Visualisation of spatio-temporal patterns in public transport data

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by

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To

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Abstract

Public transportation systems (PTS) offer a choice of movement to people. The operation of the PTS depends on the demand created by people. In turn, the PTS also affects the activity system of those people. The operators and policy makers conduct surveys to measure the demand, in terms of patronage (number of people travelling in the bus or train), to create new plans or policies for the PTS. The demand for a transportation system depends on the activity system of the network, fare structure, network operation layout, type of PTS (different types of buses or trains), location of access points (bus stops, train stations) and their accessibility, type of service offered (point-to-point, zigzag, round trip) and the willingness of people to use PTS. As a result people travelling through the PTS network at different times form a different kind of patterns. For effective planning and management of the PTS, these patterns that are distributed in space and time have to be understood.

In this research work, geovisualization techniques are used to explore the spatio-temporal patterns formed by people travelling through the PTS. The spatio-temporal reasoning required by PTS operators/policy makers to extract relevant patterns from the public transport system data (comprising of its spatial network, timetable and patronage) is studied. The resulting questions are related to basic visual tasks like locate, identify, associate and compare in order to facilitate the reasoning. These are incorporated in a set of visual tools that are part of a visual environment based on time geography's space-time-cube and include multiple dynamically linked views that offer an alternative perspective on the data and patterns extracted. Finally, a visual environment that incorporates the visual tools is presented. A preliminary usability test for the visual environment is conducted with the PTS experts and its results are discussed.

Keywords

Geovisualisation, Public transport system analysis, Spatio-temporal reasoning, Spatio-temporal patterns, Visual tasks, Visualisation environment, Multiple views, Dynamic queries, Usability evaluation
Abstract
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Chapter 1

Introduction

1.1 Problem description

Public transportation system (PTS) operates through a fixed network and adheres to schedule. Performance of the PTS is measured by carrying out periodic survey on parameters like number of people travelling in the bus and schedule maintenance. The data from such survey is called public transport data. The public transport data shows the spatial and temporal characteristics of the PTS. The nature of public transport data is complex. As a result, it is difficult to get insight into spatial and temporal characteristics of the PTS. Visualising such a public transport data may help in getting some insight into them and to answer some domain specific questions. Currently the transport data is modelled as network models in a geographical information system environment. This helps in modelling the spatial properties of the transport data along with its characteristics as attributes. However, to get insight into complex transport data, both temporal and spatial aspect present in the transport data along with the attribute information should be modelled. Space-Time Cube (STC) as conceptualised by [Hägerstrand, 1970] can be used to model the transport data as space-time paths which can implicitly represent the collective activity of people travelling from one destination to another. A space-time path (trajectory) can represent the temporal and spatial aspects in the transport data in three dimensional space with location (x,y) and time (t). The trajectories in space-time cube are modelled in multiple granularity as geospatial lifelines in [Hornsby and Egenhofer, 2002]. Further, the structure of space-time environment is modelled analytically to facilitate applications such as wayfinding in [Hendricks et al., 2003]. However our requirement does not stop in modelling the space-time environment but to get insight into the data represented in them. The problem is to identify visual tasks that help in getting insight into the transport data; and finding appropriate functions and tools to execute those tasks.
1.2 Research framework introduction

This topic ‘Visualisation of spatio-temporal patterns in public transport data’ can be looked up from two perspectives: transportation and geoinformation science. Transportation domain involves planning, monitoring, management and evaluation of different modes of transit and enabling infrastructure such as road network, traffic signals. Transport geography can be defined as ‘sub-discipline of geography concerned about movements of freight, people and information along with their physical and transactional context. It tries to link spatial constraints and attributes with the origin, the destination, the extent, the nature and the purpose of movements’ [Rodrigue et al., 2004].

Geo-information science (GIScience) concerns the development of theory and methods for capturing, exploring, processing, analysing and disseminating geographic information. Geovisualization is a part of GIScience that uses the visualisation techniques to manage, explore and present geographic information. Geovisualization stems from the field of cartography among others. Geovisualization is defined as ‘the use of concrete visual representations – whether on paper or through computer displays or other media – to make spatial contexts and problem visible, so as to engage the most powerful of human information processing abilities, those associated with vision’ [Maceachren et al., 1999].

In the broad sense, the research attempts to combine transportation and geovisualization perspectives to visually explore the transport data to get insight into them.

1.3 Research formulation

The applications in the transportation domain as stated above may require to apply spatial constraints in attempting to solve transportation-related problems. The part of GIScience that addresses this issue of spatial component in the transportation domain is Geographic Information Science for Transportation (GISci-T). GISci-T is defined as ‘a subset of GIScience that develops theory and methods for capturing, processing, analysing, and disseminating digital transportation information’ [Miller and Shaw, 2001, page 6]. The development of GISci-T is identified in three stages [Goodchild, 2000]: map view, navigation view and behaviour view. The map view with static perspective relates to the application of inventory and description in transportation. The navigation view address the network connectivity and topology with the storage of time-dependent attributes. The behaviour view attempts to deal with dynamic transportation objects and events such as transport systems, people, activity pattern occurring within static transportation space. Each of these views has potential challenges or problems to be solved [Goodchild, 2000].

The behaviour view in GISci-T has evolved from the work of people like Hägerstrand [Goodchild, 2000]. The concept of representing the moving objects in time and hence understand the behaviour of the moving objects has evolved from time-geography. This concept has been applied by human geographers to model the behaviour of people and understand the activity pattern in space and time. The time-geography concept was also applied in human geography to
get insight into socio-economic condition, migration and urban growth, political geography and other people-related activities [Pred, 1977].

In this decade, the transport geographers are interested in considering the activity pattern and other social science factors into transportation planning and analysis [Fox, 1995]. Currently, simulation models and statistical approach are used to model the transportation systems (inclusive of transport systems, people travel in them, traffic flows) and results are sometimes linked spatially in Geographic Information Systems for Transportation (GIS-T). An opportunity to tie-up the time-geography concept and transport geography will lead to model the behaviour of moving objects like transport systems, people in transport system, traffic flows and get insight into them.

It is interesting how GIScience can help in realising this opportunity. To what effect geovisualization can provide methods and tools to model transportation systems, in this case, Public Transport System (PTS) and to explore to get insight into them? is the basic motivation for formulating this research work.

1.4 Research Objectives

The following research objectives are set to solve the above problem:

• To study the characteristics of the public transport data.
• To identify visual tasks to explore and get insight into the large transport dataset.
• To define functions to perform the visual tasks.
• To identify the support for the above functions in space-time cube.
• To identify additional tools to enhance the visual tasks to get insight into the large transport dataset.
• To develop the prototype of the tools and evaluate them.

1.5 Research questions

The following are research questions posed to achieve the above objectives:

1. What are the characteristics of the transport data?
2. What are the visual tasks that are required to explore and get insight into the large transport dataset?
3. What are the functions required to perform visual tasks in order to discover the spatial and temporal patterns in the large transport dataset?
4. What are additional tools required to enhance the visual exploration to get insight into the large transport dataset?
5. What could be the role of STC to provide support for the above functions?
6. How to evaluate the applicability of this visualisation environment?
1.6 Approach

The research will analyse the public transport data, at hand, to understand its characteristics. Spatio-temporal reasoning required by the public transport operators/policy makers to get insight into the public transport data will be studied through discussion with transportation domain people. Based on spatio-temporal reasoning, visual task required to explore the public transport data will be identified. The visual tools and functions required to accomplish the visual task will be identified and developed. A visualisation environment will be created by incorporating the visual tools and functions. A preliminary usability test for the visual environment will be conducted with the PTS experts and its results will be discussed. The figure 1.1 shows this research approach.

1.7 Thesis structure

Figure 1.2 shows the structure of the thesis with emphasis on the contents of the individual chapters. Part I on public transportation system, starts with chapter 2 about the background on the public transportation system. This chapter discusses about the public transport system analysis and factors influencing the PTS. Chapter 3 focuses on the characteristics of public transport data and spatio-temporal modelling of the PTS data. Part II on visualisation, starts with chapter 4 about the background on the visualisation techniques. Part III on spatio-temporal pattern visualisation, starts with chapter 5 about the visualisation environment. This chapter focuses on the identification of
visual tasks. It continues to identify and develop the visual representations. Chapter 6 discusses about the design and implementation of the prototype of this visualisation environment. Chapter 7 focuses on the usability evaluation of this visualisation environment. Chapter 8 concludes this thesis.
1.7. Thesis structure
Part I

Public transportation systems
Chapter 2

Public transportation systems

2.1 Ponder space

This part provides basic introduction to the public transportation system and its analysis. The public bus transportation is taken as a use case of public transportation system. The characteristics of public transportation system analysis pertaining to the use case is discussed in this chapter.

2.2 Public transportation systems

Public transportation system (PTS) offers a choice of movement to the community. For a region, there can be more than one choice within PTS such as trains, buses, trams, metros, air flights, ships. The aim of the PTS is to cater the common transit interests effectively and efficiently. Effectively, in the sense, planning the services between optimal origins and destinations at appropriate schedule catering common needs. Efficiently, in the sense, operating the service as planned, using the resources optimally, catering the needs of the common and finally making profit or at least not making loss.

The planning of PTS for a region takes into consideration, the demand and the resources available in the region. The demand is an important characteristic as it determines the need for the service. The demand varies with space and time. The demand has a direct relationship with the activity pattern of the people. People going to work, children going to school in the morning hours increase the demand. Also the demand increases, when people retreat to their home from their workplace in the evening hours. Rest of the day and on weekends, demand is fluctuating and mostly tends to be less. This general activity pattern of the people has a direct effect on the planning of service giving rise to peak hour and off-peak hour services.

People travelling in the PTS network at different time form a different kind of patterns depending on the socio-economic structure of the region, the accessibility to the PTS and geometry of the PTS network. The phenomena is highly dynamic as it is difficult to estimate the activity pattern of every individual travelling through the PTS. Apart from activity of the people, the other factors which affect the demand are fare structure, network operation layout, type of
PTS (different types of bus such as mini-bus, bi-articulated bus), location of access points (bus station, train station) and their accessibility, type of service offered (point-to-point, zig-zag, round trip) and the willingness of the people to use PTS.

The resource to the PTS is supplied by analysing the factors such as demand, socio-economic system, demography. The public transportation system analysis is considered a specialisation within the transportation domain that concentrates on the analysis of demand and chartering the required supply. The following section will provide insight into the public transportation system analysis and system components involved in such analysis.

2.3 Public transportation systems analysis

The challenge of transportation systems analysis is

‘to intervene, delicately and deliberately, in the complex fabric of a society to use transport effectively, in coordination with other public and private actions, to achieve the goals of the society’ [Manheim, 1979].

This analysis is performed to understand the existing demand in the region through various methodologies for different kind of transportation system and supporting infrastructure. The methodologies varies from computer based numerical and graphical simulation models, to simple algebraic models, to informal models based on experience. Hence the aim of the transportation system analysis is to focus on the interaction between the transportation system and activity systems of a region and understand the interaction patterns for planning or policy making purposes. There are two vague terms in this case: transportation system and activity systems of a region and definition of these terms are far beyond the scope of this research. However, this research concentrates only on the public transportation system and hence the analysis that are discussed here will focus on them. The research considers that the effect of activity system on the PTS is represented through the demand it creates in the PTS network. Henceforth, the PTS analysis discussion will focus on the interaction between the supply of and demand for the PTS.

