2007 9:01:00 AM
2	Point	0	6/21/2007 9:02:00AM
3	Point	0	6/21/2007 9:03:00 AM
4	Point	0	6/21/2007 9:04:00 AM
5	Point	0	6/21/2007 9:05:00 AM
6	Point	0	6/21/2007 9:06:00 AM
7	Point	0	6/21/2007 9:07:00 AM
8	Point	0	6/21/2007 9:08:00 AM
9	Point	0	6/21/2007 9:09:00 AM
10	Point	0	6/21/2007 9:10:00 AM
11	Point	0	6/21/2007 9:11:00 AM
12	Point	0	6/21/2007 9:12:00 AM

Record: 0 Show: All

Attributes of moveSEG1_e

FID	Shape	FID1	ID	DateTime
0	Polyline	1	0	6/21/2007 9:01:00 AM
1	Polyline	2	0	6/21/2007 9:02:00AM
2	Polyline	3	0	6/21/2007 9:03:00 AM
3	Polyline	4	0	6/21/2007 9:04:00 AM
4	Polyline	5	0	6/21/2007 9:05:00 AM
5	Polyline	6	0	6/21/2007 9:06:00 AM
6	Polyline	7	0	6/21/2007 9:07:00 AM
7	Polyline	8	0	6/21/2007 9:08:00 AM
8	Polyline	9	0	6/21/2007 9:09:00 AM
9	Polyline	10	0	6/21/2007 9:10:00 AM
10	Polyline	11	0	6/21/2007 9:11:00 AM
11	Polyline	12	0	6/21/2007 9:12:00 AM
12	Polyline	13	0	6/21/2007 9:13:00 AM

Record: 0 Show: All

Figure 5.8 Attributes of the point and line shape files. The selected highlighted rows have the same time attribute.

5.4. Summary

This chapter has explained how the data of moving individual objects (walking people) are visualized in single static maps, multiple static maps, animation, and the space-time cube. The use of visual variables in the representation of moving objects in this research has been illustrated. Some aspects of walking people are represented in all the representations at three levels of complexity: stops, returns, speed change, and path. Stops are, however, not represented in single static maps. For the implementation of the representations, different software programs have been used from the generation of the data to the actual representation. The visualizations are designed and implemented in such a way that they would enable the conceptualization and understanding of the movement characteristics in each representation. In single static maps the whole path of movement and different symbols for start, return, direction and end are used. For the multiple static maps the same symbology is used except for the symbol for return, while the symbol for stop is added. In the animation a dot symbol is used to indicate location. The space time cube is represented by the trajectories that grow with time, supplemented by the foot prints. Grids that divide the space and the time axis are drawn to enrich the visualization. The visualizations will be assessed to verify the suitability levels. This will be described in the next chapter.

6. Test and analysis

6.1. Introduction

The types of movement, properties of movement along a trajectory, and movement characteristics (aspects) of individual moving objects are identified in chapter 2. Chapter three provides cartographic visualization (in which how the cartographic representation methods represent spatiotemporal phenomena is discussed) and cognitive issues that determine map users' ability to see important changes. The strengths and weaknesses of the cartographic representations in terms of depicting spatiotemporal phenomena are discussed in chapter 4. This chapter identified some user questions, the important movement characteristics to be tested, and made predictions as to the suitability of each representation method. But, this prediction is not sufficient to make selections of one or a combination of these representations. Next, in chapter 5 the actual design and implementations of the representation methods are undertaken.

To test which method is optimal with respect to representing moving objects (specifically of walking people) and some of their movement characteristics, a usability evaluation is necessary. Owing to the availability of many cartographic visualization methods the issues of suitability and usability are getting increasing attention. These issues are addressed in (MacEachren and Kraak 2001; Slocum, Blok et al. 2001; Koua, MacEachren et al. 2006). Usability/suitability has been defined as to have multiple components: learnability, efficiency, memorability, errors, and satisfaction (Nielsen 1993). It is also defined by ISO9241-11 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 (URL 1). Thus, effectiveness, efficiency and satisfaction are the most commonly applied measures to find the suitability of the representation methods.

This chapter looks at suitability issues about the four representation methods in visualizing moving objects (walking people). It gives a clear picture of the evaluation procedures, the results of the evaluation methods and the associated discussion, and a summary of the chapter.

6.2. Measures of evaluation

As is attempted to be mentioned in section 6.1, ISO9241-11 defines usability at three aspects: effectiveness, efficiency and satisfaction. These usability assessment aspects are defined as follows: Effectiveness: the accuracy and 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.

In geovisualization, use and usability testing is needed because it gives an insight into how the representation methods are suitable in terms of visualizing the characteristics of spatiotemporal data, such as movement characteristics. This will help to make a selection of the optimal method for the visualization of, in the context of this research, the behaviour of walking people.

In this research the power of single static maps, multiple static maps, animation, and the space-time cube in terms of representing some movement characteristics of walking people (see chapter 4) will be tested against these three ISO usability measures.

Effectiveness can be measured by asking objective questions for which users reply objective answers, e.g. effectiveness can be measured by correctness or errors of answers to the questions asked. Whether or not users understand things clearly or not can be a measure of effectiveness. It can also be measured by the amount as well as accuracy of tasks performed. Efficiency basically measures the resources and efforts users expend in the process of task execution for a particular use. The resource can be, for example, measured in terms of time spent. In the context of visualizing walking people in this research, effectiveness and efficiency can also be assessed subjectively by asking users to give their judgements based on a task they performed earlier, because the users know how easy/difficult the tasks were, and the time it took them to understand something in the tasks. Satisfaction is basically a subjective phenomenon. It can be assessed by asking individuals to give their opinions and comfort about a certain thing. Since the entire purpose of having a subjective satisfaction usability attribute is to assess whether users like the representation methods to represent a particular topic (in this research movement of walking people), it is appropriate to ask users to give their feelings and opinion. This is what is usually done in usability testing activities.

In the context of conceptualizing and understanding the movement characteristics of the walking people represented in this research, the following questions can be asked to give context definitions for the measures of usability.

- Do the representation methods clearly depict the aspects of the moving objects represented?
- Can the users clearly and easily conceptualize the aspects of the moving objects represented?
- Does it take the users reasonable effort and time to conceptualize these aspects?
- Do the users feel comfortable with the representation methods, used to visualize the selected aspects?

In this research the first and second questions help to define effectiveness; the third question defines efficiency; and the fourth defines satisfaction. They are defined below.

- Effectiveness: whether or not the representation enables to execute the tasks correctly.
- Efficiency: Whether or not the representation enables to execute the tasks easily (with minimum effort) and quickly (with minimum time).
- Satisfaction: How acceptable is the representation in terms of representing moving objects (walking people).

6.3. Empirical testing

6.3.1. Test methods

Assessing the effectiveness and efficiency or investigating the satisfaction of the users with the representation methods is realized by selection of appropriate usability test methods. Some commonly used methods are questionnaires, interviews, focus groups and the think aloud method.

The questionnaire method ensures the possibility of investigating various user categories as well as the specific needs of small groups of users (Nielsen 1993). Qquestions that irritate the users by being too long, too hard to understand, or too unprofessional will often get a low response rate. Therefore, this method needs to be subjected to a pilot test and redesigned before distributed to the actual respondents. Questionnaire methods are usually prone to misunderstanding of questions, false responses, and negligent replies. Thus, questionnaires should rely on closed questions, where the users have to supply a single fact, go through a checklist, or state their opinion on a rating scale (Nielsen 1993), particularly if there are no possibilities to verify or check the answers personally.

