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VISUALIZATION OF GEOSPATIAL METADATA FOR SELECTING GEOGRAPHIC DATASETS

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Abstract

The importance of geospatial metadata that describe geographic data resources has grown along the increase of supply and use of geographic data. Discovery services have been developed on geospatial metadata systems, but supporting tools for users evaluating the suitability of geographic datasets for an intended use are lacking. This dissertation studies how different visual representation forms of metadata could support users in selecting suitable geographic datasets.

Maps are a traditional representation form of geographic data, and therefore, maps representing samples of datasets were considered in this research. In addition, multivariate visualization methods were of interest, as they enable users to study and compare multiple characteristics of multiple datasets at a time. These visual representation forms were tested with professional users of geographic data in two stages. First, static displays were used to test the design concepts. Successful concepts were implemented in an interactive prototype that included sample maps, a parallel coordinate plot and star glyphs as multivariate visualization methods, and textual metadata. A user test was carried out with this prototype. Users' thinking protocol was applied in both tests.

The findings of the research suggest that sample maps, when displayed individually, provide little concrete support to users of geospatial metadata. However, comparison of sample maps of different datasets stimulates users of geospatial metadata in questioning the data quality and searching for detailed descriptions of datasets.

A parallel coordinate plot proved to be a valuable method to users who need to compare datasets by aspatial metadata elements. Already six alternative datasets in the prototype test indicated its usefulness, and the value of this method increases when the number of alternative datasets rises. The test results suggest that a parallel coordinate plot is easily adoptable to occasional users of geospatial metadata. However, the thinking aloud of the subjects confirmed that users need support for understanding the concepts and special terminology used in geospatial metadata.

Although the textual form of metadata alone does not support comparison and evaluation of geographic datasets, it proved to be an essential form in the selection process when confirming or checking details of metadata. As a whole, use patterns of the different representation forms during the process varied between the subjects.

The research results strongly indicate that tools for visual representations of geospatial metadata are useful in metadata services. The different representation forms should provide linked views to metadata in order to support users' thinking. The proposed visualization of metadata includes both presentational and exploratory characteristics.

Keywords: metadata, geographic information, map, multivariate visualization, parallel coordinate plot, usability

Preface

My work with geospatial metadata started about 15 years ago when the term metadata was hardly ever used. The inspiring attitude in the development team of the shared use of geographic information at the National Land Survey of Finland was encouraging, and I am grateful to my colleagues for the stimulating cooperation of that time. Especially I want to thank Anna-Maija Ainola who has since challenged me many times with her pragmatic viewpoints and consideration of what is useful and what is feasible in practise.

During these years I have shared the opinion of many who claim that metadata is a dead boring issue. But it is boring only at the mechanical level of encoding characteristics of datasets in catalogues. More thoroughly, studies of metadata extend to the profound question of how we can represent the real world by geographic data and tangle the whole discipline of geoinformatics. In this research, I could combine my interest in visualization to the consideration of usefulness of metadata.

I want to express my gratitude to Prof. Kirsi Virrantaus who has encouraged me throughout the research and, as my superior, arranged for me the opportunity to carry out the research. Prof. Menno-Jan Kraak has supervised my work with many discussions. I want to thank him for the valuable comments and assistance in searching the focus of this research. I also want to thank Dr. Gennady Andrienko and Prof. Werner Kuhn for thorough review of the manuscript and constructive suggestions for improvements.

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I give my sincere thanks to my parents who were available for the daily practicalities when the workload was high. At home I have received care and joy, which have brightened my days and motivated me to get this project to the end. I want to thank my son Aapo for his cheerfulness and tolerance. The warmest thanks are due to my husband Antti for his patience and love and the professional debates we have shared for two decades.

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1 Introduction

Digital information has a growing importance in economic, social, environmental and technical activities in a modern society. Vast investments are made in capturing, administrating and disseminating information of all types, the majority of which includes a spatial component. In this dissertation I use the term **geographic data** for the digital representation of this type of information that has a direct or indirect association with a location relative to the Earth[1]. Because the value of information results from its use, increasing amounts of geographic data are provided for shared use outside the data supplying organisations. The value of these data depends, first of all, on the awareness of their existence among potential users of geographic data and, secondly, on their suitability for analysis and solving of spatial problems at hand.

Geographic data provide a representation of the real world for use in computational analysis and visual display. Any representation of the real world is an abstraction that simplifies, approximates and filters some objects and phenomena and completely ignores the others. The need to view the real world from different perspectives for different purposes has resulted to a wide variety of geographic datasets. These datasets differ by semantics, data models and structures, and quality. In addition, suppliers or producers impose conditions and constraints that regulate their access and use.