2.4 Interaction involved in PTS

The transportation system in the region will affect the activity system in that region. For instance, socio-economics involved in the activity system is affected by the one of the characteristics of the transportation: accessibility. The land value in the activity system increases with the proximity to the transportation network, expressed as accessibility to the transportation system. The activity system influence the way in which the transportation service operates or the infrastructure is created. For instance, variation in the level of service\(^1\) during

\(^1\)The level of service is often used to express the quality of service. It is expressed based on basic, accessibility, travel time, reliability, directness of service, frequency of service and passenger density.
the peak hour and off-peak hour is an effect of activity system on the transportation system. The resultant vector of this interaction between the transportation system and the activity system is the flow through the transportation system such as number of people travelling in the PTS, number of trips made through different origins and destinations, amount of goods transported through the transportation network. This basic relationship is represented through the figure 2.1. Three kinds of relationships can be derived from the flow patterns within a transportation system as shown in figure 2.1:

1. The transportation system and the activity systems determine the flow patterns.

2. The current flow pattern will cause changes over time in the activity system. This is caused through the patterns of transportation services provided and through the resources consumed in providing that service.

3. The current flow patterns will also cause changes over time in the transportation system. This is caused in response to actual or anticipated flows, operators will develop new transportation services or modify existing services and governments can change or create new policies such as subsidies, service price.

In this relations, the scale of changes in the system caused by the flow patterns vary in both space and time. The changes that influence the public transportation system, in particular, the PTS is reviewed in the next section.

### 2.5 Changes affecting the PTS

Three types of changes relevant to the public transportation system are identified for analysis in [Manheim, 1979] as below:

**change in demand** The changes in population, income level of the people, land-use patterns directly cause the change in the activity system. This
results in change of demand for the transportation system. Hence, the amount of transportation required is distributed in the spatial and temporal dimensions according to the activity system.

**change in technology** The changes in the technology or introduction of new technology has a direct effect in the activity system. The choice of mobility is affected either positively or negatively and in turn affects the activity system. For instance, introduction of the dockable buses with no steps for boarding helps in effortless boarding for the people in wheel chair. Possibly, this has changed the way in which disabled people move in the region. Similarly, the display of expected arrival time of bus in the bus stops help people to ascertain their waiting time and think of other choice, if they are in urgency.

**change in values** The changes in the socio-economic system and ecological system should be taken into account for decision making in the transportation system. Not all section of the user community will be interested in using the PTS. Also not all section of the community get the equal opportunity to use the PTS. Identifying the need for the PTS system in a region is vital and the need mainly depends on the socio-economics within a region. The environmental concerns also affect the decision making about the transportation. Noise pollution, air pollution, community disruption and ecological effects are few parameters among the environmental concerns.

These changes affect the decision making about the PTS like scheduling of service, reallocation of resources. The changes are slow but has a critical effect on the transportation system if they are not considered in the planning process. For instance, a bus stop would have been created to cater the Pension house for the region. However, if the pension place has been relocated, the bus stop may not be still in use. The service through the bus stop increases the travel time and in turn affect the other associated variables like frequency of the bus, driver work time and increase the cost of the system. Finally, we see these changes boil down to economics and policy making issues. In this research work, geovisualization techniques are developed to explore the spatio-temporal patterns present in changing demand. The next section discusses about the actor who are influenced by these changes.

### 2.6 Actors in the PTS

There are three main actors involved in the PTS decision and policy making.

**Users of the system** make decision about where, how and whether to travel through the PTS. They constitute to the demand side. They exhibit varying characteristics both in space and time corresponding to their activity system.
Operators make decision about the vehicle routes & schedules, fare structure, type of vehicle used, level of service, frequency of vehicles and enabling infrastructure within PTS. They constitute to the supply side.

Government/Policy makers make decisions on taxes, subsidies, and other financial matters that influence users and operators, on the provision of new or improved facilities, and on legal and administrative devices to influence, encourage or constrain the decisions of operators or users. They also indirectly constitute to the supply side.

This research takes the stand of bus operators and to some extent the government who analyse the demand and do policy making. The PTS operators conduct surveys to measure the change in the demand for planning and management purpose. The next section gives a brief idea about the characteristics of such measurements.

2.7 Measuring performance

The performance of a PTS is measured through efficiency parameters like productivity, cost efficiency, labour productivity, vehicle utilisation, energy efficiency and effectiveness parameters like service utilisation measures, accessibility, level of service. These performance indicators vary from micro to macro scales. The micro scale means the measures are disaggregated both in space and time. The macro scale means the measures are aggregated over space and time. The aggregated parameters are given more preference for the bus operation planning generally. But, as the activity system is actively being considered in the transport geography, the disaggregated measures are also considered by the transportation system analyst. The bus operation planning also needs to consider analysis at both aggregated and disaggregated scales to get better insight into the system. An analyst can move from aggregate to disaggregated views and vice versa depending upon the objective of the analysis.

2.8 Chapter digest

In this chapter, the basic characteristics of the public transportation system and analysis were discussed. The interaction between supply and demand is found as an important characteristics which essentially interests the decision makers. The interaction is often studied by carrying out surveys for measuring the supply and demand, by the PTS operators and decision makers. The next chapter brings out the spatio-temporal characteristics of the one such PTS survey data and explains how it is modelled to facilitate for visualisation of spatio-temporal patterns in that data.
2.8. Chapter digest
Chapter 3

Spatio-temporal look into public transport data

3.1 Ponder space

This chapter provides an overview of the public transport data and its characteristics. The term public transport data is vague, unless the reason behind ‘why the data is collected’ and ‘what parameters are measured’ are explained. The public transportation system analysis depends entirely on such collected data. Next is its characteristics; what could the data tell about the public transportation system? Public transportation system operates in space and time. Hence the data collected has also spatio-temporal characteristics. We are interested in the spatio-temporal patterns present in such public transport data. To achieve the aim of this research work - visually explore these spatio-temporal patterns, it is also important to model the public transport data. In this chapter, spatio-temporal data modelling used for this research work is also discussed.

3.2 Use case

The public transport data used for the research is obtained from Connexxion bus transportation system. Connexxion is one of the major bus service operators in the Netherlands. The data is about the number of passengers travelling in their network collected through a survey. This survey is done every year during the month of November for a period of one week or 10 days. This survey is conducted to measure the usage of the PTS network and make decision about bus line operations. This research uses the public transport data of the Enschede region in the Netherlands. Apart from this survey, Connexxion also conducts survey about the origin and destination of the people travelling and their purpose of travel at least once in 5 years, to understand the activity system. However, this survey is not modelled in this research work. Instead, arbitrary data about activity system detailing about the activity centres is created and used.

The geometry of the PTS network is radial, that is, all bus lines pass through the centre of Enschede city. The data is collected during November 2003 and
3.3 Characteristics of the transport data

3.3.1 Ontological characteristics

A bus line has fixed origin and destination. A transit of a bus from origin to destination is called a trip. Each bus line has one or more trips. Each trip has a set of bus stops where it drops and picks up people. Each trip of bus line need not operate over the full network. During off-peak hours and weekends only partial network is covered. Each trip need not have the same set of bus stop. Depending upon the service (off-peak, peak or limited stop service), each trip has distinct set of bus stops. For measuring the performance on the bus lines, in this use case, observation, i.e., the number people travelling in the bus, is made at certain bus stops. The bus stop where the observation is made, is referred as observation point. Figure 3.1 shows these characteristics.

We have two different level of ontologies for modelling a bus line. A bus line could be expressed as a set of trips or set of observation points for time t. A trip could be expressed either as a set of bus stops or as a set of observation points. Remember, all bus stops are not observation points. In Connexxion case, the observation point represents flow in a region [Shrinivasan, 2004]. For example, an observation point would be located just outside a town/city, to measure the
Chapter 3. Spatio-temporal look into public transport data

in-flow and out-flow of the people for that town/city. In this research work, a trip is modelled as a set of observation points in order to explore the flow in a region. However, the set of bustops for a trip is also modelled in order to give idea about spatial configuration of the bus line during visualisation process.

3.3.2 Spatial characteristics

The spatial configuration of Connexxion bus lines is shown on the map of Enschede city in figure 3.2.

- Observations are made at certain bus stops representing a region covered by the bus line. Hence each observation has a valid path. This is shown in figure 3.3.

- Observation points are ordered for a bus line. This means always the transit passes through the observation points in a pre-fixed order. This gives rise to three different types of representation for a trip as shown in figure 3.4.

  1. Geographic map - where observation points and its valid path are represented using geographic coordinates.
  2. Schematic map - where the geometry of the PTS network is not maintained but the topological relations for observation points, bus stops and bus lines are maintained. For instance, the underground network map of London [tub, 2005] could be an example of schematic map where the route line does not represent the actual geographic path.
  3. Schematic - observation points are represented in a linear form according to their order of access.

3.3.3 Temporal characteristics

A formal treatment of models of time is found in [Frank, 1998] based on taxonomic approach. Basically there are four hierarchical divisions of time. On top, is the temporal objects considered as event which occur at an epoch (without duration) or intervals between two events. The second sub-division is the based on the temporal processes that derive the temporal objects: linear, which extends from past to future and cyclic, which has repetitive pattern. The next sub-division is based on the scale of measurement used to observe the temporal process: ordinal which measures just the time sequence of the event and continuous where the events are marked on a continuous time scale. The fourth sub-division is based on the viewpoint adapted to observe the event: total order; where there is a single viewpoint and all events are completely ordered, partial order; where sequence of events are not related, branching; where possible states of the world for the event is described. and multiple perspective; where multiple possible states of the world are considered. This taxonomy is shown in figure 3.5.
3.3. Characteristics of the transport data

Figure 3.2: Map of Enschede city with bus lines

Figure 3.3: Spatial characteristics of PTS data

Figure 3.4: Representations of the bus lines
Chapter 3. Spatio-temporal look into public transport data

A bus line has a set of trips scheduled for a week. The set is repeated through the year until new set of trips are scheduled. In this construct, the observation is taken for one or two week period continuously and aggregated as working days, Saturday and Sunday. The temporal characteristics of observation made for the trips are as follows:

- Ordinal - Each observation has a valid time period (start time - end time) and observations are aggregated over working days, Saturday and Sunday for a week.
- Cyclic - The trip repeat weekly and yearly cycles until a new set of trips are introduced for a bus line.
- Total order (Single experience) all observation are completely ordered for a trip of a bus line.

This temporal characteristics is highlighted with the components of the PTS data in figure 3.5.

3.4 Spatio-temporal data modelling

An initial note on the conception of cartographic time in geographic information systems can be found in [Langran, 1992]. She elaborates on four spatio-temporal models: space-time cube, sequence snapshots, base state with amendments, space-time composite model. These models try to introduce time as fourth dimension which is more to representation but does not fully support the
3.5. Chapter digest

spatio-temporal analysis [Peuquet, 1994]. An integrated representation framework based on location, time and object components of the geographic phenomena is introduced in [Peuquet, 1994] referred as triad framework. The basic components of the triad framework are shown in the figure 3.6. This framework adds time-based representation to the dual spatial representation (object-based and location-based) found in traditional GIS. This framework helps in basic spatio-temporal reasoning like:

1. when + where → what: provides information about the object view based on location and temporal views; What were temperature readings at Twente weather station during January 2005?

2. when + what → where: provides information about the location view based on temporal and object views; Where maximum temperature reading was recorded during January 2005?

3. where + what → when: provides information about the temporal view based on location and object view; When did the maximum temperature reading occurred in Twente?

Further, we have to incorporate the ontological characteristics into the modelling of the PTS data. The triad framework is extended to incorporate this knowledge component along with data component (what, where and when) as pyramid model [Peuquet, 2002a]. The pyramid model is shown in figure 3.7. The knowledge component helps to represent the categories/taxonomies and interrelationships in the object view. This helps to represent the trips as a part of bus lines and observation points as a part of bus stops as shown in figure 3.9. The theme in the data component is similar to the thematic views in traditional GIS. The survey on number of people travelling in the PTS is taken as the theme. The PTS network is the location component that incorporates the spatial characteristics of the PTS data. The time table based on which the PTS works, is taken as the temporal component. The pyramid model for the PTS data is shown in figure 3.8. The PTS data model is implemented using MySQL 5.0.1-alpha open-source database server. The database design is shown with object, location and temporal component in figure 3.10.

