5 Space and Time

5.1 Motivation

People have to solve problems in time and space every minute of the day. Most of our decisions and actions depend on where we are and when. They also usually involve where other people or significant things are and how we expect the situation around us to develop. When the spatial scope of such decision-making exceeds an area that is directly observed or well-known people have traditionally used maps. These imperfect representations of reality serve as adequate models to solve problems and support decisions. Maps not only help people to orient themselves in geographical space but also to gain an understanding of events and evolving phenomena and to make discoveries – indeed, much map use can be considered (geo)visual analysis.

An historic example is the discovery of the relationship between locations of reported cholera deaths in London and the location of a contaminated water pump. This geographic relationship was established in 1854 by plotting the locations of the deaths and water pumps on a map (see Figure 5.1). Doing so enabled Dr. John Snow to infer that the water source was contaminated. There is a temporal component to the story too. Decrease of the number of the cholera deaths after removing the pump handle subsequently confirmed the causal link.

More mundane problem solving in time and space is frequent and personal – avoiding slow traffic on the way to work, watching the weather forecast to decide what to wear, finding a nice place to live or go on holiday.

More complex systems, and their representation in larger datasets with more detail, greater scope, and higher resolution, enable us to address more complex spatial and spatio-temporal problems. To address the current issues faced by international society, people need to consider and understand global processes involving demography, economy, environment, energy, epidemic, food, international relationships, and other factors. They need to know how characteristics of these processes vary, develop and relate in time and space. People must strive for sustainable life, whilst preserving the environment and using the resources in a manner that is wise and just. People also need to know the risks from possible natural and man-made disasters and be prepared to protect themselves and to deal with the consequences. In these circumstances, simple maps with points and crosses are insufficient. To approach these problems, people need sophisticated maps and advanced computational techniques for data analysis.

Space and time are essential

An historical example

Complexity of spatio-temporal analyses increases



support decision making in ways that take advantage of the kind of visual thinking deployed by Dr. Snow.

Figure 5.1: In the map made by Dr. John Snow in 1844 the death cases (indicated by bars) are clustered around the location of one of the water pumps. The cluster is encircled. Cited and analysed by Gilbert^[49] and Tufte^[115] (Source: http://johnsnow.matrix.msu.edu/)

This need refers not only to scientists and highly qualified experts. Nowadays, more and more citizens become spatio-temporal analysts when planning their journeys, looking for jobs, or searching for suitable places to live and visit. Those concerned about the development of their communities, regions, and countries want to understand the current situation and how this might be changing. They want to compare possible options and to take part in choosing the right strategies. They want to take advantage of the mass of data that is being collected and to which they are contributing. To do so, they take advantage of their visual and spatial capabilities in using maps. These maps show the locations of things and also reveal spatial and spatio-temporal patterns. They may be weather maps, election maps or disease maps and include maps reproduced in traditional ways on paper and their more sophisticated electronic descendants, which provide interactive tools for analysis. Our task is to give them such tools and help them use these tools to meet their information needs. The following scenario describes one of the possible ways in which visual analytics tools for spatio-temporal analyses could be developed and deployed to address a complex and changing process that affects large numbers of people.

Visual analytics tools are needed

5.2 A Scenario for Spatio-Temporal Visual Analytics

Late on Tuesday afternoon in mid-summer a severe thunderstorm passed through The City.

The Insurance Analyst

A number of reports of large hailstones mean that an insurance company requires a rapid overview of the damage incurred. To run an initial damage assessment, the insurance analysts need information about where the hail events occurred and about the things that are damaged. They therefore look for information from weather services, which provide data from different weather stations. Since hailstorms are very local, their exact locations cannot be detected entirely from existing sensor networks – storms often fall between the sensors. Therefore, the analysts make use of information from affected citizens provided on the Internet. Searching blogs, micro-blogs, photo sharing sites and other services where users make personal information available (including Flickr, Twitter and RSS feeds) reveals more detailed information about the spatial and temporal distributions of the hail events. The analysts use an interactive map to position the reported observations and transform them into structured, spatially and temporally referenced data, which are added to the database and simultaneously visualised. Spatial statistics are then used to identify possible tracks of the hailstorm derived from the data and probabilities associated with each. The results are also added to the map interface and data points are visually differentiated from the tracks that are derived from them. By combining these with the depicted observations, the analysts determine areas that are probably affected.

Next, the analysts are interested in the things that were damaged during the storm. Those most vulnerable to hail include cars and agricultural areas. Cars are not static in time and place; therefore, data depicting traffic flow is considered. Such data is available from roadside sensors and increasing numbers of vehicle mounted devices. The analysts do not have access to 'live' data but quickly extract typical usage patterns for Tuesday rush hour in the summertime from a traffic database. By applying spatial and temporal filters to this dataset, the analysts can estimate the number of cars that passed through areas affected by the hailstorm during the time when it occurred, and make an initial assessment of the damage. The analysts put the filtered traffic flow data on the map and look at the typical destinations of the flows, to see in which districts the car owners live and to compare this with the spatial distribution of the clients of the insurance company.

In order to detect the agricultural damage, satellite images showing information about the present status of agricultural areas are considered in combination with a land use database. One of the analysts recalls driving through the affected area some time ago and noticing strawberry fields. At this time of the year, the strawberries should have been already harvested. The analysts locate these areas on the map display and remove them. They also look at the other fields Analysis of storm tracks

Estimate disaster consequences

and exclude those where no real damage from the hailstorm is expected. For the remaining fields, they calculate the estimated damage using the data about the types of the crops, the productivity of the fields, and the prices for agricultural products.

Report results of analysis by visual aids Using interactive visual aids for report generation, the analysts report their findings. Besides a printable illustrated document, a series of annotated snapshots are developed from the visual displays. These are interactive and have links to the corresponding data and analysis artefacts, which are stored in the database. This report is forwarded to other working groups in the insurance company.

One of these groups examines long-term trends in hazard development and damage distribution. They investigate whether the frequency of hail events, their intensity or the associated damage are changing. Are hail events concentrated in certain areas? Another group deals with insurance contracts and customer issues and examines whether the spatial distribution of hail insurance customers is related to the spatial pattern of hail events. How many people in the most affected areas have an insurance policy? Should the insurance conditions be changed? How can exposure to risk be reduced?