In this context, **geospatial metadata** that describe characteristics of geographic data are an important asset in attaching value to geographic datasets. Metadata are "a set of data that describes or gives information about other data" (OED, 2001). The meta-prefix here, as with other technical terms, especially in computing, denotes the data that operate at a higher level of abstraction. Although this definition does not consider the forms of metadata, metadata are generally presumed to be formal and consistent so that they can be handled by computers. Metadata can be embedded in the dataset that they describe or be external and used without the actual data at hand. The content of metadata may vary from brief, identifying information to an exhaustive description of a dataset.

While geospatial metadata have been collected and made accessible in increasing amounts, concern about usefulness and usability of geospatial metadata has been pronounced (Crompvoets et al., 2004). Lack of usable metadata services may lead to narrow use of data resources, as users tend to continue to use those datasets that they know from earlier experience (Flewelling and Egenhofer, 1999). Research and development relating to geospatial metadata have been very data-oriented, focusing on metadata contents and, especially in earlier work, to metadata compilation and management (e.g., Beard, 1996). Use and users of geospatial metadata have gained

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[1] Adopting the terminology of the of ISO/TC 211, see URL http://www.isotc211.org (accessed 1.10.2004)

little attention (MADAME, 2000), though readability and usefulness of standard metadata have been questioned (Foresman et al., 1996; Timpf et al., 1996). This research focuses on user-oriented functional capabilities of geospatial metadata systems proposing a visualization environment that would support users when selecting geographic datasets.

1.1 Brief history of efforts on geospatial metadata

The roots of metadata lie in the earliest collections of information, and extended to sophisticated analogue cataloguing systems in libraries, citation indexes, and the likes, but the concept has received far more interest in the digital era. Computer-readable metadata have a crucial role in database management and, more recently, in data transfer and management of information services. Efforts on spatial data infrastructures (Groot and McLaughlin, 2000; Williamson et al., 2003) state the role of metadata for the benefit of society in getting into use the vast investments on geographic data resources, reducing duplicated data production, and maintaining the value of data over time by making data available for a wide variety of applications.

The need to describe geographic datasets to users was acknowledged in the mid 1980's (DoE, 1987; Vahala, 1986) when the production of digital geographic data was establishing, and ideas of national spatial data infrastructures started to emerge. The early 1990's was a period when several geospatial metadata projects were launched, as described, e.g., in (Medyckyj-Scott et al., 1991) and (Frank, 1994). In Europe, the first national geospatial metadata services were running in 1991 – already before graphical terminals and the WWW became a standard – as interactive text-based services were accessible via data transfer networks in Finland (Paikkatietohakemisto) and the Netherlands (NexpRi Informatiebank). Soon after, a call-in service (SINES) based on a stand-alone metadata system was launched in UK, a metadata base with related software was delivered on a diskette in Denmark, and a printed metadata catalogue was published in France. The co-operative body of European mapping agencies, MEGRIN (Salgé et al., 1992b), launched a European wide on-line metadata service covering national digital maps and DEM's in 1995. Penetration of metadata systems accelerated with use of the WWW after the mid 1990's, and metadata services are now running at the local, regional, and national levels in most European countries as well as across national boundaries[2].

Although standardisation of geospatial metadata contents started in 1992 as one of the first work items of the Technical Committee CEN/TC 287 (Geographic Information) in the European standardization organisation CEN, and research and development programmes of EU have encouraged development of metadata services

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[2] See a link list of geospatial metadata services world-wide at URL http://www.gsdi.org (accessed 1.10.2004)

since the mid 1990's[3], metadata systems in Europe are based on heterogeneous specifications and lack compatibility. A recent proposal for a directive aiming at a European infrastructure for spatial information (CEC, 2004) emphasises consistent metadata and interoperable services across Europe for exploiting the geographic data already available.

In the USA, efforts towards a spatial data infrastructure at the federal level led to a contents standard for geospatial metadata in 1994 (FGDC, 1994) and development of an extensive, distributed clearinghouse (FGDC, 2004). A presidential executive order (Clinton, 1994) supported the development ordering all new geographic data to be documented according to the standard and these metadata to be publicly available through the National Geospatial Data Clearinghouse. Development of similar clearinghouses has been active in Canada and Australia (Groot and McLaughlin, 2000; McLaughlin, 1991; Williamson et al., 2003).