Questionnaires and interviews are very similar methods due to the fact that both use questions and record the responses. However, interviews have some advantages over questionnaire methods. They are flexible, they are free-form, they generate immediate results, and they have high response rates (Nielsen 1993). Interviews are flexible because if users do not understand the questions, the interviewer can explain them in depth and rephrase questions. Interviews might not depend on pre-prepared documents. Both questionnaire and interviews have problems regarding the trust of the answers given by users. Users usually give answers that they think they ought to give, especially to sensitive questions where the answers may be embarrassing or may be deemed socially unacceptable. Users may also give random answers to questions they can't answer.

A focus group is a special type of group with respect to purpose, size, composition, and procedures. The purpose is to gather information as to what they think and feel about an issue, product, or service (Krueger and Casey 2000). Focus group methods are basically for qualitative analysis of information (Morgan and Krueger 1997). Focus groups generate verbal and observational data (Stewart, Shamdasani et al. 2006). After the sessions of discussions are accomplished, a simple qualitative analysis will be done.

In the think aloud method the users are left with the system and think out loud their thoughts (and sometimes actions) when performing tasks (Nielsen 1993). The problem of think aloud is that the experimenter is left to code and interpret the meanings of the verbalizations, actions, and sometimes the physical expressions of the users (Blok 2005). Even a simplified think aloud method (with limited coding) is an extensive and expensive method which needs using videotapes where recording, watching, an analyzing the videotapes is needed (Nielsen 1993; Blok 2005).

In this research the questionnaire method (with users performing tasks) is thought to be appropriate. It is appropriate basically because it enables gathering both objective data (correctness of answers) and subjective data that provide information about the three commonly used measures of usability (see above). Focus groups are often used to get a first feedback on a design to improve before further testing. Since designs are relatively straightforward here, a focus group session is not considered. The interview method is not necessary if questions are clear, and a pilot is organized to secure the clarity. With the questionnaire method, both qualitative and quantitative analysis would be possible, and it is cost effective in terms of finance and time.

6.3.2. Materials and environment

Two materials were made ready: the representations and the questionnaire document (see Appendix 1). The four representations (single static map, multiple static maps, animation, and the space-time cube) were stored in different folders in all the computers in the cluster that was used to conduct the evaluation session. Each folder contained the representations at three levels of complexity. The users opened the visualization required for the tasks section of the questionnaire. The real the space-time cube couldn't be used because it might create problems if users unintentionally use unnecessary function in the software. Failure in the functioning of the software may also happen and in this case it may need time to restart it. In this case it might also need to work with the data to display the data in the space time cube again. Thus, it is prepared in a video version. This is done to give the participants the opportunity to see different views of the space-time cube to perform the tasks, to pause at a certain view and to continue to another view).

The questionnaire gives important notes first, like definitions of terms and the legend. Next the tasks came, divided into three parts: part one included questions related to the conceptualization and understanding of the movement characteristics, part two holds questions related to the usability measures (effectiveness, efficiency, and satisfaction), and the third part questions about possible improvements of the visualizations. The experiment was conducted in one room with enough computers to work individually. In the session, discussion was not allowed. In case more explanation was needed, they raised their hand and asked the evaluator.

6.3.3. Participants

A selection of users who would understand the visualizations was considered essential. For this research, GFM.2 students (graduating class) were selected. But before the evaluation session with the GFM students, a pilot test was conducted with two participants. The participants in the pilot test were students in other programs in ITC. From the pilot I understood that it is not easy for students with relatively little experience with different visualizations to understand the representations. Thus, GFM students were selected as appropriate test participants because they gained the required level of knowledge about the visualizations during their study. The number of test participants was 16. These participants were placed in four groups with the intention to encounter each group with the four visualization methods at different levels of complexity, but each group was answering questions about another aspect of movement for a particular visualization method. This was done to reduce learning effects from one visualization method to the other and also to enable the assessment of the impact on different levels of complexity.

6.3.4. Sessions

The test session was held on 18 January 2008 at 10:40. It took 1:30 hours to finish the tasks. The visualizations were briefly introduced to inform and familiarize the participants. After explaining the objectives of the research and what aspects the participants are supposed to see, sample visualizations for a single static map, multiple static maps, and the space-time cube were shown by the experimenter. A sample animation was not prepared with the assumption that it is easy for the participants to understand it, and to reduce the learning effect. After the introduction (for about 15 minutes) the users were provided with a questionnaire (see Appendix 1).

6.3.5. Results

6.3.5.1. Conceptualizing aspects of moving objects: correctness of answers

In the first part of the questionnaire, the participants were asked to answer questions about each aspect for a different visualization method, at various levels of complexity (see Table 6.1).

Table 6.1 Number of respondents in each representation for each aspect at all levels of complexity. The same respondents answered at each level of the respective method and aspect.

Aspects	Single	Multiples	Animation	STC	Total
Stops		•4	⦿4	◆4	12
Returns	•4	⦿4	◆4	◈4	16
Speed change	◆4	◈4	•4	⦿4	16
Path	⦿4	◆4	◈4	•4	16
Total	12	16	16	16	

• Group 1
⦿ Group 2
◆ Group 3
◈ Group 4

The data collected were analyzed based on the percentage of respondents who give correct answers. For the aspects which have two questions, the average percentage is taken. Figure 6.1 describes the percentage of correct answers in each representation for each aspect at different level of complexity. The result shows that for *stops* the users answered most correctly in the space-time cube at Level 1, in multiple static maps at Level 2, and in animation at Level 3. For *return*s, correctness is the highest in single static map at Levels 1 and 2 and in animation at Level 3. For *speed change* the highest is in animation at Levels 1 and 3, and in animation and the single static map at Level 2 (their difference is less than 5%). In depicting *path* users answered most correctly in the space-time cube at Level 2 and in animation at Level 3. Extracting information about *speed change* seems the most challenging task. Single static and multiple static maps have zero percent at Level 1, while the space-time cube has zero percent at all levels of complexity. The space-time cube has also zero value for *returns* at Level 1. For the percentage values, see Appendix 2.

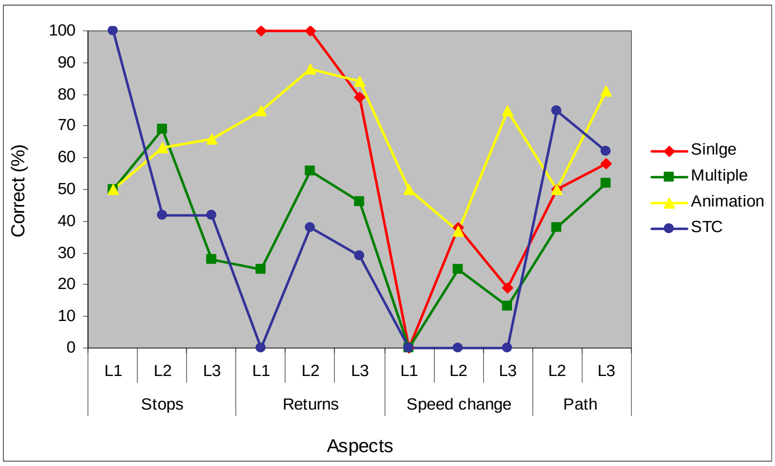


Figure 6.1 Correct answers for each aspect at different levels of complexity of the visualizations.

Impact of level of complexity and overall result

With respect to the impact of the level of complexity in the visualization, there is no uniform trend in the results (Figure 6.1). In some cases the correctness is very low at Level 1 and high at a higher level; in other cases it is the other way around. However, in some representations and for some aspects there is an indication that the complexity influences the visualization. For example, it has influences in single static map in visualizing *returns*; and in the space-time cube in visualizing *stops* and *path*.