The Family

A family living in The City has been affected by the hail. Their car was damaged whilst the father drove home from work. They are very upset about this and want to get more information about hazards in The City. They also want to know what they could do to protect themselves against hazards. They do this through a 'risk explorer' on the Internet. This interactive application enables citizens to examine their exposure to different hazards at different times and places according to different assumptions and levels of uncertainty. They are able to simulate different hazard events, such as historical or recent storms or floods and extremes with particular return frequencies to get an impression of their exposure to this type of hazard and the likely consequences. The risk explorer includes a discussion forum and a story-telling facility where people can place information about local hazard events on a map and an associated timeline. They can also post descriptions, annotations, and photos. People can report hazard events and discuss their occurrence and protection measures. The family subscribes to a warning service that will inform them about hazardous events more precisely in the future. The service provides information tailored to their situation. It derives the family's current and predicted location from an electronic diary, GPS-enabled mobile device, or cell-phone. If it coincides in time and space with predicted hazards, personal warnings are sent and alternative routing options and travel times are provided that account for the hazard. A visual display, which is adapted to the available device (PC, netbook, or mobile phone), explains why the warning has been sent and what the options are. By interacting with the display, people can enter additional facts about the current situation and their planned movements and ask the service to update predictions and recommendations. It is possible to compare the suggested options, choose the most appropriate one and,

Access to individually adapted information

Development of

long-term strategies



Figure 5.2: A flooded chemical factory. © Greenpeace/Vaclav Vasku

if necessary, further adjust it interactively according to personal needs and priorities.

The Decision-Makers

Although the hail was a heavy and damaging event in The City, floods are the predominant problem. Politicians and local authorities have heard about an increase of heavy rainfall events and related flash floods as likely effects of climate change. They have to decide how to protect their community from floods in the future. To support decisions and develop strategies they need scientifically derived information that is presented clearly with assumptions, uncertainties, and alternative outcomes at the fore. Thus, expressive models are needed to simulate different situations related to different local conditions and climate parameters (see also Chapter 4). Scientists apply such models to calculate possible scenarios for The City and explain to the authorities the implications for their community.

An Industrial Town is upstream of The City in a neighbouring country. The River that flows through The City originates in this country and passes through the Industrial Town on its way downstream. In the past floods have inundated factories in the Industrial Town (see Figure 5.2) and resulted in toxic material reaching The City and adjacent municipalities. Close collaboration between local and national governments is necessary in order to discuss safety precautions, to access and share relevant data, and to rapidly exchange information for early warning and protection. The Town's authorities have established contact and working relationships with neighbouring local and national authorities.

Simulation of scenarios and consequences

Collaborative decision making

Now they start a collaborative decision finding process where all stakeholders are involved: different authorities, scientific advisors, the public, and several interest groups as well as stakeholders from the neighbouring country. The goal of this process is to establish risk and develop a pragmatic flood prevention strategy to protect future interests. Interactive visual tools facilitate the collaborative process. Analysts may look at specific aspects in detail by issuing interactive queries. Individual insights can be placed as annotations on the map. Annotation can be made visible to other analysts to initiate discussion. The arguments made are automatically tracked and a visualisation of the discussion flow helps in finding a good compromise for the discussed matter.

The Community

Since local authorities know that successful risk management requires not only technical and planning measures but also well-informed people with high risk awareness, they have also started a risk-awareness campaign in the schools. Teachers and school children work with the Internet 'risk explorer'. They explore the risk in their home area and also in other areas around the world. They can apply simulation models in a user-friendly manner to get a better impression about the effects of hazardous events and protection measures. A 'serious game' allows them to take the role of hazard defenders or decision makers to learn about the complexity of risk management; with a high score they can win a prize.

The Spatio-Temporal Analyst

Note that all actors in these linked scenarios are spatio-temporal analysts: the insurance experts, administrators, politicians, scientists, engineers, insured and affected citizens, and school children. As spatio-temporal analysts, they must be enabled to find, see, summarise, relate, and comprehend changing and alternative relevant information effectively and efficiently and to record, report upon, and share discoveries. Sophisticated analytical tools with appropriate interactive visual interfaces for discovering relationships, synthesising knowledge, and making decisions can support this activity by providing the right people with the right information at the right time. Providing these is a challenging task, but one that can take advantage of a number of recent and developing technologies and scientific knowledge. To work effectively and enable beneficial decisions to be made, these tools must deal appropriately with the specifics of time and space.

5.3 Specifics of Time and Space

Most of the existing techniques for computational analysis, such as statistics and mathematical modelling have been developed to deal with numbers.

Share insight with the community

Visual analytics methods must handle space and time appropriately Temporal and spatial data have a number of properties that distinguish them from other types of data^[8]. Unfortunately, their specifics are often ignored. Thus, temporal references and spatial coordinates are often treated just in the same way as ordinary numeric variables. This approach cannot yield valid analytical results. Time and space require special treatment and specific analysis methods.

5.3.1 Dependencies Between Observations

The processing, integration, and analysis of spatio-temporal data is both constrained and underpinned by the fundamental concept of spatial and temporal dependence. In the spatial domain, this is often referred to as 'the first law of geography' or 'Tobler's first law': "everything is related to everything else, but near things are more related than distant things"^[112]. According to this law, characteristics at proximal locations tend to be correlated, either positively or negatively. In statistical terms, this is called spatial autocorrelation. Similar concepts of temporal dependence and temporal autocorrelation exist for relationships in time. Spatial and temporal dependencies forbid the use of standard techniques of statistical analysis, which assume independence among observations, and require specific techniques, such as spatial regression models, that take the dependencies into account.

However, spatial and temporal dependence not only set constraints but also serve as sources of information and give important opportunities for data processing and analysis. Thus, spatial and temporal dependence enable:

- interpolation and extrapolation, which can be used to fill gaps in incomplete data,
- integration of information of different types and/or from different sources using references to common locations (spatial overlay),
- spatial and temporal inference,
- and many other operations (e.g., spatial and temporal navigation).

However, the effect of the first law is not absolute. In geography for instance, the law is weakened by the heterogeneity of the geographical space, where water differs from land, mountain range from valley, forest from meadow, seashore from inland, city centre from suburbs, and so on. Moreover, every location has some degree of uniqueness relative to the other locations. Spatial dependence is also affected by natural or artificial barriers. For example, the climate may significantly differ in two neighbouring valleys separated by a mountain range, and people's lives in two villages separated by a state border may also differ quite a lot. Similarly, temporal dependence may be interrupted by events; for example, radical changes may be caused by storms or floods. Relatedness between things may depend, not only on their distance (proximity) but also on direction. Thus, a flood or water pollution spreads downstream along a river. Events in time have an effect on future rather than past events. The notion of proximity is also phenomenon-dependent. It may be defined spatially, for example, in terms of distance by roads, rather than the straight line distance or distance on the Earth's surface. Temporal distances may be measured, for Time and space are more than just numbers

The first law of geography

Applicability of the first law

instance, in terms of 'working days' or 'number of hours under particular conditions' – inundation for example.

Some of these discontinuities, complexities and characteristics can be modelled and accounted for in informed spatio-temporal analysis. But it is impossible to account for all diverse factors affecting spatial and temporal dependence in developing fully automatic methods for analysis. Instead, visual analytics techniques may allow the analyst to see where and how the effect of the first law is modified by particular local conditions and to make necessary adjustments in the analysis, e.g., by varying parameters of analytical methods or choosing other methods (see also Chapter 4).