The main effort of the late 1990's was the development of the international standard ISO 19115:2003 that defines metadata elements and their structure (ISO, 2003). The standard was drawn up in the Technical Committee ISO/TC211 (Geographic Information/Geomatics) building on the experience gained in development and use of previous metadata standards in Europe (CEN, 1998), the USA (FGDC, 1994), Canada (CGSB, 1994) and Australia (ANZLIC, 1995). Also considered were standards for geographic data transfer and exchange that include metadata elements, such as the Digital Geographic Information Exchange Standard DIGEST, The International Hydrographic Organization Special Publication 57, and the Spatial Data Transfer Standard SDTS (Danko, 1997). Recently, several initiatives have been announced to convert existing metadata collections to conform to the ISO 19115:2003 standard or its profiles. This will cut down the versatility of currently used official and de-facto standards on geospatial metadata (Moellering et al., in press).

Continuing interest in metadata issues is demonstrated also in the scientific community. During the past few years, metadata has been a topic in most conferences of geographic information science, and technical sessions have been devoted to metadata issues, typically combined with topics such as spatial data infrastructures, data quality, and ontologies, for example, in SDH 2004 (Fisher, 2004), AGILE 2003 (Gould et al., 2003), and Geoinformatics 2004 (Brandt, 2004).

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[3] Notably the INFO2000 projects ESMI and MADAME

1.2 Uses of geospatial metadata

Geospatial metadata act in several roles for the benefit of a spatial data infrastructure. Different uses of geospatial metadata are discussed briefly below.

Getting geographic data into use

The most promoted use of metadata is in the chain of discovering geographic data and evaluating their suitability for an intended application, accessing and transferring a dataset, and, finally, using the data (Beard, 1996; Danko, 1997; Guptill, 1999; Lillywhite, 1991; Medyckyj-Scott et al., 1996; Taylor, 2004). This chain arises from the need to have use of geographic data that are suitable for an intended application. Discovery and evaluation are functions that support users in selecting appropriate datasets from a wide collection of data. It is important that users have access to metadata for the evaluation of data before they make the decision of putting effort in retrieving these data (or costs of purchase), as this effort often involves both money and labour. A solid assessment of the fitness of a dataset for the intended use is therefore needed before further steps are taken. In the later stages, that is, while accessing, transferring and using the data, metadata concern an individual dataset already selected.

Somewhat different metadata are needed in different stages of the chain. During discovery, users may not see the actual metadata but interact with the search system that operates on the metadata. Similarly, in the access and transfer metadata support computer operations, whereas in the evaluation, users interact with the metadata directly.

Other uses of geospatial metadata are described below. They provide different perspectives on metadata though the geographic data that are described remain the same. Although these uses can be distinguished, in working life and users' minds they intermingle. Furthermore, a practical aim is to cover as far as possible the needs for metadata arousing from different uses by a single collection of general-purpose metadata (ISO, 2003; Taylor, 2004). Resources for creating metadata are limited in the context of spatial data infrastructures, and production of metadata requires human input – despite recent attempts at automating some parts of production.

Inventory of geographic data resources

Geospatial metadata can be seen as an inventory of data resources and be utilized in their administration. This is an important aspect of metadata not only to organizations producing geographic data (Akervall et al., 1991; Nebert, 2004; Taylor, 2004) but also to user organizations when the administration and acquisition of geographic data are coordinated (Danko, 1997). In the former case, metadata may be embedded in process management systems of data production and not considered as an activity on its own.

As an inventory, metadata also serve any professional users working with geographic information in constructing pragmatic knowledge about what kind of data are available and what their potential or limiting qualities are. This knowledge is constructed throughout their careers by the means of education, working experiences and various information sources, such as colleagues, data producers, and metadata services. Therefore, metadata are only one of the means, and the role of metadata in this knowledge construction process varies from stage to stage. For novice users metadata can provide an overview that is difficult to be obtained otherwise, whereas experts benefit mainly from information about changes taking place in the data supply (MADAME, 2000). Current metadata services provide few tools that can be considered as useful for overview purposes or for updating one's knowledge. For example, recent changes that are typically marked on www pages are not singled out from collections of metadata. A positive example of a metadata service that supports novice (or any other) users in understanding the contents of metadata is the Eurogeographics' metadata service[4] that provides explanations of enumerated metadata values.