The overall result (see Figure 6.2), which is the average of all levels for each aspect, describes that for *returns* users answer most correctly with single static maps. Both animation and the space-time cube score best (having almost equal values, difference less than 5%) for *stops*, and *path*. Related to *speed change*, the participants answered most correctly using animation. Generally, the results in this part indicate that more than 50 percent of the respondents answered correctly using the animation for all aspects, while in the other representations it varies significantly from one aspect to another.

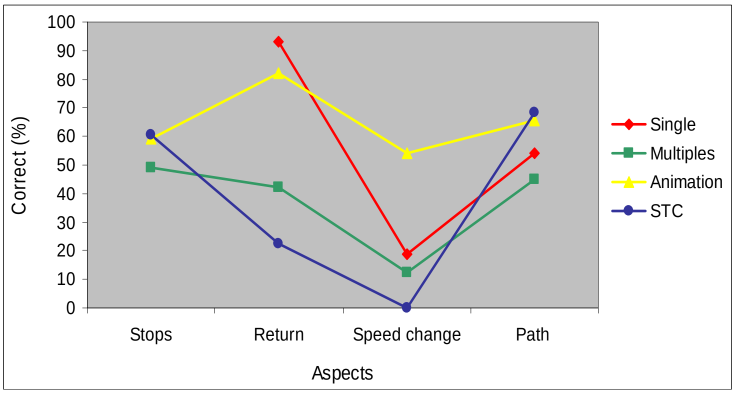


Figure 6.2 Correctness of answers in each representation for each aspect at all levels.

6.3.5.2. Usability measures

In part two of the tasks in the questionnaire, users were asked to rate the effectiveness, efficiency, and satisfaction of the visualizations for the different aspects as low, moderate, and high. The participants also rated the visualizations at different levels of complexity. Since the purpose of this research is to find which method is *most suitable* for which aspect and at what level, only *high ratings* given by the users are used to determine the suitability. Low scores would probably mean low levels of acceptance by the users, which should be avoided in applications of the visualizations. For detailed information about the ratings of respondents, see Appendix 3a.

Effectiveness

The percentage of participants who gave "high" scores for the effectiveness is shown in Figure 6.3. Animation scores the highest at Levels 1 and 3 for *stops*, at Level 2 for *returns*, and at Levels 1 and 2 for *speed change*. For the rest it shares high scores with the other methods. The space-time cube has no high values in most of the aspects. The general result (the average of all levels in each aspect) shows that animation has got the highest effectiveness for all aspects (see Appendix 3b).

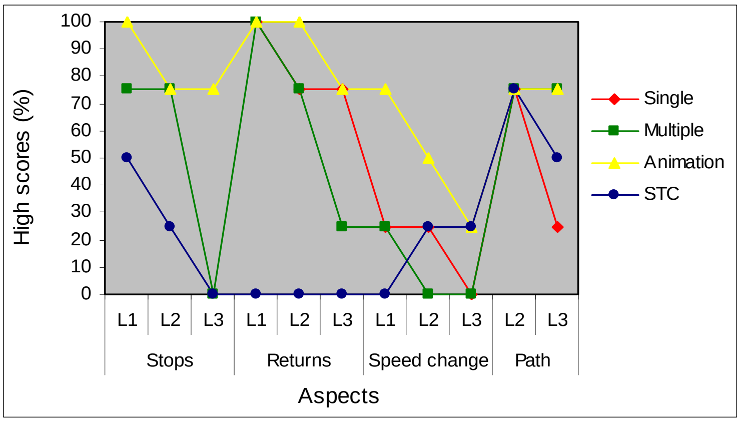


Figure 6.3 Percentage of "high" scores for the effectiveness of each representation (per aspect and level of complexity).

Efficiency

The percentage of high scores for the efficiency of the representations is shown in Figure 6.4. The scores of animation are highest at all levels for *stops*, at Levels 2 and 3 for *returns*, at Level 1 for *speed change*, and at Level 3 for *path*. It has equal efficiency scores with multiple static maps at Level 1 for *returns*, and with all the methods at Level 2 for *path*. It has no high scores for efficiency at Levels 2 and 3 for *speed change*. The space-time cube and single static maps lack more high scores than the other methods. Generally (taking the average of all levels in each aspect), animation is the most efficient method, especially for *stops*, *returns*, and *path* (see Appendix 3b).

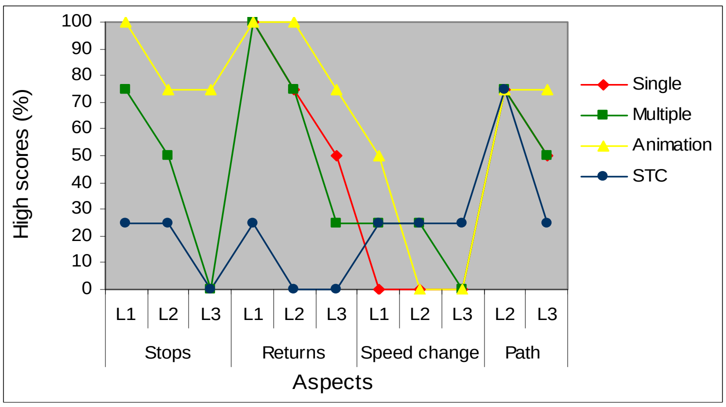


Figure 6.4 Percentage of "high" scores for the efficiency of each representation (per aspect and level of complexity).

Satisfaction

The percentage of high scores for satisfaction the visualizations give to the users is illustrated in Figure 6.5. Animation has highest scores at Levels 1 and 3 for *stops*, at all the levels for *returns* and at Level 1 for *speed change*, while it has no high scores at Levels 2 and 3 for *speed change*. The other methods lack more high scores for different aspects. Thus, animation gives greatest satisfaction to users (taking the average of all levels in each aspect), especially for *stops* and *returns* (see Appendix 3b).

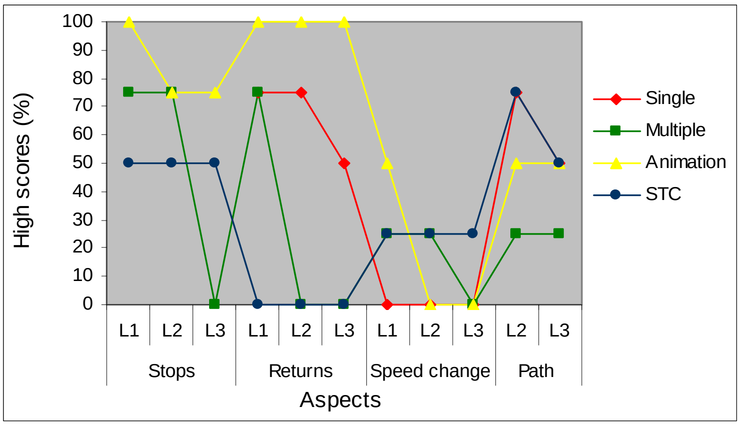


Figure 6.5 Percentage of "high" scores for the satisfaction of each representation (per aspect and level of complexity).

Impact of level of complexity and overall result

What is the impact of the level of complexity on the usability of the visualizations? The effectiveness and efficiency of the visualizations, and the satisfaction users experience at different levels of complexity are illustrated in Figure 6.6. It shows the average of the percentage of high scores for effectiveness, efficiency, and satisfaction for the representations, for each aspect at different levels of complexity. The overall usability of the representations varies with the level of complexity. In each representation, the percentage of the high scores is large at Level 1 and descends towards Level 3. However, the situation for the space-time cube for *speed change* is an exception; here it ascends from Level 1 to Level 2. This might be because users have learned from the lower level and in effect got a better impression in higher level to perceive and understand speed change in the space-time cube.