5.3.2 Uncertainty

Unfortunately, in real world scenarios data is not always 100% perfect. The quality of data is often decreased due to errors, missing values, deviations, or other sources of uncertainty (see Chapter 3). Reasons might be, for instance, inaccurate data acquisition methods, data transmission problems, or even analytical processes such as spatial interpolation or temporal aggregation that result in loss of information. As of today, there is no consensus on the definition of uncertainty (often also denoted as 'data quality problem'); a universal way to visually represent uncertain data does not exist. One of the few closed definitions explains uncertainty as the "degree to which the lack of knowledge about the amount of error is responsible for hesitancy in accepting results and observations without caution"^[60]. More generally, uncertainty can be considered a composition of different aspects such as:

- error outlier or deviation from a true value,
- imprecision resolution of a value compared to the needed resolution (e.g., values are highly accurately given for countries but are needed for states),
- accuracy size of smallest interval for which data values exist,
- lineage source of the data (e.g., raw satellite images or processed images),
- subjectivity degree of subjective influence in the data,
- non-specificity lack of distinctions for objects (e.g., an area is known to be used for growing crops, but not its specific kind), or
- noise undesired background influence.

From an application oriented perspective, one can distinguish between different geometric uncertainties; geospatial, time, and thematic data uncertainty. Some of these concepts are quite different from others and might therefore require special treatment. What we are lacking is a unified term that subsumes the relevant kinds of distrust in some data.

To allow for effective analysis of spatio-temporal data, uncertainty has to be considered. Analytical methods must be tuned to the uncertainty in the data and visual representation have to convey inherently different kinds of uncertainty. Only if people are made aware of data quality problems and understand their implications, can visual analytics methods help them make informed decisions.

Different sources and aspects of uncertainty

5.3.3 Scale

Spatio-temporal phenomena and processes exist and operate at different spatial and temporal extents. Thus, we say that a hail storm is a local, short-term phenomenon while climate change is global and temporally extended.

The dimension of time can include a single or multiple levels of scale (also called granularity of time). Temporal primitives can be aggregated or disaggregated into larger or smaller conceptual units. For example, 60 consecutive seconds are aggregated to one minute or five time steps in a discrete simulation model may correspond to one second in physical time. Most of the current tools for analysis and visualisation use models where the data is sequences of simple (time-point, value) pairs; only one level of granularity is considered. However, this is inadequate for a wide range of applications. For instance, in analyses related to hazard protection, it may be necessary to combine time scales with different granularities. For instance, the Decision Makers in our scenario would need to concurrently analyse outputs of simulation models with monthly resolution, data from weather forecast services specified for days, and annual estimates coming from prediction models of changing climate conditions (which in turn might have been mined from data based on decades or even centuries, see also Chapter 4). Developing methods and interfaces that achieve this is a challenging task, that is inadequately addressed by current methods of visualisation and analysis.

The scale of spatial analysis is reflected in the size of the units in which phenomena are measured and the size of the units in which the measurements are aggregated. It is well known in geography that the scale of analysis may significantly affect the results. For instance, patterns or relationships discerned at one scale may not be detected when examined at another scale. In extreme cases, opposite relationships may occur in the same place or time when different scales are considered. Such results can be regarded as highly scale dependent. Some phenomena and some places are more scale dependent than others. Representing this information numerically and graphically is a complex process.

In order to observe and study a phenomenon most accurately, the scale of analysis must match the scale of phenomenon under consideration. Identifying the correct scale of phenomena is therefore a key problem for analysts. It is not always easy, however. In order to understand what scale of analysis would be adequate, analysts may need to use 'trial-and-error' approaches. Given spatial and/or temporal units of a particular size available in the original data, they can be aggregated into larger units in various ways. The opposite operation, decreasing the unit size, is only possible with involvement of additional data. Thus, in our example scenario, the scale of the data provided by the weather sensors was too large for examining the hail storm phenomenon. The analyst had to involve additional data to perform the analysis at an appropriate scale.

On the other hand, the scale of analysis should also be chosen according to the goals of analysis. As an example, in Figure 5.3, traffic data is visualised at

Scales of time

Scales of space

Finding an appropriate scale is difficult



Figure 5.3: Analytic results are very dependent on the spatial scale used. At different scales, detailed or only very coarse traffic patterns can be made visible. (Source: produced using the CommonGIS visual analytics toolkit described in Andrienko & Andrienko^[7], pp. 657-658)

different spatial scales and levels of aggregation: from individual trajectories of cars and aggregated flows between crossings and turns to large-scale aggregated flows between districts. The appropriate scale depends on whether the analyst needs to investigate the movement at a specific crossing and the adjacent streets, to detect the major routes of the traffic and to assess the traffic intensity on the major roads, or to consider the amount of movement between larger areas.

In aggregation, it is essential to be aware about the modifiable areal unit problem, which means that the analysis results may depend on how the units are aggregated. This refers not only to the sizes of the aggregates (scale effects) but also to their locations and composition from the smaller units (the delineation of the zones). Therefore, it is always necessary to test the sensitivity of any findings to the means of aggregation. Furthermore, it is widely recognised that various scales of geographic and/or temporal phenomena interact, or that phenomena at one scale emerge from smaller or larger phenomena. This is captured by the notion of a hierarchy of scales, in which smaller phenomena are nested within larger phenomena. Local economies are nested within regional economies, rivers are nested within larger hydrologic systems, and so on. This means that analytical tools must adequately support analyses at multiple scales considering the specifics of space and time. Since time is still too often considered just as ordinary numbers, we next shed some light on what makes time such a special attribute.

5.3.4 Time

In contrast to common data dimensions, which are usually 'flat', time has an inherent semantic structure, which is one source of increased complexity. By convention, time has a hierarchical system of granularities, including seconds, minutes, hours, days, weeks, months, years, centuries, and so on. These granularities are organised in different calendar systems. Furthermore, time contains natural cycles and re-occurrences. Some of these are regular and relatively predictable such as seasons, others are less regular such as social cycles like holidays or school breaks or economic cycles. In particular, two specific aspects of the dimensions of time have to be taken into account when devising analytical methods for temporal and spatio-temporal data.

First, the temporal primitives that make up the temporal dimension must be considered. The temporal dimension can be viewed as composed of time points or time intervals. A time point is an instant in time. In contrast, a time interval is a temporal primitive with an extent. The choice of appropriate primitives must depend on the properties of the data and the problem at hand. Most of today's visual representations and analytical techniques do not differentiate between point-based and interval-based temporal data and do not represent the validity ranges of the data appropriately; and we know little about how to do this effectively.