Although, the activity system is not modelled for the real situation, arbitrary activity system is modelled. The activity centres located in the PTS network such as university, schools, industrial areas, recreational area, shopping area are considered. An arbitrary weight is given to the activity centre based on the temporal events that occur there, which could affect the usage of the PTS. For example, the probability of the people at schools to use the PTS is more during the school opening and closing time and hence a more weight is given to the school during these times. The implementation of the arbitrary activity system is shown in figure 3.10.

3.5 Chapter digest

In this chapter, the details about the PTS data used in the research work is studied. After analysing the ontological, spatial and temporal characteristics
Chapter 3. Spatio-temporal look into public transport data

Figure 3.6: Basic components of the Triad framework (Peuquet, 1994)

Figure 3.7: Pyramid model with triad model identified at the base of the pyramid and knowledge component at the apex of the pyramid
3.5. Chapter digest

Figure 3.8: Pyramid model for PTS data

Figure 3.9: Spatio-temporal data model for PTS data
Figure 3.10: Implementation of Spatio-temporal data model for PTS data using MySQL 5.0.1-alpha

Temporal components are underlined
of the PTS data, the spatio-temporal modelling for the PTS data is done. The spatio-temporal model is based on the pyramid model. The arbitrary activity centres are constructed to provide a link between the transportation flow and activity system. The model is implemented in the MySQL open source database server to facilitate the visualisation process. In the next part, visualisation techniques to explore the PTS data are discussed.
Part II

Visualisation
Chapter 4

Visualisation

4.1 Ponder space

We tend to create visual metaphors for the objects in the real world in our mind. Close your eyes and think of an object called ball. Immediately, your mind pops up with your version of the object called ball and displays in your mind screen. Don’t ask, where the mind screen is? This is a visual metaphor for the object in the mind. The object has two properties: geometry and appearance. Geometry describes the structure of the object in $\mathbb{R}^n$ space. Appearance describes ornamentation of the object which might identify the object in the $\mathbb{R}^n$ space either uniquely or in clusters. These visual metaphors are inherently present in our thinking process. This has become basis for the visualisation domain; to wrap up the data from scientific and non-scientific communities over some visual metaphors, and to derive appropriate information by playing with the visual metaphors.

We see from the history, science has always derived inspirations from the world of visual art. The creation of perspective visual illusions during the renaissance period in 15$^{th}$–16$^{th}$ century had led to the creation of stereometry. We have perspective vision; we see depth. Harnessing this capability, we could represent 3d information like geographic information with height, or visually correlate 3 independent processes in a scatter plot. With the advent of computing, the representation of 3D objects has been realised and could be used to wrap the visual metaphors in to them. But, does the use of 3D representation improve the insight on the information presented?

This part focuses on visualisation of spatio-temporal processes. How to develop a visualisation environment that can help getting insight into the complex spatio-temporal data? This chapter discusses about the spatio-temporal process visualisation and the visualisation environment appropriate for exploring such spatio-temporal process.

\footnote{The art of measuring and computing the cubical contents of bodies and figures}
4.2 Visualisation

Visualisation is often referred to the creation of visual metaphors in the mind for the physical concepts. *Oxford English Dictionary* defines *visualisation* as *constructing a visual image in the mind*. Instead of bothering too much the mind, life is made easy by constructing the visual objects in an external environment like using computers, building miniature; and exploring them. Generally, visualisation is divided into two domains: scientific visualisation and information visualisation [Duke, 2001]. Scientific visualisation helps in creating graphical representation for the data derived from physical measurements or simulations grounded in geometry space. For instance, figure 4.1 shows relationship between atmospheric pressure and altitude. The data space is metric; hence one can derive measurement from the graph apart from seeing the general trend in the physical measurement. Scientific visualisation hence has algorithms defined in metric space similar to the data space. Information visualisation specialises in creating the representations for the non-metric datasets. In this case, data space is abstract and topological one. For instance, figure 4.2 shows parallel coordinate plot for four variables namely sodium (sod), calcium (cal), fibre and protein (prot) for different cereals. The graph shows the trends in the dataset and one cannot further make any measurements from the graph. Also one can play with the representation by changing the order of the variables in the dataset as shown in figure 4.2 (a) & (b).

Apart from creating visual metaphors for the objects, map-metaphor is used to represent those objects with their location and attributes. The use of map-metaphors for visualising objects is not new. The grammar of creating such map-metaphors for visualising those objects in geographic space through maps is well-established through Cartography - the art and science of map-making. The visualisation domain that stems from integrating approaches from disciplines including cartography with those from scientific visualisation, image analysis, information visualisation, exploratory data analysis and GIScience is Geovisualisation [Dykes et al., 2004]. Geovisualisation is mostly seen as a part of GIScience that uses the visualisation techniques to manage, explore and present geographic information. Geovisualisation is defined as ‘the use of concrete visual representations whether on paper or through computer displays or other media to make spatial contexts and problem visible, so as to engage the most powerful of human information processing abilities, those associated with vision’ [Maceachren et al., 1999].

In the following sections, the visualisation environment and techniques required to present and explore the spatio-temporal process are discussed.

4.3 Spatio-temporal visualisation

Visualisation of spatio-temporal processes requires different kind of treatment compared to geospatial data visualisation. Visualisation techniques for representation and exploration of geospatial data are well established [Kraak and Ormeling, 2003b]. [Langran, 1992] discusses about the display aspects in temporal GIS. She distinguishes three class of temporal objects: state,
event and evidence. She identifies four major classes of spatio-temporal displays:

1. Time sequences e.g. multiple editions or time series
2. Change data e.g. text, graphic, or digital amendments to base representation.
3. Static maps with thematic symbols of a temporal theme, e.g. symbols depicting dates, rates, paths, or order of occurrence.
4. Animations

This basic treatment of visualisation of temporal component of geospatial data is extended by [Kraak and MacEachren, 1994]. They try to extend the graphic variables for geospatial data visualisation to the temporal maps. Temporal maps are defined as a representation or abstraction of changes in geographical reality; a tool (that is visual, digital or tactile) for presenting geographical information whose locational and/or attribute components change over time. The following are the different types of temporal maps:

1. Single static maps which helps in mapping an event/episode. The temporal components are expressed using the visual variables of the graphic sign
4.3. Spatio-temporal visualisation

system.

2. Strip maps which helps in mapping an event/episode by ordering the state maps chronologically. The temporal variations are shown by difference between the individual maps of event/episode and not necessarily by visual variables.

3. Animated maps which maps an event/episode by a quick chronological sequence of ‘static’ maps. The animated map displays changes in position or attributes from a fixed view point and hence variation in time is shown by actual change in the image objects.

For representing temporal maps, Bertin’s visual variables are not sufficient and appropriate treatment of movement is necessary [Kousoulakou and Kraak, 1992]. [DiBiase et al., 1992] proposed three dynamic variables for temporal mapping: duration, order and rate of change. Further MacEachren adds three more dynamic variables: display date, frequency and synchronisation. However, so far, the work on temporal maps helps in representation of temporal components in geospatial data. The work on visual exploration of the spatio-temporal process is still under investigation. [MacEachren, 2004] derives inspiration from simulation modelling and categorises the visualisation application for spatio-temporal processes as process tracking, post-processing and process steering. He provides two viewpoints for visualising spatio-temporal processes: Phenomenon representation; using visualisation tools to explore the process by measuring real-world variables over time and examining their relationships, and Concept representation; using visualisation tools to explore process through manipulation of model parameters. In the following subsections, the categories of the visualisation application is discussed based on [MacEachren, 2004].

4.3.1 Process tracking

Tracking can be done in the above viewpoints, however the task that is to be accomplished is the identification of abnormal events. Such identification can be alerted using visual/sonic cues in the visualisation environment. Tracking of hurricane path, vehicles are some of the examples of process tracking. Process tracking does not involve in exploring the archived data, hence effectiveness of processing tracking for identifying events depends on the spatial scale and temporal resolution involved. Primary visual task that is required in the process tracking is feature identification. Feature identification can be accomplished by colour-highlighting method and blinking, sometimes along with sonic cues.

4.3.2 Post-processing

Post-processing involves exploration of archived or measured spatio-temporal processes. Here the temporal component is not real-time. Hence, we can also looking into temporal order of attributes of the data apart from chronological events. Visual tasks such as feature identification and feature comparison can be accomplished for understanding of the spatio-temporal processes. The data
components can be aggregated or exaggerated by applying spatio-temporal filters to accomplish appropriate visual information seeking process. For instance, the study of epidemics could involve analysis of the epidemic data which distributed in space and time. Post-processing of the epidemic data might involve certain basic spatio-temporal reasoning operations such as feature identification in space, time and attribute domain, feature comparison of epidemics in various locations in varying time periods. Visualisation environment for post-process exploration should help in carrying out basic spatio-temporal reasoning that could help better understanding of the process.

### 4.3.3 Process steering

Process steering involves triggering, maintaining the process based on the conditions or models. Visualisation environment help the users to control parameters of the model or conditions of the process. Also visualisation environment could have certain behaviour assigned and can be invoked based on the user/model interaction with visualisation environment. For instance, virtual reality could demonstrate the design of a building. The design could be tested for the stability by creating scenarios like overloading of the building, case of fire accident, bomb blast. The virtual reality has the behaviour assigned for each components of the building. These accidents effect the building and trigger appropriate behaviours of the building components. This could help in assessing the stability of the building. In case of any such accidents, the virtual reality can also help to ascertain the building component’s proximity to damage both in space and time. This could help in rescue operations. Similarly, the virtual reality environment can be built for the air traffic control to maintain certain conditions like minimum distance between two aircraft, landing conditions during heavy fog.

In the above discussion, we see the spatio-temporal process visualisation requires task-based exploration. These visual tasks become key to accomplish spatio-temporal reasoning required to understand the spatio-temporal processes. Apart from visual tasks, the multiple views have become important in the exploratory visualisation providing additional insights and alternative viewpoints. In this research work, aimed to visually explore the PTS data, treats visualisation as an environment, not only as a tool. In the next section, the visualisation environment and its components are discussed.

### 4.4 Spatio-temporal visualisation environment

A visualisation environment is defined based on the activities the user wants to perform within that environment [Chen, 1999]. Only in this context, the visualisation techniques such as visual tools, interaction between them and dynamic queries will serve the purpose of the visualisation environment. The visualisation environment could involve single user or multiple users. For single user, the design may focus on the use of visual metaphors, the construction of environment and user interaction with the visualisation environment. For multiple users, focus may be extended to support communication and social interaction
4.4. Spatio-temporal visualisation environment

apart from those for single user design of visualisation environment. In this section, the visualisation techniques are briefly discussed.

4.4.1 Visual functions

Shneiderman's famous visual information seeking mantra: *overview first, zoom and filter*, then *details-on-demand* has been used as an useful starting point for designing advanced user interfaces. He, further extended these functions and associates with the seven data type taxonomy (comprising of: 1-dimensional, 2-dimensional, 3-dimensional, temporal, multi-dimensional, tree, network which reflect an abstraction of reality) [Shneiderman, 1996]. The following are the seven visual functions:

1. Overview: gain an overview about the object of analysis.
2. Zoom: zoom in on objects of interests.
3. Filter: filter out uninteresting objects.
4. Details-on-demand: select an object or group of objects and get details when needed.
5. Relate: view relationships among objects.
6. History: keep a track of actions to support undo, replay, and progressive refinement.
7. Extract: allow extraction of sub collections of objects and of query parameters.