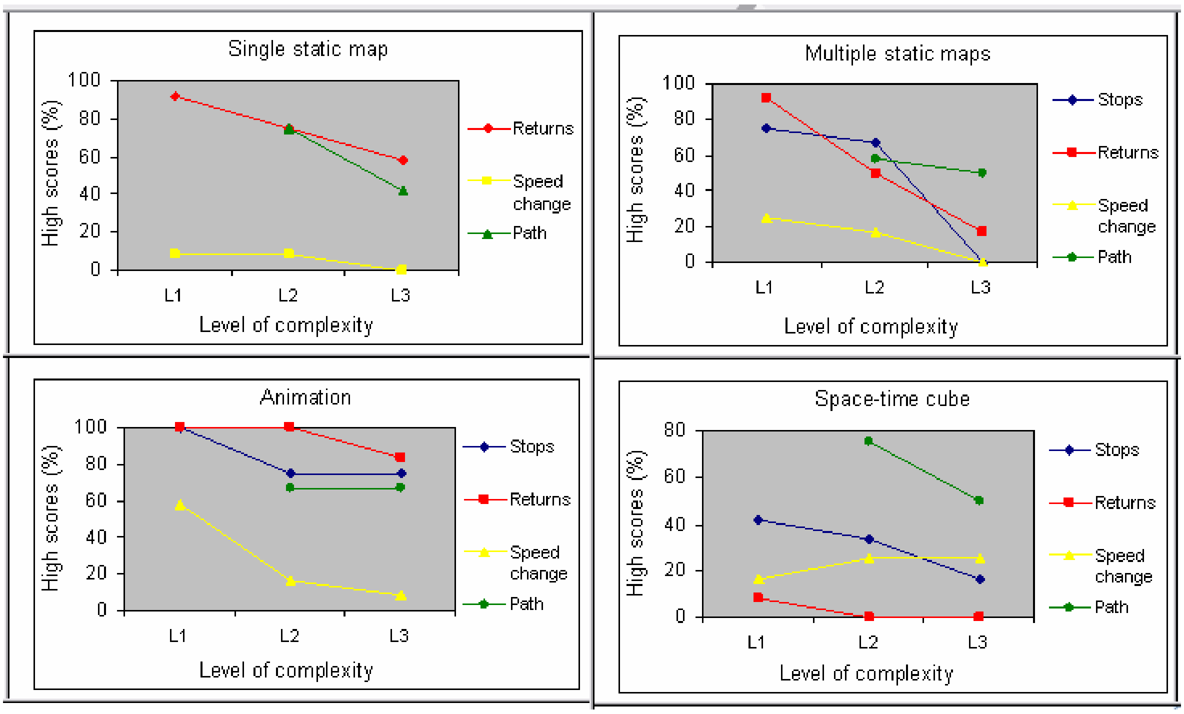


Figure 6.6 The impact of level complexity in the visualization for each aspect

The results at each level of complexity show that animation is the most usable at all levels of complexity for visualizing *stops and returns*, at Level 3 for path, and at Level 1 for *speed change*. The space-time cube is the most usable for speed change at Levels 2 and 3 and for path at Level 2.

The overall result (the average of high ratings of all levels for the usability measures: effectiveness, efficiency and satisfaction-regardless of the level of complexity) (Figure 6.7) describes that animation is the most usable method for all aspects. Another important depiction is that the usability of the space-time cube is very low for visualizing *returns* as compared to the other methods.

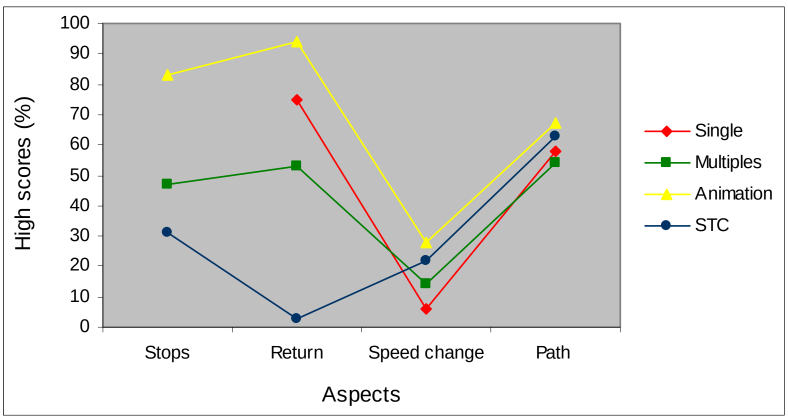


Figure 6.7 Overall usability taking the average of high scores of all levels in all usability measures (effectiveness, efficiency, and satisfaction).

6.3.5.3. Questions related to improvement

To the questions related to how the design of the visualizations should be improved, the users have given their own views for each representation as summarized below:

Single static map

- Include legend in each map, so that the user can immediately refer to the legends in stead of to another document.
- Add scale bar on the maps

Multiple static maps

- Even though the time between two frames is constant it is difficult to identify which object stops first if they stop in the same frame. Suggest to show key frames (frames in which some important events occur) and record the time it occurs on the map.
- Suggest giving symbols for stop and returns like in single static maps.
- When two paths are overlapping, put them side by side to make them visible
- Better to make the size of each snapshot larger.
- Many snap shots to follow, would help if reduced.

Animation

- Highlight the returns with a darker colour.

The space-time cube

It is better if the paths can be animated, so that the movement in time can be followed. Better to represent only one object. If more, it needs too much time to understand and visualize their relation.

6.3.6. Adjusted framework

In chapter 4, a prediction is made about the suitability of the visualizations for showing *returns*, *stops*, *speed change*, and *path* at three levels of complexity (Table 6.2). In this chapter (6.3.5), two results are observed: first results about the conceptualizing of movement characteristics (correctness), and second related to the effectiveness, efficiency, and satisfaction (usability). Therefore, for the purpose of adjusting the framework (Table 6.3), both the correctness and usability measures are considered. The percentages in correctness and usability at each level are added and their average percentage is taken. The resulting percentages are translated into three classes as shown below:

- 0-<50 = low
- 50-<75 = moderate
- 75-100 = high

Table 6.2 : Predicted suitability of the representations at three levels of complexity: from low (Level 1) to high (Level 3). The predicted suitability is represented by tints from light (low) to dark (high). Stops are not tested for single static maps. Since the questions related to path needed more than two objects, Level 1 is skipped.

	Stops			Returns			Speed change			Path	
	Complexities										
Methods	L1	L2	L3	L1	L2	L3	L1	L2	L3	L2	L3
Single	NA	NA	NA								
Multiple											
Animation											
STC											

NA: Not Applicable
L1, L2, L3=levels of complexity

Table 6.3 Adjusted framework from the results found out in 6.3.5.2

	Stops			Returns			Speed change			Path	
	Complexities										
Methods	L1	L2	L3	L1	L2	L3	L1	L2	L3	L2	L3
Single	NA	NA	NA								
Multiple											
Animation											
STC											

NA: Not Applicable
L1, L2, L3=levels of complexity

According to the adjusted framework, animation has high suitability for *stops* at Level 1, and at all levels for *returns*. For the visualization of *path* the space-time cube has high suitability at Level 1. Space time cube is the most suitable in depicting *path* might be because the main paths are accompanied by the footprints. Overall, the framework shows that animation is the most suitable method.

6.3.7. Discussion

The results found (in part 6.3.5.1 about the conceptualization (correctness) and in 6.3.5.2 about the subjective usability) are different. In conceptualization, the level of complexity has no influence on the perception and understanding of users. Sometimes, the percentage of correctness increases with level of complexity, other times it decreases. Increase might be because the users learn at the lower level and when they come to the next higher level, they perceive and understand things better. So there may be a learning effect, even though the participants saw different trajectories at each level of a representation.

The subjective suitability results clearly show that the level of complexity matters, as expected. The level of complexity had an impact on the effectiveness and efficiency of the methods, and on the satisfaction of the users.