Secondly, the structural organisation of the temporal dimension is a relevant aspect. Three different types of temporal structures exist: ordered time, branching time, and multiple perspectives. Ordered time can be subdivided into two further subcategories: linear and cyclic time. Linear time corresponds to our natural perception of time as being a continuous sequence of temporal primitives, i.e., time proceeds from the past to the future. A cyclic time axis is composed of a finite set of recurring temporal primitives (e.g., the times of the day, the seasons of the year). Natural hazards such as flood events can also exhibit cyclic behaviour. To communicate the time patterns of such hazardous events and to allow for appropriate crisis management, this cyclic behaviour has to be represented. The concept of branching time facilitates the description and comparison of alternative scenarios, which is particularly relevant for planning or prediction. Time with multiple perspectives allows more than one point of view at observed facts. This type of time-related data is generated, in particular, when people describe their observations about hazard events via blogs or other

Granularity of time

Temporal primitives: time points or intervals

Different structures of time

online means: each reporting person may have a distinct perspective on the events. While linear and cyclic time have already been addressed by existing visual analytics approaches, methods for analysing data related to branching time and time with multiple perspectives are still scarce. There is a need for methods that allow analysts to consider, compare and report upon different types of time in combination. Without such consideration, the complexities and subtleties of spatio-temporal data will not be accessible to analysts. This is important for risk management but also for other areas and problems. There may be hidden patterns in Dr. John Snow's data that would only be revealed through these perspectives.

Let us now look at the existing disciplines and technologies addressing the specifics of time and space.

5.4 State of the Art

5.4.1 Representation of Space

Cartography

Cartography has a long and venerable history

Maps represent spatio-temporal phenomena visually Cartography is the discipline dealing with the conception, production, dissemination and study of maps. Geographers and other professionals working with spatial data don't have to be convinced of the unique qualities of maps. They use them to express their ideas, to make a point, to obtain new knowledge and communicate among colleagues, and of course along with almost everyone else they use them to orientate and navigate. Outside the professional community, maps are also very much appreciated.

Maps have the ability to present, synthesise, analyse and explore the real world. Maps do this well because they present a selection of the complexity of reality and visualise it in an abstract way. The cartographic discipline has developed a whole set of design alternatives and guidelines to realise the most suitable map that offers insight in spatial patterns and relations in particular contexts. The guidelines are partly based on conventions and partly on human perception. Examples of conventions are the use of blue hues to indicate water on maps in Western societies or the use of a colour scale from greens for lowland, via yellows to browns for mountains in topographic maps. Often these conventions are universal, but local exceptions do exist. Examples of perceptual design rules are the application of big symbols to represent large amounts and small symbols to represent a few items and legends that are designed to account for the nonlinear perception of visual variables such as size.

Much has been done in cartography to address the issues of spatial scale. There is a dedicated sub-area of cartography called cartographic generalisation. Cartographic generalisation is the process of reducing multidimensional realworld complexity for depiction in a typically lower-dimensional map and entails reduction in detail as a function of depicting the world at a smaller scale. Cartographic generalisation is not just about filtering unnecessary



Figure 5.4: Maps show different graphical elements and different semantic content depending on the presentation's current scale. Reproduced by permission of swisstopo (BA100617) (Source: http://www.swisstopogeodata.ch/geodatenviewer/)

information, or information loss. It includes condensing the essential attributes (semantic generalisation) and preserving the geometric characteristics (graphic generalisation) of the depicted features. An example is given in Figure 5.4. As one moves from a larger scale representation across the scales to a small-scale representation, not only does the graphic density change, but also the meaning associated with the graphic marks. Thus, individual buildings are visible at the highest level of detail (large scale, high resolution), whereas only the size of the urban area, its shape and major transportation routes associated with the city may be relevant at lowest level-of-detail (small scale, low resolution)

Maps are very suitable for visual analysis. Co-location of patterns such as those between population density and recreation areas can often be seen at a glance. Cartographic theory and practice, much of which is based upon the interpretation of experimental results, enables us to show multiple themes in a single map. Cartography has developed techniques for the individual representation of particular types of phenomena and data and their effective combination enabling us to make use of the human perceptual and cognitive system to visualise several characteristics concurrently. We can, for example, compare terrain characteristics and land use, or use techniques for relief representation that can show key characteristics of topography such as slope, aspect and form concurrently. Initially, such maps were produced manually, but recently automated analytical techniques have been developed (see Figure 5.5).

The Internet is changing the way that maps are produced, disseminated and used. Web maps are available to a wide and diverse population. They can be linked to a variety of sensors that make it possible to observe the current weather, traffic or water levels at any time during the day. Mobile devices ensure that these interactive real-time maps can be queried and contributed to anytime and anywhere. The cartographic discipline has also put lots of effort in usability research to determine whether maps deliver particular messages or achieve particular aims effectively. The existing design guidelines have been tested, but new technological developments continuously challenge these guidelines because new representations and interaction options become available. How, for example, do we make the best use of mobile devices to contribute to spatial

Maps on the Internet



Figure 5.5: Multiple characteristics of topographic surfaces are visualised concurrently using combinations of hue, saturation and lightness. Image created with Landserf http://landserf.org/. Reproduced with permission of Jo Wood, giCentre, City University London. http://www.soi.city.ac.uk/~jwo/relief/

databases? How do we take advantage of opportunities for augmented and mixed reality applications?

The traditional role of a map is to 'present', but today the map should also be seen as a flexible interface to spatial data, since maps offer interaction with the data behind the visual representation. Additionally, maps are instruments that encourage exploration. As such, they are used to stimulate (visual) thinking about geospatial patterns, relationships and trends. In modern software systems, maps are combined with other types of graphical displays by dynamic coordination mechanisms, allowing, for instance, interactive probing for accessing multivariate data at different locations (see Figure 5.6).

Geographic Information Systems

Most professional geographical analyses are undertaken with the use of geographic information systems or GIS. These systems combine data management, computational analysis, and map displays. GIS are widely used: the leading GIS vendor, Environmental Systems Research Institute of Redlands, California supports over 1 million users in 200 countries with more than 4000 employees. Recent reports of annual revenue are in the order of more than \$600 million. Commercial GIS make steady incremental advances by incorporating cuttingedge research results from relevant scientific domains. These include GIScience through which a whole host of useful approaches that model, manipulate, summarise, project, generalise, relate and analyse geographic information have been developed. However, the main emphasis of GIS is on data management, transformation and computation and subsequent mapping. Their initial design deals well with (in today's terms) small, static spatial datasets and produces high quality static cartography that replicates and automates traditional paper-based mapping. Current GIS are weak in terms of the way in which they deal with

Maps for the Information Age

GIS – a technology for millions



Figure 5.6: Multivariate socio-economic data associated with locations are explored by means of probes interactively placed on the map display. The visualisation on the left hand side is updated according to the probes location automatically through dynamic coordination^[22] © 2008 IEEE

the temporal nature of geographic data. Time is routinely modelled as a highlevel linear characteristic of spatial entities and maps and other analyses simply compare a limited number of particular moments rather than take advantage of the full structure of time.