4.4.2 Visual queries

Most of the visual exploration is driven with the data at the backend. Filtering of the large dataset is often required before starting the visualisation process. Visualisation users are mostly non-programmers and it would be difficult for them to write a query (SQL) statement correctly repeatedly to perform the filtering operation. However, an visualisation environment can also have a visual programming language as implemented in APOALA project [Peuquet, 2002b]. One can see such visual programming language in commercial image processing software like model maker in Erdas IMAGINE Professional® and GIS package like ESRI ArcGIS® 9.0. This visual programming language is used to create work flow or process flow graphically, incorporating the constraints, to run the process. However, in this research work, visual query tools are used to set the constraints to select or filter objects from the large dataset based on objects, location and time components of the data. The advantage of the visual query tools is that it allows user to concentrate on applying constraints rather than creating such constraints in text mode.
4.4.3 Dynamic queries

Dynamic queries involve direct manipulation of database from a visualisation environment. Dynamic queries describes the interactive user control of visual query parameters that generate a rapid (100 ms update) visual display of database search results [Shneiderman, 1994]. The direct manipulation may include presenting a visual overview, filtering tools, continuous visual display of information, pointing rather than typing, and rapid, incremental, reversible control of the query.

4.4.4 Alternative representations

Breaking the regular thinking pattern is an important key to creativity. This could be done by providing alternate views about the same concept. Alternative representations have become integral part of exploratory visualisation environment. This has been emphasised in [Roberts, 2003, Roberts, 1998]. Further, for the visualisation of temporal components in geospatial data is emphasised in [Kraak and Ormeling, 2003a] and they suggest space-time cube and travel cartogram as an alternative representation for temporal maps discussed earlier in this chapter. While discussing about alternative representation, there are two important terms: multiple views and multiform. [Roberts, 2000] defines them as follows:

**Multiple views** describes multiplicity (more than one view of data) in visualisation, where various realisations of the data are depicted in separate windows.

**Multiform** realisations represent a change in the visual representation method (use of different visual metaphor for representing the data).

Further he discusses about usefulness of the alternative representation techniques in that paper based on correct dissemination, scientific exploration, alternative viewpoints, realisation comparison and collaboration. He describes two methods of generating multiple views and are shown in figure 4.3. About generation of multiform representation, four methods are described as follows:

- Altering the visual metaphor used to represent the object.
- Altering the appearance of the object.
- Altering the projection of the geometry like perspective or parallel projection of the visual metaphor representing the object.
- Simplification of the geometry of the visual metaphor using smoothing or abstraction.

4.4.5 Linked views

Linked views involves coordination between multiple views or multiple visual tools. Linked views enables users to rapidly explore complex information, dynamically mix them and correlate them visually without programming.
Some of the well known coordination techniques are brushing, drill down, overview and detail view, and synchronised scrolling or navigation. Coordination is made possible through the relational schema available in the data model used to represent the process. For instance, one of the alternate representation could provide an aggregated view about the process while one other view could present the process without aggregation. Coordination between the two views using techniques such as brushing, highlighting could help in easy exploration and understanding of the complex information.

4.5 Chapter digest

In this chapter, a brief discussion about the visualisation required for spatio-temporal processes is done. Now we have idea about how to handle visualisation application for spatio-temporal process like process tracking, post-processing, process steering. Exploratory visualisation environment with its possible components is discussed. Now the challenge is to define appropriate visual tasks to explore the PTS data. In the next chapter, we will see how the tasks are identified and appropriate visualisation techniques are constructed.
Part III

Spatio-temporal pattern visualisation
Chapter 5

Exploratory behaviour view

5.1 Ponder space

Recalling the research formulation (section 1.3), in this research work, an exploratory behaviour view for transport geography creation is attempted, within the purview of PTS explained in part I. Having taken geovisualization for creating such a behaviour view, the possible components that could help in creating the exploratory geovisualization environment was discussed in part II. Indeed, it is important to know ‘what is the relevance of spatio-temporal patterns’ in PTS data to get insight into the PTS. In this part, spatio-temporal reasoning required by the PTS operator / policy makers to get insight into the PTS data are briefed. Based on this reasoning, visual tasks will be identified. Multiple views to analyse the PTS data will be created. Visual tools required to visualise the multiple views of the PTS data will be identified. To execute the visual tasks in the visual tools, to make spatial context and problem visible, appropriate visualisation techniques (as discussed in section 4.4) will be incorporated in the visual tools.

5.2 Spatio-temporal patterns in PTS

The key points in measuring the performance of the PTS is discussed in section 2.7. Often the performance is measured through parameters as listed in that section. We are interested in the variations in those parameters. In this research work, patronage, that is, the number of people travelling in the bus at a given time, is considered.

To gain insight into the PTS, two transportation groups: research group and user group, were identified. Two PhD students from the Centre for Transport Studies, University Twente were part of research group, who helped in understanding the public transport system and its analysis. Two planning architects from Connexion bus company were part of user group, who helped in understanding the current analysis of the PTS data described in section 3.2. Based on the discussion with transportation group, the following questions were found interesting for understanding the behaviour in the usage of the PTS.

1. How often the bus is over-crowed or under-utilised?
5.3. Visual tasks

2. When did such over-crowding happen?
3. Where did such over-crowding happen?
4. How often such over-crowding had repeated?
5. What is the trend in the patronage for the bus line?
6. How does the trend in the patronage vary among bus lines?
7. What happens in the activity system, in the event of over-crowding and under-utilisation and is there a mutual relationship between activity system and public transportation system?
8. What is the difference in the variation of patronage for the bus line during different time period like working days, Saturday, Sunday?

The answer to the above reasoning questions will result in revealing the patterns in the usage of PTS. Basically, the variation in patronage is presented in space and time. There could be 1-n relationship or multiplicity for patronage to space and time, resulting in spatio-temporal pattern, which we are interested in visualising. Further patterns can be derived by aggregating the event (use of PTS) by spatial order and temporal order of that event. This also provides opportunity to analyse the PTS at different aggregation level which might be useful in understanding the behaviour of patronage. In the next section, visual tasks required to perform the visual exploration based on the spatio-temporal reasoning will be discussed.

5.3 Visual tasks

In this research work, the visual task required to perform spatio-temporal reasoning are identified as below:

**Locate** task helps to find out when and where an event has occurred, in this case, the occurrence of certain patronage.

**Identify** task helps to provide information behind the visual representation based on information in the database.

**Associate** task helps to provide information about the activity system and other parameters like vehicle type, reliability measures so as to relate visually to the patterns of patronages. This helps in providing clue to what has happen in the parallel world (concurrent events) which could then be used for user-specific reasoning.

**Compare** task helps to compare performance of bus line at different time period and to compare performance between bus lines.

In the following sections, the primary visual tools and multiple views of the PTS data, which could help in provide visual exploration at different aggregation levels, are presented.

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1 usage of PTS
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5.4 Primary visual tools

The visual tools such as object box, time box and space box provide overview of the object, temporal and spatial characteristics of the PTS data respectively. These three visual tools form visual query tools which helps to apply filter on objects, time and space in the pyramid framework (shown in figure 3.7). The space-time cube is used to represent the event of observing patronage, while making bus trips, in both space and time.

5.4.1 Object box

The object box provides overview of bus lines available in the PTS data. The overview is given by listing the bus lines available in the PTS. The object box is shown in figure 5.1. This tool is used to apply filter on objects used for visual exploration. For instance, the PTS analyst might be interested in only exploring the spatio-temporal pattern for certain bus lines like line1a, line2a in the figure 5.1. The analyst can select those objects in the object box and proceed to visual exploration.

<table>
<thead>
<tr>
<th>Bus lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>line1a</td>
</tr>
<tr>
<td>line1b</td>
</tr>
<tr>
<td>line2a</td>
</tr>
<tr>
<td>line2b</td>
</tr>
<tr>
<td>line3a</td>
</tr>
<tr>
<td>line3b</td>
</tr>
<tr>
<td>line4a</td>
</tr>
<tr>
<td>line4b</td>
</tr>
<tr>
<td>line5a</td>
</tr>
<tr>
<td>line5b</td>
</tr>
</tbody>
</table>

Figure 5.1: Object box

5.4.2 Time box

The time box provides an overview about the temporal characteristics of the PTS data as discussed in section 3.3.3. The time box has a hour line representing the hour block per day. It has a weekday list representing working day, saturday and sunday, and a year list to list the years in which observations of patronage are made. The time box is shown in figure 5.2. This tool is used to apply temporal filter on the PTS data by selecting the required weekdays, years and hour blocks.

5.4.3 Space box

The space box provides locational information about the objects in the PTS data such as bus lines, observation point, activity centres, bus stops. It has a base
5.4. Primary visual tools

5.4.1 Time box

Figure 5.2: Time box

map which helps in providing overview about the spatial characteristics of those objects. It is same as a traditional GIS that provides *map view*. The space box is shown in figure 5.3. This tool can be used to apply spatial filter by selecting required ‘area of interest’.

Figure 5.3: Space box

5.4.4 Space time cube

The space-time cube (STC) is used to represent the movement of people in space and time, by human geographers, to understand the behaviour of the people. Having conceptualised by Hägerstrand in late 1960’s, it has been difficult for geographers to realise it for an application due to the lack of computing technology. Recently, attempts are made to utilise the concepts uncovered by STC in the works of [Forer et al., 2004, Forer and Zhao, 2004, Kraak, 2003, Kwan and Lee, 2004].

With the advent of computing technology and software engineering, 3d visualisation has become easy to realise.

STC represents the *behaviour view* that helps to study the behaviour of the moving objects in space and time. STC is a three-dimensional environment, where x-y plane represents geographic space and z-axis represents the progres-
Chapter 5. Exploratory behaviour view

In this research work, the trips of each bus line is modelled as space-time paths representing the transit of bus from origin to destination in space and time. Hence, STC presents both spatial and temporal characteristics of the PTS data. Apart from representing the trips, the activity centres are modelled as stations in STC. For each hour block, the activity centres are given certain weight on the scale 1-10, depending upon the probable contribution to the PTS patronage. This helps to visually associate the activity system to the patronage of the bus line (flow). The STC is shown in figure 5.4, with trips as space-time paths and activity centre as station. However, other concepts in STC such as potential path space are not used, since the trip is predetermined with no uncertainty.

![Figure 5.4: Space-time cube](image)

5.5 Multiple views

As discussed in the section 4.4.4, multiple views provide opportunity to analyse the system from different perspectives. For creating multiple views, the ontological characteristics of the PTS data could be evoked. The exploration of public transport data could be accomplished at the observation point level, trip level or bus line level as below:

**Observation point level** - The patronage measurement at a observation point is referred as an *event*. At the observation point level, the variation in the event could be analysed with or without aggregation. Since, the patronage is directly dependent on the activity system which is location-specific, the spatial aggregation or generalisation may not be useful. However, aggregation could be done using temporal characteristics. The temporal characteristics of the PTS data is ordinal for a week and has cyclic week throughout the validity period as discussed in section 3.3.3. Since the data is already aggregated into working days, saturday and sunday, it is
only possible to aggregated the data into hour blocks (as minimum time resolution is minutes) for each working days, saturday and sunday. At this stage, the aggregated observation could be grouped for certain week of a year. Since the observation is only taken for one week of a year, that leaves only with option of grouping observation points of a bus line over working days, saturday or sunday for a year. Hence, it is possible to have two views, at the observation point level, i.e., one without any aggregation and other with aggregation over hour blocks.