In the two results, however, given the difference, the general situation reflects that animation is the most suitable representation because it has got overall higher scores in both results (regardless of the levels of complexity and the aspects). An important thing in animation is that it has no high scores in efficiency and satisfaction for the visualization of speed change at Levels 2 and 3 (even in the correctness and effectiveness measures, its value for *speed change* is the lowest of all other aspects). This implies that perceiving change in speed in animation is difficult at high complexities.

For the purpose of adjusting the framework both the results in the correctness and the subjective usability are considered. Thus, according to the framework, animation is the most suitable representation, except that the space time cube is more suitable for showing *path* at Level 2. That animation is the most suitable might be because it shows real dynamics and that makes it easier for users to perceive and understand the aspects.

The predicted frame work and the adjusted one have some similarities and differences. The two frameworks are similar for multiple static maps for all aspects except for *path* at Level 2. That is, the prediction almost fits the results found after assessment. There are bigger differences for the space-time cube than for the other representations. The suitability of the space-time cube is lower than expected. This might be because of two reasons: 1) the space-time cube requires higher expertise than the other representations. 2) The space-time cube perhaps needs the real interactive interface. If we see the most suitable representation (animation), the predicted and the resulting suitability are similar for visualizing *stops* at Levels 1 and 3, *returns* at Levels 1 and 2, and *path* at Level 3. In the rest they show differences. Generally, the two frameworks show that animation is the most suitable representation.

6.4. Summary

This chapter described the result of the test undertaken to assess the suitability of the representation methods. The test was undertaken using the questionnaire method with 16 participants. The users were exposed to give objective and subjective responses. For the objective questions, the percentages of the correct answers were analyzed. In the subjective tasks, there are two types of tasks. One is related to the usability measures (effectiveness, efficiency, and satisfaction) where users rated the visualizations (as low, moderate, and high) and the second is about how the visualizations should be improved. In the usability measures the high ratings are taken to measure usability of the methods. The overall results show that animation is the optimal representation for most aspects of moving objects (walking people). It seems from the results that users encountered problems in understanding the space-time cube. Finally, the framework which was predicted in chapter 4 is adjusted based on the objective and subjective results found in the tests. Regarding the comments given by the participants as to how the visualizations should be improved, they can be used for other related works in the future.

7. Conclusion and recommendations

7.1. Introduction

This chapter gives a conclusion about what is investigated in this thesis and recommendations for further work in the future. It starts by giving a summary of the work by providing answers to each research question. It next gives conclusive remarks about the whole work in the research. It closes by giving recommendations for works that could be conducted in the future.

7.2. Conclusion

7.2.1. Summary of answers to the research questions

I will summarize the research work by addressing each research question

1. *What are the different types of movements of objects?*

The concepts of change, movement and moving objects have been explained in chapter 2. The movement behaviours of objects might be determined by the properties of space, properties of time, properties and activities of the moving object, and various spatial, temporal, and spatiotemporal phenomena. Movement behaviours are classified as along a trajectory and pure internal movements. Trajectory movement is usually conceived as movement along a linear path. Movements along a trajectory might exhibit different properties (connected/not connected, have shape, branched/not branched, directed/not directed). Internal movement is described by movements like rotations of disks and spheres as well as the motion of fluids in a closed system. In this research, the trajectory movement is the focus. Trajectory movements do have some characteristics which can be categorized as individual and collective movement behaviours. This research is interested in the individual movement behaviours of moving objects (they define the movement behaviours of individual moving objects along the trajectory).

2. *What are the aspects of moving objects that can be visualized in static maps, animation, and the space-time cube?*

In this research the interest has been in movement characteristics of moving individual objects. Chapter 2 and 3 are dedicated to answer this research question. In chapter 2 some movement characteristics of individual moving objects have been identified: stops, returns, speed change, the path of the movement (location), direction of movement, and turn (change in direction). From these aspects some of them are taken to assess the optimal representation: stops, returns, speed change, and path. These aspects are taken because of two reasons: 1) time constraint; and 2) these aspects are thought to be strong points to make the assessment. These are strong points because if we want to represent these aspects, they may not be equally well represented in animation and in the other representations, or it may be difficult to represent them in either of these representations. Chapter three explains about the principles of cartographic visualization (with special emphasis to static maps, animation, and the space-time cube in the representation of the dynamics of the world). It explains how the dynamic world (e.g., trajectories of moving objects) can be represented in the cartographic representations.

3. *What are the strengths and weaknesses of static maps, animation, and the space-time cube so far investigated in representing dynamic phenomena.*
4. *What are the spatiotemporal questions users can in theory ask about moving objects?*

In chapter 4, the strengths and weaknesses of static maps, animation, and the space-time cube have been discussed. There are various strengths and weaknesses of these representations attested by different researchers. We can see some of them here. Static maps are described to be highly influenced by events for a long period of time. Information extraction is difficult in animation and the space-time cube when the complexity of the phenomena or process increases. There are also some contradictions between results from different researches. The strengths and weaknesses of each representation methods made clear in different researches seem to be affected by the purpose of the researches and the nature of the data represented. The fourth research question is answered in chapter 2, where the movement characteristics of moving objects are identified; in chapter 3, where how cartographic visualizations represent dynamics is discussed; in chapter 4, where some user questions related to the represented aspects are raised; and in chapter 5 in trying to design the visualizations based on the use context in mind. A framework as to the suitability of each representation has also been developed. In the frame work, the prediction is made by explaining/justifying expected suitability in terms of low, moderate, or high for different aspects at different levels of complexity. This framework is the outcome of the whole literature review made in chapters 2, 3 and 4, having in mind what users can, in theory, ask about moving objects.

5. *How can the aspects of moving objects be represented in single static map, multiple static maps, animation, and the space-time cube?*

In chapter 5 the representations are designed in such a way that they represented the aspects of the moving objects (movement characteristics) investigated (stops, returns, speed change, and path). In single static map some graphic variables (*location* and *colour*) are used to represent the temporal and thematic components of the maps respectively. The geographic component is also represented by location. In multiple static maps, location for the geographic and colour for the thematic components are used. The temporal component is represented by the sequence of snapshots having the same time interval. In animation the geographic and thematic components are represented by location and colour, respectively, while the temporal component is represented by the dynamic visual variables (moment, order, duration, and frequency). In the space-time cube the geographic, thematic, and temporal components are represented by location, colour, and the third dimension of the cube, respectively. For details about how each aspect is represented in the visualizations see chapter 5. The outcome is the four representation methods: single static map, multiple static maps, animation, and the space-time cube.

6. *How can the suitability of animation, static maps, and the space-time cube be assessed to find the optimal one for moving objects?*
7. *Which representation method is optimal in terms of visualizing moving objects (and their movement characteristics) at different levels of complexity?*

In order to investigate which representation would be the optimal for visualizing moving objects (for an application involving walking people), a user test is undertaken (dealt in chapter 6). A questionnaire method is used to assess the effectiveness and efficiency of the representations, and the satisfaction of the users in the representations. First pilot test was conducted to test the questionnaire and to determine on the users. In the actual user test session, users were given a refreshment description of the representations (by preparing sample visualizations). Then the test was held in a closed session where users had no opportunity to have discussions to avoid learning from each other. After the user test is conducted successfully, the results were analyzed. In the results two concepts are found: one that affirms level of complexity doesn't have influence on the visualization (in the correctness of answers), and another that upholds level of complexity exerts influence (in the subjective usability). Given these differences, animation has been found to be the optimal representation method for most of the aspects of moving objects (walking people). After making the analysis in both the correctness of answers and subjective usability measures (effectiveness, efficiency, and satisfaction) the framework of predictions about the suitability of each representation is adjusted. The outcome in chapter 6 is therefore an adjusted framework of suitability from which we can read which method is an optimal one for different aspects of moving objects at different levels of complexity.