The heritage of GIS means that they are not designed to support map use for interactive collaborative exploratory visual analysis. They are not designed to effectively deal with large dynamic datasets through a multitude of dynamic and novel displays that are considered by a range of disparate users. This legacy can be considered a significant hindrance to spatio-temporal visual analytics where dynamic maps are essential to the exploratory processes.

Geographic Information Science (GIScience)

Geographic information science, also known as geomatics and geoinformatics, is the academic theory behind the development, use, and application of geographic information systems. GIScience studies the fundamental issues arising from the creation, handling, storage, and use of geographical information. In particular, it deals with the representation of geographical information for computer processing, database design, efficient information retrieval, transformation of geographical information, and computational methods for analysis such as spatial statistics (see also Chapter 4). It also deals with the visual representation of geographical information; therefore, cartography can be considered as part of GIScience.

GIScience develops academic theories

GIScience does not deal well with space and time concurrently. Space always

comes first - due to the geographic and cartographic heritage. Geographers tend to think spatially ahead of temporally. There is a need to change this way of thinking.

Geovisualisation

Techniques and tools for interactive visual analysis of spatial and spatiotemporal data and for spatio-temporal decision-making are designed, developed and evaluated predominantly in the field of geographic visualisation, or geovisualisation. This developing research domain addresses the visual exploration, analysis, synthesis, and presentation of geographic data, information, and knowledge^[38] and focuses on dynamic maps that are used to support exploratory processes. A characteristic feature of geovisualisation research is integration of approaches from multiple disciplines, including geography, geographic information science, cartography, information visualisation, data mining, and other cognate disciplines. The need for cross-disciplinary efforts to support the visual exploration and analysis of spatio-temporal data is a function of the growing size and complexity of the datasets that need to be analysed. The main achievements in the field of geovisualisation include developing cartography and GIScience in the contexts of large dynamic datasets. There is also the need for exploratory approaches through:

- novel methods of visual representation for particular tasks, phenomena and data types;
- effective means of interacting with such displays that not only enable various kinds of visual queries but can rapidly change their appearance in response to user's manipulations;
- the development of knowledge and theory relating to responses to particular methods.

5.4.2 Representation of Time

Irrespective of the presence of a spatial component, data that embodies change over time poses challenges to all disciplines related to data visualisation and analysis. A wide repertoire of interactive techniques for visualising datasets with temporal components is available in the field of information visualisation. Figure 5.7 shows an example in which temporal patterns can be analysed at multiple scales. However, because it is difficult to consider all aspects of the dimension of time in a single visualisation, the majority of available methods address specific cases only – mostly the visualisation of data with a linear time axis. Moreover, as is the case in GIS, many of the current visual analytics and information visualisation systems do not include any special functions and techniques for dealing with all aspects of time but rather treat time as one among many other numerical variables.

Visualisation of time and temporal data The existing approaches can basically be categorised as techniques that visualise time-related data and techniques that visualise time per se. In the first case,

Geovisualisation for exploratory use of dynamic maps

Only isolated solutions for selected aspects exist



Figure 5.7: These visualisations of energy consumption data allow the analyst to investigate daily and seasonal temporal patterns^[119] © 1999 IEEE

the focus is set on representing data, that is, quantitative or qualitative timedependent attributes are represented with respect to a rather simple time axis (e.g., multivariate data represented with respect to linear time). The second case focuses on representing the characteristics of the time domain and its temporal primitives, while the representation of data is kept to a necessary minimum (for example, Gantt charts to represent relations between time intervals). In general, there are two options for visualising time and temporal data. Either we create a spatial arrangement of the time axis on the display or we utilise real world time, so that an animation shows visual representations of different time steps in quick succession.

Secondly, visual methods for temporal data can be categorised based on the time characteristics they were developed for:

- linear time vs. cyclic time,
- time points vs. time intervals, and
- ordered time vs. branching time vs. time with multiple perspectives.

Figure 5.8 demonstrates the difference between linear and cyclic representations through an example related to patterns in human health data. While common line graphs are useful to show general trends and outliers, spiral visualisations address cyclic aspects of time-related data. The spiral's main purpose is the detection of previously unknown periodic behaviour of the data. This requires appropriate parametrisation of the visualisation method. Usually, it is difficult to find suitable parameter settings for unknown datasets. Therefore, it makes sense to support the detection of patterns either by applying analytical methods or by animating smoothly through different cycle lengths. In the latter case, periodic behaviour of the data becomes immediately apparent by the emergence of a pattern. Interaction facilities are needed to allow users to fine-tune the visualisation. Only then can we take full advantage of our perceptual system, e.g., in recognising patterns and motion.

Whether temporal attributes are conceptually modelled as time points or time intervals, is another important characteristic that influences visualisation methods. Most of the known visualisation techniques that represent time-oriented data consider time points. Other approaches focus on representing temporal Visualisation can reveal cyclic patterns

Visualisation of temporal uncertainty



Figure 5.8: Two views of the same health related time series: In the linear plot (left) patterns can hardly be discerned. Switching to a cyclic spiral representation (right) makes an inherent cyclic (weekly) pattern apparent^[3]

intervals and their interrelations. A particular challenge is the representation of uncertain temporal primitives, be it imprecise specifications of time points or fuzzy interval boundaries. Uncertainty might be introduced by explicit specification usually connected with future planning (e.g., "The meeting will start at 11 a.m. and will take approximately one hour" – which means that it is not quite clear when the meeting will be over) or is implicitly present in cases where data is given with respect to different temporal granularities (e.g., days vs. hours).

Visualising structures of time Most of the visualisation techniques for time-related data known in the literature are suited to represent ordered time. Branching time and time with multiple perspectives, however, are definitely relevant types of time in visual analytics, especially when it comes to analysing data from heterogeneous sources like different sensor networks or public online forums, and when predictions of possible future scenarios are required. The few techniques for representing the latter types of time are capable of depicting only univariate qualitative data, or even visualise temporal primitives only; they can neither represent multiple time-dependent attributes nor are they combinable with visual representations of space, predominantly geographic maps. There is a strong need for advanced techniques to effectively visualise multivariate data exhibiting these specific time characteristics.

> The characteristics of the dimension of time have to be considered when devising new visual analytics methods for spatio-temporal data; integrating appropriate interaction methods is a key concern. Casual users and expert analysts must be allowed to adapt visual representations and analytical processes to a variety of tasks, including exploration in time, search, comparison, prediction, and manipulation. Only adequately adapted visual analytics techniques can fully support a broad range of users in reasoning about time- and space-

Aspects of time must be addressed adequately

dependent data.