**Trip level** - The trip consists of set of observation points and the variation in patronage within a trip could be analysed. In this case, temporal aggregation is not possible as each trip is unique per week. However, the trips could be grouped based on working days, saturday or sunday per year. Also the trips could be grouped based on the attributes (characteristics) of the trip like vehicle type used. Hence we have one view at the trip level where the PTS data could be grouped as above.

**Bus line level** - The bus line could be expressed either as a set of trips or set of observation points for time t, as discussed in section 3.3.1. To avoid variation in these two expression, we can aggregate the patronage over hour block and analyse the variation in patronage. The bus lines could be grouped based on working days, saturday or sunday per year. Hence we have one view at bus line level.

Based on the ontological characteristics, now we have four different views of the PTS data. For each view, appropriate visual representations are to be identified or developed. In the next section, the visual representations that could help in presenting the variation in patronage at observation point, trip or bus line level are discussed.

### 5.6 Visual Representation

#### 5.6.1 View 1: observation point level without aggregation

The variation in the patronage at observation point level can be shown with the help of frequency of the occurrence of the patronage at observation points. This provides information about how often the bus is over-crowded or under-utilised at observation points. The histogram [Chambers et al., 1983] provides graphically summary of the distribution of a univariate data set. Apart from showing the distribution, histogram [sta, 2005] also helps to identify outliers (exceptional cases in the distribution, if any). Histogram represents the frequency among the data classes. In this case, we need to represent the frequency of the patronage. Such a histogram is shown in figure 5.5.

#### 5.6.2 View 2: observation point level with aggregation over hour block

We have three variables in this case: observation point, hour block and aggregated observation. The variables, observation point and hour block are not
continuous but are of categorical domain. The spatial order and temporal order of the PTS data could be used to show variation in aggregated observation as the bus travels in space and time. A three dimensional space is used for visualising these variables. The x-axis and y-axis are discrete and represents the hour block and schematic space (section 3.3.2) respectively. The z-axis is continuous and represents the aggregated observation. This representation is termed as “Three axis plot” in which two axes represents schematic space and time against single valued function like aggregated patronage. The three axis plot is shown in figure 5.6 with the points connected using a surface. [Wilkinson, 1999] suggests such a surface connecting the data points in 3d space provides a holistic judgement on the relations among the variables assigned to the axes. However, a warning message that such a surface should not be interpolated between data points as we do in the case of digital elevation model (DEM, TIN, etc.) should be presented to the users. A surface is created for a bus line for certain week day for a year like line1a-working day-2002, line1a-saturday-2002. Each surface is termed as layer similar to notation of layers in a GIS.

5.6.3 View 3: trip level

In this view, we need to represent the trip as a set of observation points and the variation in patronage within that trip. Set of observation points is multivariate of spatial type for a trip. Parallel coordinate system is often used to represent the multi-variate objects. [Inselberg, 1984] proposed the parallel coordinate system which could represent the multi-variate objects through connected points on axes drawn parallel on a plane. There are rectangular and polar parallel coordinate system which is shown in figure 5.7.

Parallel axes could be constructed at observation points for a trip in schematic space. The axes could represent the patronage at each observation points. Then the trip could be represented by connecting corresponding patronage on each axes. Thus, the variation within a trip can be represented along with an opportunity to compare variation in other trips. The parallel coordinate plot representing variation in patronage in the trips is shown in figure 5.8.
5.6. Visual Representation

Figure 5.6: Three axis plot

Figure 5.7: Parallel coordinate system adapted from [Wilkinson, 1999]
5.6.4 View 4: bus line level

In this view, we have to represent bus line as a whole, which could have many trips and different sets of observation points. The patronage is aggregated over hour block for each bus line. We are interested in representing the variation in patronage over different hour block per day. [Keim et al., 2004] suggests a visualisation technique called Circle View that helps to compare continuous data changing their characteristics over time so as to identify patterns, exceptions and similarities in the data. The circle view is shown in figure 5.9. Circle view is a combination of hierarchical visualisation techniques, such as treemaps, and circular layout techniques such as Pie Charts and Circle Segments. The circle is divided into number of sectors corresponding to the number of attributes. Then each sector is divided into number of tracks corresponding to the time interval. And each segment in a sector is coloured corresponding to the value of the attribute at the time, \( t_n \).

In this case, the patronage changes for a bus line for each trip. If the pa-
tronage is aggregated over hour block, then the variation in the number of trip for different bus lines per hour block can be ignored. However, the number of trips for each hour block for bus line should be shown so as to avoid the bias while comparing. The circle view representing the change in patronage for a bus lines for different time period is shown in figure 5.10.

![Figure 5.10: Circle view representing the variation in patronage for a bus lines for different time period](image)

5.7 Making spatio-temporal context

The visual tools discussed in each multiple views represents certain reasoning component (what, when and where). In this section, each tool is analysed for the support of visual tasks identified earlier in this chapter: locate, identify, associate and compare; to accomplish spatio-temporal reasoning.

5.7.1 Histogram

The histogram represents the frequency of patronage. It shows how often the bus is over-crowed or under-utilised, in other words, trend in the usage of PTS. However, when and where such a over-crowding or under-utilising has happened, is not shown. Hence, it is not possible to accomplish the locate task through histogram. Space-time cube provides both spatial and temporal information about the trip. Linking space-time cube with histogram, will help in making spatio-temporal context. When certain patronage is selected in histogram, corresponding valid path within a trip should be highlighted in space-time cube to accomplish locate task. Associate task to the selected patronage could be accomplished by displaying activity centres in space-time cube. Identify task in histogram should provide information about the frequency of a selected patronage value. Compare task could not be accomplished within a single histogram representation. However, different histograms could be created for distinct constraints (on object, space and time) and compared visually as shown in figure 5.11.
5.7.2 Three axis plot

The three axis plot represents the variation in patronage aggregated over hour block in schematic space and time. There are two possible locate tasks. One, to locate the objects, in schematic space; in the geographic space, so as to get impression about PTS network in reality. Linking the space box with three axis plot, to highlight the observation point in geographic space (space box) for the selected observation point in schematic space (three axis plot). Next, to locate the aggregated patronage at observation point over hour block, so as to see the trips that contributed to the aggregation. This allows to move from aggregated view to disaggregated view in time for the observing the variation in patronage. Space-time cube is linked to three axis plot, to highlight the valid path corresponding to the selected observation point in three axis plot for an hour block.

Identify task should provide information about the aggregated patronage: object(bus line no), time(year, week day, hour block), space (observation point name) and aggregated patronage value. Associate task is similar to that in histogram, which is accomplished via space-time cube. Compare task in three axis plot helps to compare the bus line grouped in time as layers like between line1a-working day-2002 and line1a-Saturday-2002, between line1a-working day-2002 and line1a-working day-2003. The comparison is accomplished by studying the visual overlap between layers. Also to get insight into each layer, a layer could be given an artificial shift along the aggregated patronage and separated from other layers to study the variation in layers. This is shown in figure 5.12.

5.7.3 Parallel coordinate plot

The parallel coordinate plot represents the variation in patronage within the trips. The trip is shown with observation points in schematic space and by connecting corresponding patronage on each axes, representing the patronage
5.7. Making spatio-temporal context

![Artificial shift of layer in three axis plot to enhance compare task](image)

Figure 5.12: Artificial shift of layer in three axis plot to enhance compare task

at each observation points. There are two possible locate task. One to locate the observation points of a trip, which is in schematic space, in the geographic space. The space box is linked to parallel coordinate plot, to highlight the observation point in geographic space (space box) for the selected observation point axis in schematic space of parallel coordinate plot. Then, to locate the trip in both geographic space and time, the space-time cube is linked to parallel coordinate, to highlight the trip in space time cube for that selected trip in parallel coordinate plot.

Identify task should help to provide information about the trip: object(bus line no, trip no, vehicle type), time(year, week day, hour block), space (set of observation point names with patronage). There are two associate task possible. One, with the activity system, similar to that in histogram via space-time cube. Other, is to associate other parameter of the trip such as vehicle type and system reliability. In this research, to demonstrate this association, vehicle type is chosen. For a chosen vehicle type in parallel coordinate plot, the trips made using that vehicle type are plotted with indication to maximum seating capacity and total capacity of the vehicle. This helps to associate the usage of PTS to the vehicle type.

Compare task in parallel coordinate plot helps to compare the trips of bus line grouped in time like between line1a-2002 and line1a-2003. It is also helps to compare between different week days for the trips of the bus line.

5.7.4 Circle view

The circle view presents the variation in patronage for the bus lines aggregated over hour block for certain week day of a year. It may be necessary to locate where the bus line is routed in geographic space. This is accomplished by highlighting the bus line in space box for the selected bus line in circle view. Identify task should provide information about the aggregate patronage for the selected circle segment in a sector. Since, the circle view represents variation in patron-
Chapter 5. Exploratory behaviour view

age at bus line level, it is not useful to associate with the activity system as it is at higher aggregation level. However, after having the overview in circle view, drilling-down to trip level or observation point level could help in association to activity system or other parameters of PTS like vehicle type, system reliability.

The main goal of circle view is to accomplish compare task as the interface is defined for. To remove the bias in the comparison, the following dynamic queries are used:

- hour block at the centre can be changed
- assignment of bus line for each sector can be changed
- class breaks for classifying the aggregated patronage can be changed

5.8 Enhancing space-time cube

Moving space along time - the geographic space in the space-time cube can be shifted to the required time in the cube so as make the clear spatial context (to avoid perspective disparity in space).

Multi-form visualisation - instead of displaying the space-time path on geographic map, it can also be displayed on schematic map, as discussed in section 3.3.2, to reduce the complexity in the representing many bus trip lines.

Dynamic query for highlighting - The 'located' space-time path is highlighted with the following options which could help in easy location of selected space-time path and to have better representation of spatio-temporal patterns revealed in STC.

- Highlighting the selected space-time path with an unique colour (yellow) and retaining the default colour of other space-time path.
- Highlighting the selected space-time path with an unique colour (yellow) and reducing the intensity of colour (dimming) of other space-time path.
- Highlighting the selected space-time path with an unique colour (yellow) and removing other space-time path.

5.9 Chapter digest

In this chapter, visual tasks required to explore the public transport data are identified as locate, identify, associate and compare. Multiple-views to the PTS data are created based on the ontological characteristics. The visual representation for each view were identified and functions to execute the visual tasks to make spatio-temporal context are created. Sum of all the visual tasks, multiple views, visual representations and visual functions that help to explore the PTS data visually to reveal spatio-temporal patterns give rise to exploratory behaviour view. In the next chapter, a prototype developed to demonstrate the exploratory behaviour view, discussed in this chapter, is presented.
Chapter 6

Prototype design and implementation

6.1 Ponder space

A research prototype 'just' - just ur space 'n time is developed to demonstrate the visualisation environment conceptualised in the previous chapter. This prototype is used to evaluate the concepts developed in this research work, which is discussed in the next chapter. In this chapter, the design and implementation of this prototype is discussed. After the initial implementation, a focus group analysed the prototype. The results of the analysis are used to improve the prototype design. Further improvisation on interface design could always be done. However, the prototype is designed to check visual representations and functions whether it could accomplish the spatio-temporal reasoning required by the PTS planners.

6.2 Visualisation environment design and implementation

In the previous chapter, while elaborating the exploratory behaviour view, we came across the visual representation and visualisation techniques like linked views, dynamic queries to accomplish the visual task for spatio-temporal reasoning. The exploratory behaviour view is realised as a set of visual tools incorporating the visual representations and visualisation techniques. These visual tools are the essential components of the visualisation environment - 'just'. The visual tools are developed as independent software components so that they could be emerged with each other as per exploratory process requirement.