7.2.2. Concluding remarks

The main goal of this research is to find the optimal visualization for moving objects (for an application involving walking people). Moving objects exhibit various behaviours, among which their movement behaviour was the concern of this research. This research was about investigating how users can understand and acquire geospatial knowledge about moving people from cartographic representations (static maps, animation, and the space-time cube). In the course of investigating the optimal representation, there is the issue of comparability. Many researches make comparisons of these representations to find which one is more effective for a particular use. Some contend that comparability should be taken in to account so as to come to the deduction that one is more effective than the other.

In this research comparability has not been an important issue. Finding the optimal representation is made without the demand that all the representations should be exactly the same in design. Except for the stops in single static maps, however, the information that could be extracted is comparable in each map type, while leaving the potential power of each representation unaffected. A minimum interactive environment is given to animation and the video version of the space-time cube to enable the users to stop, pause, and rewind. So, when trying to find the optimal representation (for example, for moving objects), the possible potential of the representations is maintained. In effect, in this research, every possibility to exploit the potential of the representations is undertaken. For example, animation is accompanied by growing path; and the space-time cube is prepared with foot prints, grids for space and time indication, and it is also provided to users as a video to enable the users to see different views. Thus, whether these representations are comparable with the static maps is not of prime importance.

After making the assessments in this research, over all, it is found out that animation is the optimal representation for most aspects moving objects (for walking people application). It has been easier for users of animation to conceive and understand the movement characteristics (stops, returns, speed change, and path) than other representations. It might be because dynamics can more easily and lively be seen in animation than in the other representations. That is, the real dynamics of the objects can be seen (represented) in animation. The result of this research can also be used for other applications, such as the visualization of moving cars for visualizing traffic situations, visualizing clouds for meteorological application, visualizing migration of birds (without considering altitude), and hurricanes to visualize their movement (in which speed, direction change, etc can be seen.

7.3. Recommendations

1. *Other aspects:* This research focused only on four aspects (stops, returns, speed change, path) of individual moving objects. There are other aspects, such as direction, pattern, trend, etc which are not investigated in this research. Other researches can undertake studies on the effectiveness of single static maps, animation, and the space-time cube in the visualization of these aspects. Moreover, this research doesn't include in the scope issues like how fast an object moves in real world, which might be needed for certain applications. Future researches can work on these issues; especially in animation to give users the ability to determine the speed of an object in the real world.
2. *Other applications other than moving objects:* There are various dynamic geospatial phenomena, such as water flow, agricultural expansion, urban growth, etc which can be represented by static maps, animation, and the space-time cube. Since these dynamic phenomena have different behaviours from moving point objects, studying these phenomena might give users to select the optima representation for a particular use in these applications
3. *Group of moving objects:* another potential area of research that would be recommended is to investigate movement behaviour of groups of moving objects. In this research only the movement behaviour of individual moving objects is investigated and represented in the visualizations. But, it will be interesting to see some behaviour that would be exhibited by groups of moving objects. For example, birds have group behaviour. Further more, their movement includes change in altitude. It would also be nice to see how the time can be represented in addition to the three geographic dimensions of their movement.
4. *The space-time cube*: In the space-time cube, users have asked why the paths of movement are not animated. They want to see the movement of the paths growing up wards with time to see when certain events occur, and the foot prints to see where the corresponding events occurs. The space-time cube might become more an optimal representation if animation is added to it.
5. *Gender difference, and level of expertise and number of respondents:*
    - *Gender difference:* in this research assessing gender difference in the perception and understanding of the visualizations was not considered. For further work, I recommend to make distinctions between gender groups and assess how the perception and understanding of users in different gender groups differs in visualization. Their difference might even be assessed for different aspects. The ability of males might be different from the ability of females to see the aspects.
    - *Level of expertise and number of respondents*: The users involved in the test are though to have the same level of expertise in the representations. The problem is that not all the representations might need equal level of expertise. For example, the space-time cube might need higher levels of expertise than the other representations. It is recommended to vary the user groups in level of expertise. As regards the number of users, in this research 16 participants were used. There might be more precise results if larger number of participants can be used.

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URL

URL 1: http://usability.ru/sources/iso9241-11.htm

Appendix 1: Questionnaire

Testing the usability of representations of moving point objects

Important notes

1 The aim of this questionnaire is to test the suitability of different representation methods for moving point objects (walking people). Testing the abilities of the *participants* is **not** the aim.

2 You will be provided with different types of representations: single static map, multiple static maps, animation and Space Time Cube, each at different levels of complexity (see below):

Level	Number of moving objects
1	1
2	2
3	>2

3 The tasks consist of three parts:

1. Using the representations to find answers to questions about different aspects (e.g. number of stops of a moving object, speed increases, etc.).
2. Based on your experiences with the visualizations in task 1, rate the visualizations.
3. Suggest improvements to the visualizations.

4 In part 1, you are asked to answer questions about one or two different aspects for each visualization method, at all three levels of complexity.

5 Below you will find some definitions. These definitions explain some of the concepts that are used in the tasks. It is advised to read these definitions before doing the test. If necessary, you can refer back to them later as well.

Definition of terms

- ***Speed of movement:*** distance travelled per time unit. There will only be questions about increase in speed below, not about constant speed or decrease in speed.
- ***Return****:* Moving back along the same path (or along a previously visited path).
- ***Stop:*** Stay for some time at one location along the path.
- ***Path:*** Route of the movement defined in terms of locations hit over time from start to end.

6 You will also see a legend below. The same legend will be used for all the visualizations, but it is not displayed on the screen together with the visualizations. You can, however, always refer to the legend below during the tests.

Legend

▬ Route of the movement (in different colours)

All point symbols along the path (listed below) indicate the location of the object at 15 minutes interval (from the start up to the end).

☆ Start

▷ Location and direction of movement

◎▷ Return

□ End

ST Start Time

Note: The grey lines on the map (district boundaries and main roads) are not included in the legend.

Tasks

Part 1: Questions related to conceptualizing the aspects of moving objects represented

1.1 Please indicate below how many **returns** the objects listed make.

Single Static Map	Moving objects	Number of returns
Level 1	Green	
Level 2	Blue	
	Red	
Level 3	Yellow	
	Green	
	Blue	
	Red	

1.2. Which object makes a **return** first and which last?
(Put a tick mark on your choice)

Single Static Maps	Moving objects	First	Last
Level 2	Blue		
	Red		
	Yellow		
	Green		
	Blue		
	Red		

1.3. Please indicate below how many **stops** the objects listed make.

Multiple Static Maps	Moving objects	Number of stops
Level 1	Green	
Level 2	Blue	
	Red	
Level 3	Yellow	
	Green	
	Blue	
	Red	

1.4. Which object makes a **stop** first and which last? (Put a tick mark on your choice)

Multiple Static Maps	Moving objects	First	Last
Level 2	Blue		
	Red		
	Yellow		
	Green		
	Blue		
	Red		

1.5. Please indicate below how many times the **speed increases** for the objects listed.

Animation	Moving objects	Number of speed increases
Level 1	Green	
Level 2	Blue	
	Red	
Level 3	Yellow	
	Green	
	Blue	
	Red	

1.6. The objects below hit **the same location**. Mark the column with the correct answer (a), (b) or (c) in the table below.

Meanings are:

(a) at the same time

(b) the second object hits or passes the common location earlier

(c) the second object hits or passes the common location later

The space-time cube	Moving objects	(a)	(b)	(c)
Level 2	Blue and Red			
Level 3	Yellow and Blue			
	Green and Blue			
	Green and Red			
	Blue and Red			

1.7. Below you see pairs of objects listed. Indicate for each pair which object is the **first one to complete its path**.