5.4.3 Interactive Methods for Visual Exploration

Various applications and prototypes have been developed to facilitate and, moreover, stimulate data exploration. Figure 5.9 gives an example of an interactive map that dynamically changes its appearance to support visual detection of spatial patterns. Animated maps portray time-dependent data and dynamic phenomena by mapping the temporal dimension in the data to the physical time as it is experienced by the onlookers. The interactive space-time cube is an important visualisation technique for spatio-temporal data (see Figure 5.10). It implements one of the ideas of time geography^[53], which considered space and time as inseparable and suggested a three-dimensional visual representation where two dimensions encode spatial aspects of the data and the third dimension represents time. This is contrary to commercial GIS architectures which fundamentally separate the spatial and temporal aspects of geographic information.



Figure 5.9: An interactive map display can dynamically change its appearance (here, the encoding of the data by colour shades) and in this way support perception and exploration of patterns of the spatial distribution. (Source: produced using the CommonGIS visual analytics toolkit described in Andrienko & Andrienko^[7], pp. 657-658)

Typically, the size, dimensionality, and other complexities of data being analysed preclude the simultaneous representation of all data items, dimensions and relationships in a single display. Hence, the analyst has to understand the whole by looking at subsets, components, projections and selected aspects of the data. Some aspects of spatio-temporal data cannot be effectively visualised by means of maps alone and require other display types. Therefore, the effective combination of maps with statistical graphics and other visualisation techniques for temporal or structural aspects of the data are required. Since any view can only convey partial information, the analyst needs multiple views. These need to be linked so that the pieces of information contained in them can be related.

Coordinated multiple views visualisation

Time and space visually combined



Figure 5.10: This interactive space-time cube portrays the movement of the Napoleon's army during the Russian campaign of 1812. By interactively moving the horizontal plane, the user can better see the positions of the army at different time moments. (Source: http://www.itc.nl/personal/kraak/1812/minard-itc.htm)

Means of enabling and symbolising selections and links are at the core of much visualisation activity.

One of the possible mechanisms for linking multiple displays is through 'dynamic filtering' (see Figure 5.11). The map (A) and the space-time cube (B) show the same subset of a dataset about 10,560 earthquakes selected by means of three different filters: 1) spatial window, which has been drawn by the user within the map display; 2) attribute filter (C), which selects the earthquakes with the magnitudes 4 or more; 3) temporal filter (D), which selects the earthquakes that occurred in the period from the beginning of 1995 until the end of 1999. All three filters may be interactively changed by the user; in response, the displays will immediately change their content to satisfy the new filter conditions.

5.4.4 Effectiveness of Visual Techniques

Visual analytics is different from 'standard' approaches to analysis. It is based on the assumption that interactive visual representations can amplify human natural capabilities for detecting patterns, establishing links, and making inferences. This assumption, however, needs to be empirically validated in order to arrive at effective visual analytics approaches for spatio-temporal data. Particularly in cartography there is a tradition for obtaining empirical evidence by means of experiments in which people use different variants of maps and graphics to find the information necessary for answering certain questions.

In some experiments, the measurements of the accuracy of the answers and the time spent seeking information are combined with methods that track the eye movements of those being tested. In this way, for example, it was found that people have difficulties in retrieving relevant information from colourful

Interactive dynamic filtering

Empirical evidence through user studies



Figure 5.11: Linking multiple displays via 'dynamic filtering'. (Source: produced using the CommonGIS visual analytics toolkit described in Andrienko & Andrienko^[7], pp. 657-658)

weather maps, which are often published in mass media. They are more able to detect what is relevant on a carefully designed, cognitively adequate map that uses established cartographic and visualisation principles to depict the same information content (see Figure 5.12).

However, the empirical studies conducted so far have addressed only a small fraction of existing techniques. We still know very little about the perception and use of interactive dynamic maps, different representations of time, three-dimensional and large scale displays, and maps combined with other graphics or multimedia content. Furthermore, new interaction devices and corresponding interaction methods need to be evaluated with regard to their usefulness for spatio-temporal visual analytics, for instance, map navigation and temporal browsing. Chapter 8 discusses general aspects of evaluation in more detail.

5.4.5 Dealing with Larger Data Sets

The traditional visualisation approach involves the direct depiction of each record in a dataset so as to allow the analyst to extract noteworthy patterns by looking at the displays and interacting with them, as illustrated in Figures 5.6, 5.9, and 5.10. However, these techniques may not be effective when applied to very large and complex datasets that are increasingly common. The displays may become illegible due to visual clutter and massive overplotting associated with large numbers of cases – would Dr. Snow have noticed the relationship between cholera deaths and pump location if he had access to the locations of all deaths and all pumps in London? For example, the Times Labs blog asks "How perilous is it to cycle where you live?" alongside a typical online map in which overplotted symbols render the question unanswerable (see Figure 5.13). Users may also have difficulty perceiving, tracking and

Large and complex data is difficult to deal with



Figure 5.12: The yellow circles represent the locations and durations of eye fixation of the test participants seeking relevant information in two variants of a weather map with the same content. Those who used the cognitively more adequate map (on the right) detected the relevant information (located in the centre of the map) immediately

comprehending numerous visual elements that change simultaneously. The technology may not be sufficiently powerful to update the display fast enough or respond quick enough to user interactions, to enable efficient inference making.

Two alternative approaches are being increasingly utilised in response to the current challenges. One modifies the traditional visualisation approach by involving methods for data aggregation and summarisation prior to graphical depiction and visualisation (see Chapter 3). The other approach involves applying more sophisticated computational techniques, such as those developed in data mining, to semi or fully automatically extract specific types of feature or pattern from data prior to visualisation. This visual data mining approach may apply to summaries and along with the visualisation of summaries, may take advantage of ideas and advances developed in direct depiction. Figure 5.14 gives an example of combining geovisualisation with data mining (see Chapter 4), specifically, the method known as 'Self-Organising Map', or SOM, which reduces the dimensionality of multivariate data to two dimensions and simultaneously groups items with similar characteristics. In this example, SOM has been applied to aggregate data about companies that operated in the USA during 12 years. By grouping the data, SOM has derived a number of distinctive economical profiles in terms of the activities of different industries, such as computer hardware, computer software energy, telecommunications, etc. The map series, where the states are coloured according to these profiles, allows the analyst to investigate how the profiles of the states changed over time. Thus, the analyst can notice that by the end of this relatively short time period no states remain where software companies would play a leading For larger time series or more complexly structured time axes or role. maps, currently existing techniques reach their limits. Future visual analytics methods will still have to face the challenge of dealing with immensely large datasets.