Management of customer satisfaction

Customer satisfaction is a mutual interest of users and producers of geographic data, even though public sector assets dominate the market of geographic data. The process of building customer satisfaction is complex, including cognitive and emotional factors (Gale, 1994; Kotler, 1997). From a users' perspective, proper metadata can prevent unrealistic expectations and consequent dissatisfaction when using geographic data. Users of geographic data have frequently expressed their dissatisfaction with the lack of metadata and brought up its consequences in various discussions. Therefore, the availability and quality of metadata are gaining more attention. Taylor (2004) states the role of metadata in proper use of geographic data. Furthermore, Danko (1997) mentions metadata as a legal documentation that protects an organization if conflicts arise over the use or misuse of data, but until now, metadata are not legally regulated like product descriptions for, e.g., foods or medicines.

Data Warehouses

Metadata can also be seen as a condensed representation of underlying data and used for decision-making (Günther and Voisard, 1998). In this sense, both metadata and data appear to users as means of gathering information for a proper decision and distinction between them is irrelevant. UDK, an environmental data catalogue described by Günther and Voisard (1998), is an example of this kind of use of metadata. Longley et al. (2001) consider metadata as an abstraction of geographic data and, as such, an extreme generalization of geographic data. Also this approach obscures the distinction between data and metadata. In these cases, metadata come

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[4] URL http://www.eurogeographics.org/gddd/index.htm (accessed 1.10.2004)

close to a data warehouse concept (Widom, 1995), given that they also provide a consistent representation of the underlying data that may be very heterogeneous by data models, formats, and storage media as well as information about the data quality (Bédard et al., 2001).

Semantic interoperability

Recent innovative use of metadata relate to semantic interoperability of geographic information systems (Bishr, 1998) and geographic information networks (Green and Bossomaier, 2002). In both uses the role of metadata relates to computer-interpretable semantics. In information networks in particular, the roles of metadata and document mark-up are merged.

Online services of geographic data (Green and Bossomaier, 2002) assume metadata to be embedded in data files. Metadata may be generated as a fixed part of data throughout the data production process, or they may be generated separately and then attached to data.

1.3 Geospatial metadata services

Current services of publicly accessible geospatial metadata systems concentrate heavily on data discovery. Services for evaluation of datasets scarcely exist.

Discovery functions for searching datasets are based on cataloguing indices in cataloguing, which have a long tradition in library systems. Traditional text based systems of libraries do not, however, match the cognitive models employed by users of geographic data (Frank, 1994), where a combination of spatial, thematic and temporal indices is required (Beard and Sharma, 1997). In advanced systems users can specify search criteria with the help of, e.g., index maps, place name systems, and thesauruses. The development of search functionality has been most extensive in the context of digital geolibraries (Goodchild, 1998), especially in the USA. There a well-known example is the Alexandria Digital Library (ADL, 2004; Smith, 1996).

In digital libraries, the scope of resources is wide, including datasets but also text documents, imagery, videos etc. Datasets deviate from the other forms of resources in that they are accessed by computer applications, often without human intervention. This means that the semantics has to be explicitly encoded in the data. The data cannot be browsed without using the application. In addition, datasets are seldom used alone but need to be compatible semantically and syntactically with certain other data. Often a quick glance at a dataset, when retrieved, does not reveal its compatibility or fitness for an intended use, but a proper testing (or actual use with the risk of a failure) is required. Therefore, search for datasets should result to a minimum number of valid alternatives.

As for evaluation of datasets, current metadata services provide users with very limited tools. Users cannot select individually which metadata elements are presented or control how they are presented. A typical presentation is a text document or a hypertext for each individual dataset, which allows studying of only one dataset at a time. Furthermore, metadata gathered in current systems are often insufficiently detailed for evaluation of datasets, as evaluation requires more extensive metadata than discovery. Some research efforts propose approaches for better understanding of search results, which is already a step towards evaluation. This type of research in geospatial metadata includes multidimensional ranking (Beard and Sharma, 1997) and a library metaphor in the visual user interface of a metadata system (Göbel et al., 2002). Bucher (2002) proposes a knowledge-based system that identifies suitable datasets on the basis of formal modelling of users' needs. In digital libraries, understanding of the semantics of documents discovered has gained research interest, and related efforts aim at providing more contextual information than the traditional keyword searches can handle.

In research of geospatial metadata, the users' role in the process of selecting a geographic dataset has been considered only cursorily, if introduced at all. I argue that search tools and advanced query systems are insufficient when there is a need to select from alternative datasets the most suitable one for an intended use. Instead, human input is essential in the evaluation process. First of all, the requirements of various applications for geographic data can be complex so that explicit expression of them in a formal language can be very difficult. Secondly, a user may need to compromise between original requirements and what is available because, in practice, supply of geographic data is limited to the extent that an ideal dataset cannot be available to every different purpose. The optimal choice in these conflicting situations varies from case to case. Furthermore, requirements may be mutually contradicting, or they may be only vaguely defined. In these cases, studying of metadata may prompt further requirements or dismissal of some original ones.