The space-time cube	Moving objects	Colour of object that finishes its path first
Level 2	Blue and Red	
Level 3	Yellow and Green	
	Green and Blue	
	Green and Red	

Part 2: Questions related to measures of usability

Now that you have gained some experience with different visualizations - in which data are represented at different levels of complexity - you are requested to make judgments about the usability of the different representations.

Three aspects of usability are used in the table below:

- ***Effectiveness:*** Whether or not the representation enables you to execute the tasks (answer the questions) correctly.
- ***Efficiency:*** Whether or not the representation enables you to execute the tasks (answer the questions) easily (with minimum efforts) and quickly (with minimum time).
- ***Satisfaction:*** How acceptable is the representation to you in terms of representing moving objects (walking people)?

How do you rate the visualization that you have used before for the aspects listed below in the table? Select one answer in every row.

The meaning of the codes is as follows:

L low
M moderate
H high

Returns in:	**Level**	**Effectiveness**			**Efficiency**			**Satisfaction**		
		L	M	H	L	M	H	L	M	H
Single Static Map	1									
	2									
	3									

Stops in:	**Level**	**Effectiveness**			**Efficiency**			**Satisfaction**		
		L	M	H	L	M	H	L	M	H
Multiple Static Maps	1									
	2									
	3									

Speed increase in:	**Level**	**Effectiveness**			**Efficiency**			**Satisfaction**		
		L	M	H	L	M	H	L	M	H
Animation	1									
	2									
	3									

Path and finish in:	**Level**	**Effectiveness**			**Efficiency**			**Satisfaction**		
		L	M	H	L	M	H	L	M	H
The space-time cube	2									
	3									

Note: This questionnaire is for group one. For the rest of the groups the representation methods and the aspects change for the same questions.

Appendix 2: Percentage of correct answers

	Single			**Multiple**			**Animation**			**STC**		
	Level of complexity											
Aspects	L1	L2	L3	L1	L2	L3	L1	L2	L3	L1	L2	L3
Stops				50	69	28	50	63	66	100	42	42
Returns	100	100	79	25	56	46	75	88	84	0	38	29
Speed increase	0	38	19	0	25	13	50	37	75	0	0	0
Path & finish		50	58		38	52		50	81		75	62

Appendix 3a: Ratings for effectiveness, efficiency, and satisfaction

Effectiveness				**Efficiency**				**Satisfaction**			
Stops				**Stops**				**Stops**			
Multiple Static Maps				Multiple Static Maps				Multiple Static Maps			
	L	M	H		L	M	H		L	M	H
L1	0	25	75	L1	0	25	75	L1	0	25	75
L2	0	25	75	L2	0	50	50	L2	0	25	75
L3	25	75	0	L3	25	75	0	L3	25	75	0
Animation				Animation				Animation			
	L	M	H		L	M	H		L	M	H
L1	0	0	100	L1	0	0	100	L1	0	0	100
L2	0	25	75	L2	0	25	75	L2	0	25	75
L3	0	25	75	L3	0	25	75	L3	0	25	75
The space-time cube				The space-time cube				The space-time cube			
	L	M	H		L	M	H		L	M	H
L1	25	25	50	L1	50	25	25	L1	0	50	50
L2	25	50	25	L2	50	25	25	L2	0	50	50
L3	25	75	0	L3	75	25	0	L3	25	25	50
Returns				**Returns**				**Returns**			
Single Static Map				Single Static Map				Single Static Map			
	L	M	H		L	M	H		L	M	H
L1	0	0	100	L1	0	0	100	L1	0	25	75
L2	0	25	75	L2	0	25	75	L2	0	25	75
L3	0	25	75	L3	0	50	50	L3	0	50	50
Multiple Static Maps				Multiple Static Maps				Multiple Static Maps			
	L	M	H		L	M	H		L	M	H
L1	0	0	100	L1	0	0	100	L1	0	25	75

L2	0	25	75
L3	25	50	25
Animation			
	L	M	H
L1	0	0	100
L2	0	0	100
L3	0	25	75
The space-time cube			
	L	M	H
L1	50	50	0
L2	75	25	0
L3	75	25	0
Speed change			
Single Static Map			
	L	M	H
L1	25	50	25
L2	25	50	25
L3	50	50	0
Multiple Static Maps			
	L	M	H
L1	0	75	25
L2	25	75	0
L3	50	50	0
Animation			
	L	M	H
L1	0	25	75
L2	0	50	50
L3	25	50	25
The space-time cube			
	L	M	H
L1	25	75	0
L2	50	25	25
L3	50	25	25
Path			
Single Static Map			
	L	M	H
L2	0	25	75
L3	0	75	25
Multiple Static Maps			
	L	M	H
L2	0	25	75
L3	0	25	75

L2	0	25	75
L3	0	75	25
Animation			
	L	M	H
L1	0	0	100
L2	0	0	100
L3	0	25	75
The space-time cube			
	L	M	H
L1	50	25	25
L2	75	25	0
L3	75	25	0
Speed change			
Single Static Map			
	L	M	H
L1	50	50	0
L2	50	50	0
L3	50	50	0
Multiple Static Maps			
	L	M	H
L1	0	75	25
L2	0	75	25
L3	25	75	0
Animation			
	L	M	H
L1	25	25	2
L2	25	75	0
L3	50	50	0
The space-time cube			
	L	M	H
L1	50	25	25
L2	50	25	25
L3	50	25	25
Path			
Single Static Map			
	L	M	H
L2	0	25	75
L3	0	50	50
Multiple Static Maps			
	L	M	H
L2	0	25	75
L3	25	25	50

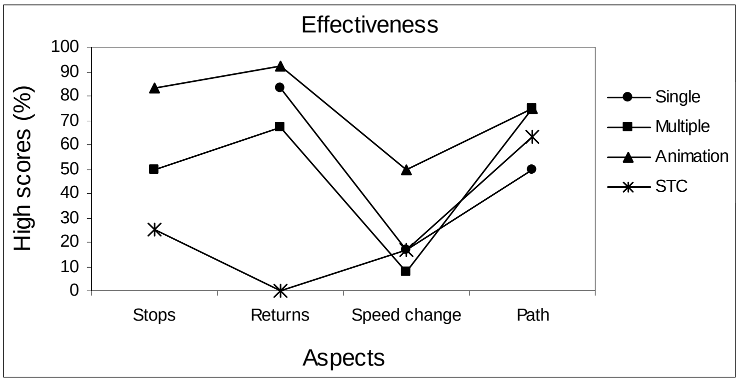
L2	0	100	0
L3	0	100	0
Animation			
	L	M	H
L1	0	0	100
L2	0	0	100
L3	0	0	100
The space-time cube			
	L	M	H
L1	75	25	0
L2	75	25	0
L3	75	25	0
Speed change			
Single Static Map			
	L	M	H
L1	25	75	0
L2	25	75	0
L3	50	50	0
Multiple Static Maps			
	L	M	H
L1	0	75	25
L2	25	50	25
L3	50	50	0
Animation			
	L	M	H
L1	0	50	50
L2	0	100	0
L3	0	100	0
The space-time cube			
	L	M	H
L1	50	25	25
L2	75	0	25
L3	75	0	25
Path			
Single Static Map			
	L	M	H
L2	0	25	75
L3	0	50	50
Multiple Static Maps			
	L	M	H
L2	0	75	25
L3	25	50	25