Aggregation in the data domain



Figure 5.13: The overplotted symbols on the map hinder the analysis. © 2009 Google, Map Data © 2009 Tele Atlas. (Source:http://labs.timesonline.co.uk/blog/2009/03/11/ukcycling-accidents/)

5.4.6 Collaborative Visualisation

A currently emerging and very important research direction is collaborative visualisation^[74] – design and use of technologies to enable groups of analysts to work productively with spatial and temporal information. The need for such approaches in which tacit knowledge is pooled is evident from our scenario.

Collaboration research addresses the following issues:

- collaboration: how interactive visual interfaces (in particular, map interfaces, which are essential for spatial problems) can enable many actors to work together in the same room, between rooms, between offices, between countries, or even between cultures;
- communication: how interactive visual interfaces can facilitate effective transfer of spatially and temporally-related information, knowledge, evidence, judgements, considerations, etc. from one actor to another.

5.4.7 Fundamental and Theoretical Research

Along with the progress in designing and developing innovative techniques and tools, a substantial amount of theoretical research has been undertaken Support people in working together



Figure 5.14: Space and time-referenced multivariate data is analysed with the use of SOM - Self-Organising Map, a computational method that groups and orders data according to the values of multiple variables^[51]

A basis for spatio-temporal visual analytics research in the areas of geovisualisation and information visualisation. The most essential monographs, which not only lay theoretical foundations and explain the principles of geovisualisation and information visualisation but also analyse the state of the art in the area and outline the main research directions, are:

- MacEachren (1995), How Maps Work: Representation, Visualization, and Design^[73]
- Slocumet al. (2009), Thematic Cartography and Geovisualization^[103]
- Spence (2006), Information Visualization Design for Interaction^[104]
- Ware (2004), Information Visualization: Perception for Design^[122]
- Kraak and Ormeling (2003), Cartography: Visualization of Spatial Data^[69]
- Andrienko and Andrienko (2006), Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach^[7]

These monographs can be considered fundamental in their respective fields. In combination, they can serve as starting points for spatio-temporal visual analytics. However, more joint research is necessary to address the specifics of time and space in an holistic way.

5.5 Challenges and Opportunities

Whilst geovisualisation and information visualisation have developed some effective techniques for supporting the visual exploratory analysis of geographic and time-dependent information, it is much more complex to effectively support analysis of spatio-temporal data. Thus, the cyclical temporal patterns shown in Figure 5.3 may only occur in particular places - or may differ across space and spatial scale. Some steps have been made towards simultaneous handling of space and time in a more complete and sophisticated manner, but there is still much to do.

Besides, a number of other challenges face those analysing spatio-temporal phenomena, and these are the subject of the following sections.

5.5.1 Dealing with diverse data

We have seen that increasing amounts of spatio-temporal data is becoming available from various kinds of sensors, aerial and satellite imagery, statistical surveys, and many other sources. These datasets have the potential to significantly extend the opportunities for comprehensive analyses and informed decision-making. In parallel, data accessibility is improving. This is being achieved through the design and development of spatial-temporal information infrastructures (see also Chapter 6), standards for data, metadata, and services, and legislative regulations concerning the collection, quality, organisation, sharing, and use of data (see also Chapter 3). For example, OGC (Open Geospatial Consortium, Inc.) develops international standards to make complex spatial information and services accessible and useful with all kinds of applications. The INSPIRE initiative works to establish the Infrastructure for Spatial Information in the European Community, enabling spatial data from different sources across the Community to be combined in a consistent way and shared between several users and applications. Furthermore, a variety of models, concepts, algorithms, and data structures have been developed in the area of temporal databases.

However, this progress concerning the collection and accessibility of spatial and spatio-temporal data poses new challenges related to:

- new types of data, for which no analytical methods yet exist;
- large amounts of data, with which current analysis methods cannot cope,
- dynamic data arriving in real time, which require highly efficient methods capable to combine previous results with new data;
- data of diverse types, which need to be analysed in combination;
- data of diverse quality and inconsistent data from multiple sources, which need to be harmonised.

In our example scenario, the analysts combine official geographic information about The City with measurements from sensors, reports about incidents, trajectories of cars, phone call data, satellite images, outputs from simulation models, Data from sensors, aerial and satellite imagery extend the opportunities for informed decision-making and historical data about similar events in the past. This is not yet feasible, but the means to address this challenge are emerging.

Hence, visual analytics has to do more than just developing adequate methods to visualise and analyse different types of data, large amounts of data, and dynamic data. Visual analytics must also devise solutions for enabling integrated processing and analysis of diverse data.

As a prerequisite for any analytical task, analysts must first look at the data and identify uncertainties, inconsistencies and missing items. Only then can the data be pre-processed accordingly to make it suitable for analysis:

- ameliorate incomplete data by deriving missing parts from related data and from simulation models;
- harmonise inconsistent data by cross-checking with related data and knowledge;
- enrich and refine the data by deriving relevant new characteristics and constructs.

These preparatory operations have to be facilitated by appropriate visual analytics tools. In our scenario, the insurance analysts initially had incomplete data from the weather sensors. They used interactive visual methods to transform community-contributed unstructured information into structured data, which were fed into a statistical model for estimating the course of the storm. When the analysts viewed the model results and the observation data together they were able to derive a probable perimeter of the storm-affected area.

The prepared data is then subject to detailed analysis. At this stage too, analysts need to combine diverse data, for example, the estimated affected area, typical traffic flows, and the spatial distribution of insurance clients. Again, analysts have to be supported by visualisation and interactive tools working in synergy with appropriate computational techniques.

5.5.2 Support for Analysis at Multiple Scales

There is much to do for visual analytics in order to change the traditional practice in analysis, focusing on a single scale. As explained earlier, appropriate scales of analysis are not always clear in advance and single optimal solutions are unlikely to exist. Analysts may need to use 'trial and error' approaches. Interactive visual interfaces have a great potential for facilitating the empirical search for the acceptable scales of analysis and the verification of results by modifying the scale and the means of aggregation. To realise this potential, we need to know more about appropriate visual representation of different types of data at different spatial and temporal scales. We need to develop corresponding analysis-supporting interaction techniques, which should enable not only easy transitions from one scale or form of aggregation to another but also comparisons among different scales and aggregations.

Solutions needed to enable integrated processing and analysis of diverse data

What visual representation is appropriate for different types of data at different spatial and temporal scales? Since various scales of geographic and temporal phenomena interact, analytical tools must also fully support analyses at multiple scales. Future research must answer the question: How do we help (a range of) analysts uncover and understand cross-scale relationships between phenomena?