Sun® microsystem JAVA is chosen to develop the visualisation environment for its famous platform in-dependency and rich 3d-library resources. JAVA version 1.5.0 (code named tiger), latest release, though not an industry standard, is used for its advanced features like 'generics', 'autoboxing' (http://java.sun.com/developer/technicalArticles/J2SE/5reasons.html, accessed on 3 Feb 2005). These features along with Sun® microsystem NetBeans 4.0 Integrated Development Environment, used to develop the prototype, had reduced
6.3 Visual tool design

Visual tool design

Visual tools present the visual representation and the function required to accomplish the visual tasks. A visual tool has two processing units: data engine and visualisation engine. The data engine has two inputs: PTS data and constraints (objects, space and time) to filter the data. This is shown in figure 6.2. Based on these inputs, the data engine prepares the geometry of visual objects in the visual representation. The visualisation engine takes these visual objects as input and sets required appearance. The visualisation engine listens to the ‘trigger behaviour’ and ‘reaction behaviour’ from the other visual tools and user interaction.

The trigger behaviour is used to accomplish the locate task. Using trigger behaviour, the user interaction from one visual tool is directed to reaction behaviour of other tool. For example, to locate certain patronage selected in histogram, in the space-time cube; the selection event in the histogram is an example of trigger behaviour and the corresponding highlighting in the space-time cube is an example of reaction behaviour. An instance of this linked views illustrating the trigger and reaction behaviour is shown in figure 6.4. The identify, associate and compare tasks are accomplished by dynamic queries. To illustrate the implementation of the visual tools, UML (Unified Modelling Language) class diagram of space-time cube tool is shown in figure 6.3 with only public functions. In this figure, one can see the components of data engine, visualisation engine, behaviour functions and visual query translator which are the core functions in any visual tools used in the prototype. In the following subsections, the functions in each visual tool are discussed briefly.

6.3.1 Visual query tools

Visual query tool consist of four visual tools namely object box, space box, time box and selection box. The function of the first three tools are discussed in section 5.4. The selection box is used to synthesize the constraints set through
Chapter 6. Prototype design and implementation

Figure 6.1: Visualisation environment design
6.3. Visual tool design

Figure 6.2: Visual tool

Figure 6.3: Space-time cube UML class diagram showing only the public functions
other three visual query tools. It harmonises the constraints to visualisation tools for creating different views. It is possible to bookmark the visual query so as to avoid repetition of the query construction process. The visual query tools are shown in figure 6.5.

6.3.2 Space-time cube

The table 6.1 lists the functions in space-time cube along with a reference number to identify those functions in the figure 6.6.

6.3.3 Histogram

The table 6.2 lists the functions in histogram along with a reference number to identify those functions in the figure 6.7.

6.3.4 Three axis plot

The table 6.3 lists the functions in three axis plot along with a reference number to identify those functions in the figure 6.8.

6.3.5 Parallel coordinate plot

The table 6.4 lists the functions in parallel coordinate plot along with a reference number to identify those functions in the figure 6.9.

6.3.6 Circle view

The table 6.5 lists the functions in circle view along with a reference number to identify those functions in the figure 6.10.
### 6.3. Visual tool design

#### Table 6.1: Functions in space-time cube

<table>
<thead>
<tr>
<th>Function accomplished through dynamic query</th>
<th>Purpose</th>
<th>Reference in figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shifting base map along the time axis</td>
<td>To make better spatial context during locate task</td>
<td>6.6</td>
</tr>
<tr>
<td>Representation method</td>
<td>To provide multi-form visualisation so as to change between geographic map and schematic map representations of the bus trips</td>
<td>2</td>
</tr>
<tr>
<td>Highlighting method</td>
<td>To clearly see the objects selected by locate task (Use uniform colour and remove unwanted) and also to have relative representation to other objects (use uniform colour and dim unwanted)</td>
<td>3</td>
</tr>
<tr>
<td>Layer Management</td>
<td>To select the bus line and the colour code those bus line to identify them in the space-time cube representation</td>
<td>4</td>
</tr>
<tr>
<td>Associate with activity system</td>
<td>To display the activity centres in the space-time cube environment to have visual association between the activity system and the transportation system (based on patronage)</td>
<td>5</td>
</tr>
<tr>
<td>Reset locate task</td>
<td>To reset the selected objects in the space-time cube environment</td>
<td>6</td>
</tr>
<tr>
<td>3d Navigation assistance</td>
<td>To assist the user in 3d rotation of space-time cube apart from those provided through mouse action</td>
<td>7</td>
</tr>
<tr>
<td>Highlighting identified object</td>
<td>To provide visual aid for identified objects in space-time cube environment</td>
<td>8</td>
</tr>
</tbody>
</table>

#### Table 6.2: Functions in histogram

<table>
<thead>
<tr>
<th>Function accomplished through dynamic query</th>
<th>Purpose</th>
<th>Reference in figure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify Frequency</td>
<td>To show the frequency of the selected patronage</td>
<td>1</td>
</tr>
<tr>
<td>Drill-down to space-time cube</td>
<td>To make spatio-temporal context to the patronage shown in the histogram</td>
<td>2</td>
</tr>
<tr>
<td>Locate by selection</td>
<td>The yellow region represents the selected patronage and highlights the corresponding valid path in the space-time cube as shown in figure 6.4</td>
<td>3</td>
</tr>
</tbody>
</table>
Table 6.3: Functions in three axis plot

<table>
<thead>
<tr>
<th>Function accomplished through dynamic query</th>
<th>Purpose</th>
<th>Reference in figure 6.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill down to space-time cube</td>
<td>to make spatio-temporal context for the aggregated patronage over hour block</td>
<td>1</td>
</tr>
<tr>
<td>Drill down to space box</td>
<td>to make spatial context to the observation points in schematic space</td>
<td>2</td>
</tr>
<tr>
<td>Layer management</td>
<td>To select the bus line of certain year for identification and visibility purpose</td>
<td>3</td>
</tr>
<tr>
<td>Artificial shift to layer</td>
<td>To give artificial shift to the layer along the aggregated patronage axis and separate it from other layers to study the variation in that layer</td>
<td>4</td>
</tr>
<tr>
<td>Draw surface over data points</td>
<td>To provide a holistic judgement on the relations among the data points representing aggregated patronage in schematic space and time</td>
<td>5</td>
</tr>
<tr>
<td>Switch for trigger behaviour</td>
<td>To enable or disable the trigger behaviour</td>
<td>6</td>
</tr>
<tr>
<td>3d Navigation assistance</td>
<td>To assist the user in 3d rotation of three axis plot apart from those provided through mouse action</td>
<td>7</td>
</tr>
<tr>
<td>Highlighting identified object</td>
<td>To provide visual aid for identified objects in parallel coordinate plot</td>
<td>8</td>
</tr>
<tr>
<td>Warning message</td>
<td>It presents the warning message that such a surface should not be interpolated between data points as we do in the case of digital elevation model (DEM, TIN, etc.) to the users</td>
<td>9</td>
</tr>
</tbody>
</table>

Table 6.4: Functions in parallel coordinate plot

<table>
<thead>
<tr>
<th>Function accomplished through dynamic query</th>
<th>Purpose</th>
<th>Reference in figure 6.9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drill down to space-time cube</td>
<td>to make spatio-temporal context for the aggregated patronage over hour block</td>
<td>1</td>
</tr>
<tr>
<td>Drill down to space box</td>
<td>to make spatial context to the observation points in schematic space</td>
<td>2</td>
</tr>
<tr>
<td>Layer management</td>
<td>To select the bus line of certain year for identification and visibility purpose</td>
<td>3</td>
</tr>
<tr>
<td>Switch for trigger behaviour</td>
<td>To enable or disable the trigger behaviour</td>
<td>4</td>
</tr>
<tr>
<td>Switch for week day</td>
<td>To switch display of trip belonging to working day, saturday and sunday</td>
<td>5</td>
</tr>
<tr>
<td>Switch for Vehicle type</td>
<td>To switch display of trip belonging to certain vehicle type to accomplish association between vehicle capacity and patronage</td>
<td>6</td>
</tr>
<tr>
<td>Identify Trip</td>
<td>To show details pertaining to a trip</td>
<td>7</td>
</tr>
<tr>
<td>Highlighting identified object</td>
<td>To provide visual aid for identified objects in parallel coordinate plot</td>
<td>8</td>
</tr>
</tbody>
</table>
### 6.4 Improvements

#### 6.4.1 Initial prototype interface

The visualisation environment consists of visual components: visual query tools and visual tools. The user had to set spatial, temporal and object constraints, and proceed to visualisation process. A visualisation toolbox will be opened and the user could open any visual tools as per the requirement for spatio-temporal reasoning and pattern visualisation. The visualisation environment interface didn’t communicate any process flow. The initial prototype interface is shown in figure 6.11.
6.4.2 Focus group evaluation

To improve the usability of the prototype, a focus group evaluation comprising 6 persons who had background knowledge on either geo-visualisation or geo-informatics in general, was formed. The focus group session had three parts.

**Introduction** - The participants were introduced to the concepts developed during this research work through a presentation for 20 minutes. Then the prototype was demonstrated and some clarifications to the participants’ questions were made.

**Evaluation** The six participant were split into three groups and each group concentrated on exploration at either bus-line level, trip level or observation point. During the evaluation, a short interview with each participant was conducted to get feedback on the usability of the prototype.

**Short discussion** After exploration of the tools in the prototype, the participants came forth with various improvement ideas which were then used to improve the prototype design.

6.4.3 Final prototype interface

The focus group evaluation became vital in the improve of the prototype design. The following are the reviews received from the evaluation group:
6.4. Improvements

Figure 6.7: Histogram with functions referenced

Figure 6.8: Three axis plot with functions referenced
Chapter 6. Prototype design and implementation

Figure 6.9: Parallel coordinate plot with functions referenced

Figure 6.10: Circle view with functions referenced
• The constraints were not uniformly used in the visual tools. For example, temporal component in the histogram, three axis plot is different from parallel coordinate as it presents a switch to week day list. Hence the space-time cube which was used common for all three tools was misleading and the drill down operation was subtle. So, separate space-time cube tool is provided in each of these tool which could be opened from those tool interface so as to make the drill down operation clear.

• Major disadvantage of the initial prototype is the lack of process flow. The group identified it clearly and suggested to convey the multiple-view creation explicitly. The group was convinced with the idea of ‘visualisation wizard’ that it could be express the process flow explicitly.

• The group also suggested to open the visual tools required in each view to be opened automatically, so that the user is not misled in the choice of visual tools for each view.

• The layer management was not initial introduced in the space-time cube. One of the group member suggested that it could help in improving the insight in the objects represented in the space-time cube.

• Uniform design for interface, as some tools had appeared in different 'look and feel' in Microsoft Windows environment although it appeared uniform in Linux.

• The group found the 3d navigation assistance quite useful. Also the group checked the visual function for its accomplishment of the visual tasks in the tools. The group expressed its satisfaction on the visual functions in the tools. However, some extra functions were suggested. The below is a short list of those functions:

  – Visual classifier in the circle view to classify the patronage.
  – To separate the vehicle type that are generally available and currently used in the parallel coordinate plot tool.
  – To provide more information on the activity centres in the space-time cube. For instance, in the case of railway station, the information about number of trains that could arrive in the hour block can be presented. The idea behind such a suggestion is to provide drill down facility for the activity system also which the system lacked due to lack of data.