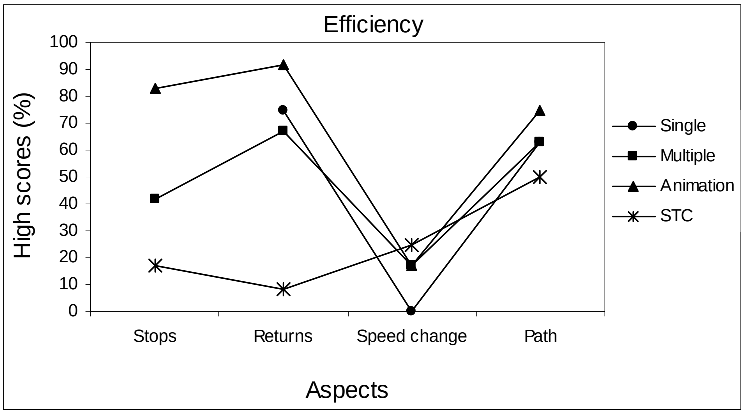
Animation			
	L	M	H
L2	0	25	75
L3	0	25	75
The space-time cube			
	L	M	H
L2		25	75
L3		50	50

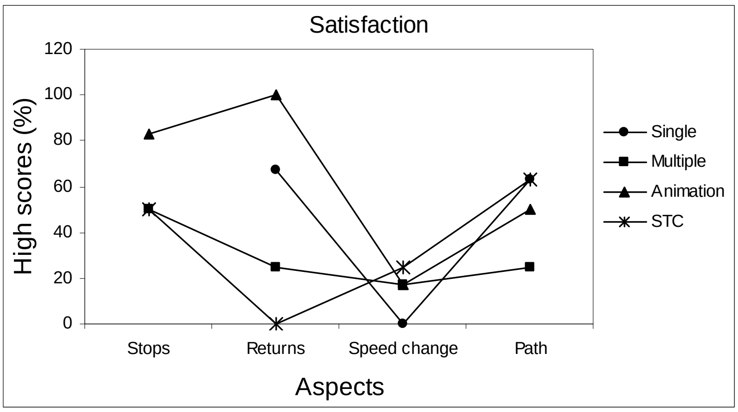
Animation			
	L	M	H
L2	0	25	75
L3	0	25	75
The space-time cube			
	L	M	H
L2	25	0	75
L3	25	25	50

Animation			
	L	M	H
L2	0	50	50
L3	0	50	50
The space-time cube			
	L	M	H
L2	25	0	75
L3	25	25	50

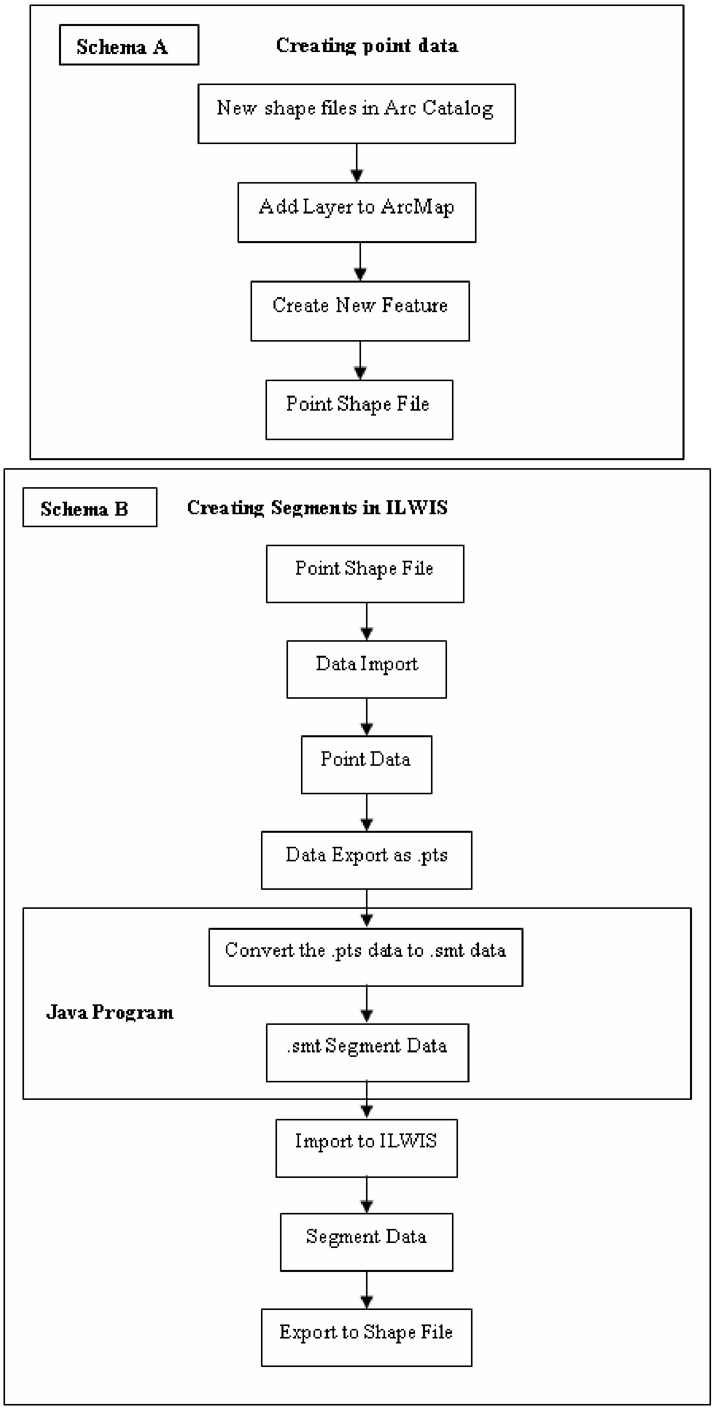
Appendix 3b: Over all results for efficiency, effectiveness and satisfaction

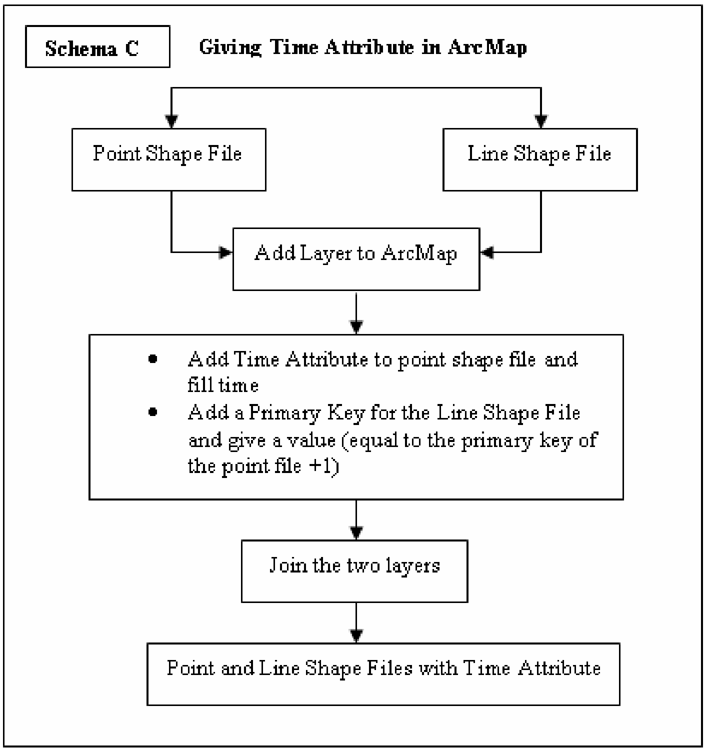






Appendix 4: Data development procedure




Schema C
Giving Time Attribute in ArcMap
Point Shape File
Line Shape File
Add Layer to ArcMap
Add Time Attribute to point shape file and fill time
Add a Primary Key for the Line Shape File and give a value (equal to the primary key of the point file +1)
Join the two layers
Point and Line Shape Files with Time Attribute