The research on scale issues in visual analytics has to utilise and build upon a number of achievements from other disciplines. One is cartographic generalisation, including theory, best practices, and algorithms for automatic geometric and semantic generalisation of many types of data. However, cartographic generalisation is restricted to maps and does not give guidelines for other types of displays. Generalisation research has also been focussed on traditional cartography rather than on dynamic maps for exploration. Too little work has focussed on the generalisation of time-dependent data at different temporal scales. Generalisation usually considers representations only, rather than user-display interaction. How do we match interaction techniques to the scale of analysis? The concerted efforts of visual analytics researchers from various backgrounds will be required to address these issues.

5.5.3 Understand and Adequately Support Diverse Users

Professional analysts are usually specially trained. In particular, professional spatial analysts get training in the use of geographic information systems (GIS) and methods of spatial statistics. However, we argue that virtually everybody is now a spatio-temporal analyst. Of course, it cannot be expected that everyone receives special training before starting to analyse spatio-temporal data and making space and time-related decisions. Still, there is a need to provide this wide range of spatio-temporal analysts with adequate analytical tools that they are able to use effectively. How can this be achieved?

Fortunately, many potential users of visual analytics tools are relatively sophisticated in terms of their use of information systems. They are experienced in using computers and the Internet. They are familiar with dynamic displays of spatio-temporal information, such as weather maps shown on television. By playing video games, people become experienced from early childhood in interacting with dynamic visual displays. Adults often use online mapping services and have no problems with basic interactive operations such as zooming, panning, and selection. Virtual globes, in particular, Google Earth and Microsoft's Virtual Earth are increasingly popular and the globe is becoming a sufficiently important metaphor for manipulating spatial information to challenge the dominance of the map.

Hence, a certain level of computer and graphical competence can be expected from the potential users of visual analytics tools for spatio-temporal analysis and decision making. We can also expect that motivated users will not mind acquiring a reasonable amount of new knowledge and skills. The problem is how to appropriately convey this knowledge and these skills to the users?

On the other hand, visual analytics is different from 'standard' approaches to analysis. It is based on the assumption that interactive visual representations Non experts and experts alike need appropriately designed analytical tools can amplify human natural capabilities for detecting patterns, establishing links, and making inferences. The amplification of human perceptual and cognitive capabilities is not something achievable merely through training. While it is possible to explain to the users how to interpret a display and how to use interactive devices, the users can hardly be trained to gain insights from graphics and to reason more efficiently with the help of graphics. What matters here is the design of the visual representations and accompanying interaction techniques.

While a number of useful design rules and guidelines exist in cartography, the design of interactive maps, dynamic maps, three-dimensional displays, multimedia maps and maps combined with other graphics are still lacking any guidelines, and available empirical evidence is fragmentary and hard to generalise. Furthermore, we still know very little about the effectiveness of visual displays in supporting more sophisticated activities than answering simple questions typically used in experimental studies, specifically, exploratory data analysis, problem solving, knowledge synthesis, and decision making. These issues definitely require thorough research, which is vital for creating usable and useful visual analytics tools. This research requires interdisciplinary efforts involving computer scientists, cartographers, psychologists and cognitive scientists.

5.5.4 Reach the Users

Geographic information systems (GIS) are and will remain in the future the main instrument for professional analysis of spatial information. The cuttingedge visualisation work being reported by research laboratories across Europe suggests possible solutions that can be adopted by the GIS industry. However, we should not just passively wait for this to happen. We can instead work on creating GISs that are temporal and analytical, with an interactive visual emphasis. We can realise the concept of spatio-temporal visual analytics as the new applied dynamic GIS that must take advantage of the range of useful algorithms and research in GIScience, GIS, geovisualisation, and information visualisation, the public interest in and experience of spatial and temporal data, the Internet, and the emerging display environments (e.g., multi-touch tables or smart display rooms), and overcome the legacy of static paper maps and traditional cartography that are based upon this model.

Spatio-temporal visual analytics draws from GIS, cartography and information visualisation, but needs to deal with the dimension of time much more effectively. Everything is geared towards the key objectives:

- deal with and make use of characteristics of time and
- deal with and make use of characteristics of space.

In the light of visual analytics, we have to develop approaches to support sensemaking from new and large datasets and to allow users to generate evidence and communicate knowledge about the data. The solutions must be visual, interactive, exploratory, scalable, collaborative and lightweight. This ambitious

Design guidelines required for interactive, dynamic and multimedia maps

Create GISs that are temporal and analytical, with an interactive visual emphasis



Figure 5.15: The interactive visual system OECD eXplorer allows specialists and general public to explore regional statistics data from OECD (Organisation for Economic Cooperation and Development, http://www.oecd.org/home/).

endeavour can only be solved through derivation of knowledge from and through close collaboration with other disciplines.

Software for spatio-temporal visual analytics should be lightweight, easily deployable and usable, rather than huge and complex like GIS, which require extensive training. Users may be especially happy if the analytical instruments they need are available as Web services or through an open APIs. The developers of visual analytics tools should strive to make their tools not only useful and usable but also accessible to users. A good example is OECD Explorer (Figure 5.15), a popular and impressive Web service that contains innovative means for recording and discussing findings. The system is implemented on the basis of the Flash/Flex platform, which is, on the one hand, suitable for enabling various interactive operations and dynamic displays, on the other hand, easily accessible to many Internet users through a Web browser plugin.

There are also other things to consider in implementing visual analytics tools:

- seamless integration of visualisations with computational techniques such as spatial statistics, time-series analysis, simulation models, spatio-temporal data mining, etc.,
- support for documenting the analysis process, keeping provenance of finding, reporting and storytelling,

- support for collaboration.

These requirements are not unique for tools dealing with spatio-temporal data but generally apply to all kinds of visual analytics software. However, the specifics of space and time definitely have an impact on implementing the requirements, which may be by itself a research topic.

5.6 Next Steps

In order to progress in the field of geo-spatial visual analytics, the following actions should undertaken:

- Develop approaches to support analysts in finding satisfactory scales of analysis, exploring and establishing scale dependency, verifying discovered patterns and relationships at different scales and with different aggregations, and understanding dependencies between phenomena operating at different scales in time and space.
- Develop scalable visual analytics solutions to enable integrated processing and analysis of multiple diverse types of spatial, temporal, and spatiotemporal data and information, including measured data, model outputs, and action plans from diverse official and more uncertain community contributed sources.
- Improve the understanding of human perceptual and cognitive processes in dealing with spatial and temporal information and visual displays of and interaction with such information. On this basis, develop appropriate design rules and guidelines for interactive displays of spatial and temporal information.
- Develop effective solutions for training both specialist and non-specialist users interested in undertaking spatio-temporal analysis.
- Develop a new generation of lightweight accessible dynamic visual analytics tools to support a range of personal and professional spatio-temporal analysts in the best possible way.
- Implement tools for spatio-temporal visual analytics in the way that allows rapid and easy deployment or online use through the Web. Make the tools compliant with the existing and emerging standards, interoperable and combinable; enable integration of the tools into user's existing workflows.