These suggestion were implemented in the prototype except for the additional function suggested. The visualisation wizard is created based on the multiple view creation process shown in figure4.3. The improved prototype interface with visualisation wizard is shown in figure 6.12.
Chapter 6. Prototype design and implementation

Figure 6.11: Initial prototype interface

Figure 6.12: Final prototype interface
6.5 Chapter digest

In this chapter, the prototype design and implementation is explained briefly. The focus group evaluation is done to improve the prototype interface design. The design of the visual tools as independent components helped in quicker implementation of the suggestions made by the focus group. However, the prototype interface design still could be improved, the improvisation process is continuous. The improvement in the prototype helped in the conducting the evaluation of the concepts developed during the research work. In the next chapter, the evaluation of visualisation concept done by the transport geographers is discussed.
Chapter 7

Evaluation

7.1 Ponder space

This chapter presents the evaluation of the concepts developed during this research work. A qualitative evaluation method, think aloud, is sought to accomplish this evaluation. A problem scenario is created. The cognitive process of solving the problem scenario is observed for each test person. This observation is done based on audio-visual data gathered during the think aloud evaluation process. A brief discussion on evaluation is provided by synthesizing these observations.

7.2 Usability evaluation

The research was carried out to aid the cognitive process to understand the existing situation in the system (to get insight into the PTS data), so as to solve certain problem scenarios, through geovisualization. Therefore, the evaluation process should assess whether the visual tasks identified help in the cognitive process of a PTS planner in such a situation. The following subsection provides a short overview on the usability evaluation techniques.

7.2.1 Usability evaluation techniques

‘Usability engineering’ has evolved as a study in the field of human-computer interaction among others. Various usability evaluation techniques are developed and could be broadly separated as quantitative and qualitative methods. Quantitative methods tries to summarise the evaluation using statistics or numbers, abstracting the cognitive process behind the evaluation process. Qualitative approach tries to bring out the cognitive process behind the evaluation process. Some of the qualitative methods are direct observation techniques, query techniques, continuous evaluation. [Suchan and Brewer, 2000] provide an overview of qualitative research methods that could be applied to mapmaking and map use pertaining to geo-context. [Blok, 2005] summarises the qualitative research methods roughly as query techniques (interviews, focus groups, questionnaires), direct observation techniques (think aloud, retrospect-
7.3. Evaluation Process

In this work, think aloud method followed by retrospecting is used for the evaluation process. The choice is based on the need to observe the cognitive process for the evaluation of concepts developed in this research work.

7.2.2 Think aloud

Think aloud is a direct observation technique for qualitative usability evaluation. Think aloud method is often applied to accomplish the evaluation through verbal protocol. However during data gathering of think aloud, visual and action protocols are also registered. [van Elzakker, 2004] provides a transcript of verbal protocol for analysis, action protocol and other context-specific outcomes like graphic model, map use matrices, shorthand overviews of the questions posed, etc. [Blok, 2005] also provides transcript of verbal protocol along with summaries on the action protocol in tables and tool use graphs, comparison between predicted and actual tool use, etc.

The visualisation environment developed, in this research work, provide different views for the user to analyse the problem from different perspectives. The process flow in solving a problem need not be similar to all user. Each user may have different approach based on their background knowledge, due to the options provided in the visualisation environment. The evaluation of such a visualisation environment should check the matching between the designed visual tasks and user’s cognitive tasks to solve the problem. Hence, cognitive process of problem solving, observed through think aloud method, is brought out explicitly by mentioning the process flow the user used, and associating each step in the process flow to the verbal and action protocol. This association could help the evaluator to judge the usability of visual tasks and functions along with the multiple views created in the visualisation environment. Figure 7.1 shows the think aloud evaluation process used in this research work along with the outcome of the evaluation such as evaluator’s direct observation, verbal protocol, action protocol and retrospecting.

7.3 Evaluation Process

The think aloud evaluation was conducted from 27-01-2005 to 03-02-2005. The cartography research laboratory at ITC, which is well-equipped with the materials required for carrying out this evaluation, was used. The complete description of the facilities in that laboratory can be found in [van Elzakker, 2004]. The laboratory had facility to record verbal protocol i.e., the user thinking aloud and action protocol i.e., user interaction with the visualisation environment. Six test persons, who had background knowledge on PTS planning, were available to carry out the think aloud evaluation process. A brief note on their background is provided in table 7.1.

The evaluation process is divided into four sessions: briefing phase, familiarising phase, think aloud phase, retrospect phase. For each phase, certain problem scenario was used to carry out the evaluation process. In the following
Figure 7.1: Think aloud evaluation process and the outcomes

Table 7.1: Test persons for Think aloud

<table>
<thead>
<tr>
<th>Test Person</th>
<th>PTS planning background</th>
<th>Geo-information knowledge</th>
<th>Whois</th>
</tr>
</thead>
<tbody>
<tr>
<td>TP 1</td>
<td>yes (Theoretical)</td>
<td>yes</td>
<td>PhD student, University Twente</td>
</tr>
<tr>
<td>TP 2</td>
<td>yes (practical)</td>
<td>yes</td>
<td>PhD student, University Twente</td>
</tr>
<tr>
<td>TP 3</td>
<td>yes (Theoretical)</td>
<td>yes</td>
<td>Lecturer, PGM, ITC</td>
</tr>
<tr>
<td>TP 4</td>
<td>no</td>
<td>yes</td>
<td>Assistant Professor, PGM, ITC</td>
</tr>
<tr>
<td>TP 5</td>
<td>yes (Theoretical)</td>
<td>yes</td>
<td>Lecturer, PGM, ITC</td>
</tr>
<tr>
<td>TP 6</td>
<td>yes (practical)</td>
<td>yes</td>
<td>Assistant Professor, PGM, ITC</td>
</tr>
</tbody>
</table>

sections, a brief insight about the problem scenario used and the four session is given.

7.3.1 Scenarios

To evaluate the support for cognitive process of getting insight into PTS data, so as to solve certain problem, scenarios were created. There are two types of scenarios. First type of scenario demands solution to optimise the resources allocated within the system so as to reduce cost or improve service. Second type of scenario demands solution to the uncertainty in the current system caused by the factors that is not controllable by the PTS operators. Two simple scenarios were created for the evaluation process. Scenario 1, which is of first type, was used during the briefing and familiarisation phase. Scenario 2, which is of second type, was used during think aloud and retrospect phase. The scenarios are given below.

Scenario 1

Connexion is the operator of the public bus transport system (PTS) for the region of Enschede. They have to cut down cost of operation. So they plan to do resource reallocation (change the vehicle type and frequency of the bus line). They would like to see the trends
in the patronage for each bus line on a working day (Mon-Fri), Saturday and Sunday for the year 2002. They are currently interested in looking at the performance of line3a running between Hengelo and Glanerbrug. After seeing the trends, they wanted to decide about the reallocation of bus type to the trips and frequency of bus line according to utilisation of the PTS.

Scenario 2

University Twente has increased the number of people attending the course by 10%. And most of the new student are given housing in Wesslerbrink. Line1a and line 1b operates between university Twente and Wesslerbrink. Connexion wants to check, whether, this will have an effect on their system in the morning peak hours (7 am -10 am) for the bus going from wesslerbrink to University Twente. They decide to look back into the survey they have conducted. They wanted to see the trends in the patronage for the past two years for that bus line to understand current status and decide on increasing the capacity of the bus or changing frequency of that bus line.

7.3.2 Sessions

The “think aloud” method had four sessions: briefing phase, familiarising phase, think aloud phase, retrospect phase. The whole session took around 2 hours (40 min + 20 min + 10 min (break) + 20 min + 20 min ).

Briefing phase

Due to lack of time, a detailed manual for the concept and prototype could not be developed. Hence, this phase was introduced. First, the concept was introduced to the test persons and followed by demonstration of problem solving using scenario 1, as above, through the prototype. This session was for about 40 minutes. It was an interactive tutoring session where test person was allowed to pose questions and also allowed to think freely to solve the scenario, conceptually.

Familiarising phase

The test person was allowed to practise the think aloud method and the prototype using scenario 1. The test person can pose questions on use of tools in the prototype and also on the concept which he/she is trying to do.

Think aloud phase

In this phase, the test person was given scenario 2 and made to do think aloud process. The test person was now allowed to pose questions on use of functions in the tools, since the visualisation environment is very complex to remember all the functions. However, when such help was sought, the test person was asked to speak out, ‘what he/she wanted to do with such a function’.
Chapter 7. Evaluation

Retrospect phase

In this phase, the audio-visual recorded in the think aloud phase is reviewed along with test person by the evaluator. The evaluator could pose questions to some lack of clarity in cognitive process of the test person. Also the test person was allowed to freely review what he/she was doing in the think aloud phase. Only TP 1 and TP 3 had time to do this phase.

7.3.3 Outcomes

The first four test persons were able to take part in briefing phase, familiarising phase and think aloud phase with only test persons TP 1 and TP 3 participating in retrospect phase. TP 5 had continuous problem in working with the prototype as the program crashed often. TP 6 had time to take part only in briefing and familiarising phase. Hence, the evaluation process had effectively four test persons. The outcome the evaluation process the first four test person is summarised in tables A.1, A.2, A.3, A.4 respectively.

7.4 Drawbacks

The evaluation has some drawbacks that one has to keep in mind before inferring from the outcomes of the evaluation.

1. The test persons involved in the evaluation process are not real users, however, they may have equal insight in the problem similar to the real users.

2. The evaluation is assumed valid based on the [Nielsen, 1994]'s recommendation that

   \[ \text{plan for } 4 \pm 1 \text{ subjects in a thinking aloud study, with the final number of subjects determined by} \]
   
   - the skills and experience of the experimenter (evaluator)
   - the number of iterations planned for the design
   - the financial or other impact of the use of the system

   (a) The number of test persons needed to completely evaluate the concept is not ascertained. Only six test persons were within reach during the evaluation period. Of the six, only four outcomes are effective due to the reasons explained in previous section.

   (b) Evaluator is not much experienced in conducting the think aloud process. However, evaluator could practise the think aloud process with one pilot test person within a short available time period.

   (c) The number of iteration for evaluation process is not ascertained. Only one iteration is accomplished to evaluate the concept developed during this research. One iteration is assumed to be sufficient, since the spatio-temporal reasoning required to develop the concept was
7.5 Inference

Multiple views help in getting insight into the problem by providing opportunity to review the opinion (hypothesis) - seeing the cognitive process of the four test person, it is clear that given an option to explore the system from different perspectives or views, the user could get better insight into the system. This helps to avoid misconceptions from single view. It is clearly observed, when TP 2 expressed that the difference in comparison based on exploration at step 2 and 5 as in table A.2. It can also be clearly seen when TP 3 sees the increase in patronage for two observation point in steps 2 and 4 as in table A.3.

Visual representations used in each view were appropriate - The visual representations identified for each view helped the test person to explore the data by presenting spatio-temporal patterns at different ontological level: busline level, trip level or observation point level with or without aggregation, during the cognitive process to solve the problem scenario.

Visual tasks helps in spatio-temporal reasoning - The visual representations used in each view did not represent all spatio-temporal reasoning components (what, when and where). This is inferred based on the cognitive process and action protocol of the test persons which is listed in the tables A.1, A.2, A.3, A.4.

- Locate task helped to accomplish the complete spatio-temporal reasoning by linking the visual representations either to space box or space-time cube or both.
- Associate task helped to relate to other parameters like bus type and activity system. However, during the evaluation process only association to bus type is often used by the test persons. The other association to activity system represented as stations in space-time cube was not used. This may due to the problem scenario used for evaluation. However, TP 3 provided feedback for enhancing the association to activity system by using space-time prism in space-time cube during retrospect phase.
- Compare task was effectively accomplished in circle view (variation in ‘what + when’), histogram (variation in ‘what’), three axis plot (variation in ‘what+when+where’) and parallel coordinate plot (variation in ‘what+where’) using dynamic query functions.

3. The scenarios used during the evaluation process are not real situations, i.e., these scenarios are not relevant to Connexxion bus company.
• Identify task was indeed useful for gaining insight into visual objects presented in each visual representations. However, information provided during the identify operation should be appropriate.

**Functions provided in space-time cube enhances its readability** It is clear from TP 4 while using space-time cube during exploration step 5 as in table A.4. However, TP 1 suggests need for ‘orientation guide in 3d space (space-time cube and three axis plot)’ while rotating where there is a possibility of losing sense of direction. TP 3 suggested ‘zoom to selected’ apart from currently used highlighting methods.

### 7.6 Chapter digest

In this chapter, the evaluation of the concept developed during this research is carried out using think aloud - qualitative usability evaluation technique. The cognitive process of the test persons are observed to arrive at inferences on the usability of the concepts which were discussed at the end. The visualisation environment is proved to explore the spatio-temporal patterns in PTS data to get insight into them, through this evaluation. However, the evaluation process did not test the visual functions in all the visual tools. The functions in space-time cube was reviewed when the test persons expressed their views on those functions without any request for reviewing them.
Chapter 8

Conclusions and recommendations

The main goal of the research is to identify and develop geovisualization methods and tools to explore the large transport dataset to get insight into them. To achieve the goal, investigation into the characteristics of the public transport data and visualisation techniques was carried out. Based on the investigation, a visualisation environment is created. This environment is tested for its usability by the public transportation system experts and results are discussed. In the next section, the investigation, visualisation environment and its usability assessment are summarised by answering the research questions. This is followed by recommendations for future work.

8.1 Research questions revisited

1. What are the characteristics of public transport data?
To understand public transport data, one has to study its ontology and its spatio-temporal characteristics. Ontological characteristics provided information about the hierarchical relations in the PTS data i.e., ‘bus line has more trips; each trip has bus stops to make; at certain bus stops observations are made’. Spatial characteristics provided information on PTS network, order of bus stops and valid path for an observation. Temporal characteristics provided information about the schedule of the bus trips, valid period for a bus line and moment of observation.

2. What are the visual tasks that are required to explore to get insight into large public transport dataset?
To explore PTS data, one has to study the spatio-temporal reasoning required by the PTS planner to get insight into them. Based on these spatio-temporal reasoning, the visual tasks such as locate, identify, associate and compare were identified. Locate task helped to find out ‘when’ and ‘where’ a patronage has occurred. Identify task helped to provided information behind the visual representation based on information from the database. Associate task helped to provide information about the activity system and other parameters like ve-
8.1. Research questions revisited

3. **What are the functions required to perform visual tasks in order to explore the spatio-temporal patterns in the large public transport dataset?**

The visualisation techniques like dynamic queries and linked views helped to explore the spatio-temporal patterns to accomplish these spatio-temporal reasoning. Visual tools such as ‘object box’, ‘space box’ and ‘time box’ acted as visual query tools to trigger the visual representations, of which, space-time cube is considered the most prominent because it represents ‘what’, ‘where’ and ‘when’ components of the objects.

4. **What are the additional tools required to enhance the visual exploration to get insight into the large transport dataset?**

A set of visual tools such as circle view, parallel coordinate plot, histogram and three axis plot are identified to represent the PTS data at bus line level, trip level and observation point level with and without aggregation. These tools offer different perspectives to the PTS data.

5. **What could be the role of space-time cube to provide support for the above functions?**

The set of additional visual tools represent only certain reasoning components (what, when, where). Space-time cube and space box are linked together with these additional visual tools to provide link to reasoning components that are not presented in them.

6. **How to evaluate the usability of the visualisation environment?**

The usability of the visualisation environment is tested at conceptual level by prototyping the concepts. The observation of the cognitive process, while solving a problem scenario using this visualisation environment, is used to evaluate the concepts of multiple views and visual tasks. Think aloud method is used for evaluation. The evaluation procedure and feedbacks have been discussed in chapter 7 - ‘Evaluation’.

The conclusion can be summarised as follows:

To solve a problem scenario, PTS planners do reasoning with PTS data to get insight into them. A visualisation environment is created, in which, this reasoning is done through the execution of visual tasks. This environment has visual query tools such as ‘object box’, ‘space box’ and ‘time box’ that triggers the visual representations, of which space-time cube is considered most prominent. A set of additional visual tools such as circle view, parallel coordinate plot, histogram and three axis plot are used to explore PTS data at bus line level, trip level, observation point level with and without aggregation. To enhance visual tasks, these additional tools are linked to space-time cube and space box. Usability evaluation of this en-
environment is done by PTS experts. The results of this evaluation has proved that this environment help to explore the spatio-temporal patterns in the PTS data to get insight into them.

8.2 Recommendations

The following are the recommendations for future work:

- Currently, one ‘what’ component i.e., the patronage is used in the visual exploration of PTS data. There could more than one ‘what’ component that can be used to visual exploration by combining them with logical operators.

- Representation of activity system as space-time prism could allow explicit representation of people’ activity pattern that could be associated with flows.

- Use of animation in space-time cube to emphasise the spatio-temporal patterns could be studied.

- Currently, there are no spatial and temporal zooming available in the visualisation environment. They are potential research topics that deals with spatio-temporal generalisation that could also help in providing insight into the PTS data.

- Currently, the evaluation of the visualisation environment is conducted at conceptual level. The evaluation can be done at implementation level so as to improve the interface design and visual functions used in the prototype ‘just’.

- Space and time are inherent components in transportation system. During interaction with transport people, the use of space-time cube in the area of traffic flows studies are found to be relevant. An attempt to get insight into traffic flows through geovisualization seems to be a good possibility.
8.2. Recommendations
Bibliography


Bibliography


Appendix

A.1 Outcomes of Think aloud

Table A.1: Test person 1

<table>
<thead>
<tr>
<th>No</th>
<th>Cognitive process</th>
<th>Action protocol</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exploration at observation point level using histogram</td>
<td></td>
<td>TP 1 obtained overview about the variation in overall patronage</td>
</tr>
<tr>
<td>2</td>
<td>Drill down to spacetime cube</td>
<td>Performed locate operation to answer the above questions.</td>
<td>TP 1 shifted the base map to the selected valid paths in space-time cube and used zooming &amp; 3-d navigation functions to perform locate operation.</td>
</tr>
<tr>
<td>3</td>
<td>Exploration at bus line level using circle view</td>
<td>Performed sector assigning</td>
<td>Apart from seeing the variation in aggregated patronage, TP 1 saw that there could be some problem in the afternoon hours for current scenario.</td>
</tr>
<tr>
<td>4</td>
<td>Exploration at trip level using parallel coordinate plot</td>
<td>Associated trips with the bus type used using ‘switch for vehicle type’</td>
<td>TP 1 concluded that the existing bus type could cater the demand created by scenario 2.</td>
</tr>
<tr>
<td>5</td>
<td>Exploration at observation point level with aggregation over hour block using three axis plot</td>
<td>Selected 'line 1 a' for working day using layer management.</td>
<td>TP 1 could see both variation in space and time for the line 1 a on working day. TP 1 identified certain observation point has more patronage between 7 am and 9 am.</td>
</tr>
</tbody>
</table>

Retrospect phase

- Circleview- "This is the easiest way to compare"
- Space-time cube & Three axis plot - "orientation problem during rotation"
- Histogram gives first impression in the variation of patronage
- "need more training for using the tools especially 3d tools"
### Table A.2: Test person 2

<table>
<thead>
<tr>
<th>No</th>
<th>Cognitive process</th>
<th>Action protocol</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Familiarization spatial configuration of PTS network of Enschede city using space box</td>
<td>Performed identify operation to locate observation point - 'Wesslerbrink'</td>
<td>TP 2 was not able to locate the observation point due to lack of labels for observation point.</td>
</tr>
<tr>
<td>2</td>
<td>Exploration at bus line level using circle view</td>
<td>Compared variation in patronage for bus line 'line 1a' for different time period.</td>
<td>TP 2 was critical about the information provided during the identify operation. TP 2 insisted that only aggregated observation and hour block was shown, but the number of trips in that hour block was not shown which could be misleading during comparison.</td>
</tr>
<tr>
<td>3</td>
<td>Exploration at trip level using parallel coordinate plot</td>
<td>Associated trips with bus type used to see the trend in usage of the bus.</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Drill down to space box</td>
<td>To locate the schematic observation point in geographic map using space box.</td>
<td></td>
</tr>
</tbody>
</table>
| 5  | Exploration at observation point level without aggregation over hour block using histogram | TP 2 created two separate histograms for the year 2002 and 2003 and compared visually. | • TP 2 wanted to compare the two histograms in the same visual representation using different colors for different years.  
• TP 2 saw not much variation in frequency of patronage in histogram but however in circle view TP 2 saw increase in patronage for the year 2003 than in 2002. |
<table>
<thead>
<tr>
<th>No</th>
<th>Cognitive process</th>
<th>Action protocol</th>
<th>Observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Exploration at bus line level using circle view</td>
<td>Performed 'sector assigning'</td>
<td>• TP 3 didn’t see much demand in the morning peak hours.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• TP 3 wanted to see in which part of the trip had the more demand.</td>
</tr>
<tr>
<td>2</td>
<td>Exploration at trip level using parallel coordinate plot</td>
<td>Associated trips with bus type</td>
<td>• TP 3 saw none of the trips had patronage more than actual capacity of the bus used.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>• TP 3 saw at two observation points, the trend in patronage remained maximum for the last two years.</td>
</tr>
<tr>
<td>3</td>
<td>Drill down to space box</td>
<td>Located the two observation point in space box</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>Exploration at observation point level with aggregation over hour block using three axis plot</td>
<td>Compared variation in patronage in space and time for bus lines on working days between different years using artificial shift to layer.</td>
<td>TP 3 could see the increase in patronage in 2003 for the two observation points clearly.</td>
</tr>
<tr>
<td>5</td>
<td>Exploration at observation point level without aggregation using histogram</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Drill down to space-time cube from histogram</td>
<td>Wanted to perform locate operation. Unfortunately, the program crashed.</td>
<td>TP 3 recalled from familiarizing phase and commented that space-time cube is really interesting where one can know where the trip is made and in what hour it occurs.</td>
</tr>
</tbody>
</table>

Retrospect phase

Circle view is easy to compare different scenarios
TP 3 suggested it will be interesting to drill down with circle view in time.
Space-time cube could also included space-time prism to represent activity system so as to improve associate task.
Three axis plot is quite useful in seeing the variation in space and time. `Zoom to selected’ function in space box and space-time cube during locate operation
### Table A.4: Test person 4

<table>
<thead>
<tr>
<th>No</th>
<th>Cognitive process</th>
<th>Action protocol</th>
<th>Observation</th>
</tr>
</thead>
</table>
| 1  | Exploration at bus line level using circle view | Performed ‘sector assigning’ | • TP 4 saw that the bus line was much crowded in the afternoons of the working days for last two years.  
• TP 4 wanted to compare the working days with Saturdays of last two years. |
| 2  | Exploration at bus line level using circle view using different constraints | • Set new constraints using visual query tools.  
• Performed ‘sector assigning’ | TP 4 could see that Saturday was much less crowded than working day and afternoon peak hour was crowded than morning peak hour in working days for the last two days. |
| 3  | Exploration at trip level using parallel coordinate plot | • Compared patronage within trips for working days, Saturday and Sunday using ‘switch for week days’.  
• Associated trips with bus type  
• Drill down to space box to located the schematic observation points | |
| 4  | Exploration at observation point level without aggregation using histogram | | TP 4 commented that information presented in histogram is strange and said ‘My mind is telling the opposite thing that higher frequency represents higher patronage.’ |
| 5  | Drill down to space-time cube from histogram | | TP 4 said ‘didn’t find space-time cube much informative. It is not easy to absorb information from it, although it is very elegant . . . The idea that space could be moved over time is very nice from a user perspective… zooming and rotating - I like a lot. It helps to see all three elements - what, when where. However when zoomed out, you get lost’. |