As a whole, evaluating datasets by metadata is a complex mental process in which users combine knowledge gained from metadata with their earlier knowledge about geographic data, their experiences, information from other sources – colleagues being the most valid information source (Flewelling and Egenhofer, 1999), and their expectations. They have to consider multiple characteristics of multiple datasets at a time and assess the way in which each dataset represents the real world. The process of selecting a dataset follows the model of decision-making where the phases of recognizing the problem, inventing and developing possible solutions, evaluating the alternatives and making the choice follow each other iteratively and in sequence (Malczewski, 1999; Simon, 1960). The aim of the process is to move from data (geospatial metadata, in this case) to information and further to knowledge that enables reasoned decisions (Awad and Ghaziri, 2004).

To perform efficiently, users need tools that support them with these tasks. However, selecting a dataset easily implies unstructured components that make use of formal decision rules inappropriate. Koivunen (1995) argues for not neglecting the intuitive capacity of human users in finding information; support is needed for finding information not only by predefined criteria but also intuitively by chance.

1.4 Visualization of geographic information

Visualization of geographic information (MacEachren and Kraak, 1997), as information visualization (Card et al., 1999a) in general, seeks to support human thinking by visual displays combined with interaction techniques. In decision-making and problem-solving situations, visual representation of information moves part of the cognitive load to the human visual perception system. Graphical images are particularly effective because detection of spatial patterns and groupings seem to be hardwired into the human visual system (Larkin and Simon, 1987). Interactive visual exploration of information engages users' knowledge and intuition in the process.

Human ability in visual pattern seeking has always encouraged use of visual presentations, but only with the development of technology for computer graphics and human-computer interaction the emphasis of visualization has changed from static images for presentation to interactive and dynamic displays that can facilitate visual thinking. Information visualization methods aim at providing insight into data that are large in quantities and complex in structures. They enable exploration of multiple variables and their relationships at a time as well as patterns, outliers, and trends in data. The use of alternative visualization approaches for geographic data is stimulated by the geovisualization research agenda (MacEachren and Kraak, 2001). Linking of interactive and dynamic maps that are designed to stimulate thinking (Peuquet and Kraak, 2002) with different methods of information visualization can reveal different aspects and broaden the insight of data (Dykes et al., in press).

Geospatial metadata are highly multivariate and frequently have a spatial component. Although metadata, at least in the case of selecting a datasets from an already limited set of potential alternatives, do not extend to amounts and dimensionality of those large databases that have stimulated the development of information visualization methods, there is complexity in metadata that can benefit from application of these methods. If the contents of metadata are the essential factor in respect to tasks, the representation of metadata is as important from a users' viewpoint. Therefore, an exploratory visualization environment with multivariate visualization methods, maps and interaction tools could be useful to users of geospatial metadata. These users in any case are familiar with maps and diagrams that represent the geographic data they work with. They are experienced in using such graphic representations to achieve an overview and to gain insight into spatial patterns in an exploratory manner (Kraak and Ormeling, 2003). Maps representing geographic datasets are the most important means of making the data perceptible to users. Experienced users of maps are considered to be able to evaluate the data quality intuitively by looking at a map, but as far as I know, liability of this kind of evaluation has not been studied.

Until now, most geovisualization environments have been designed for expert users with relatively narrow application needs (Cartwright et al., 2001). While users of geospatial metadata are professional users of geographic information, they cannot be considered as experts in respect to information visualization tools. Because these users gain only indirect value from metadata and may use the visual environment only occasionally, they need easy and intuitive tools that do not require extensive learning before use. Although usability is a key to the benefits users may derive from visualization (Slocum et al., 2001), usefulness and usability of visualization tools have gained wider research interest only recently (Fuhrmann et al., in press).

1.5 Work done on visualization of geospatial metadata

Visualization of geospatial metadata with varying aims relates to development of digital libraries, especially the Alexandria Digital Library initiative (ADL, 2004), and metadata systems, especially in the INVISIP project in Europe.

Beard and Sharma (1997) proposed a visual presentation of ranks that result from searching in digital spatial libraries. In their approach, ranking of datasets is based on a three dimensional ranking schema including space, time, and theme. The ranks are presented visually by bar glyphs that are composed of equal-size sections representing the rank dimensions in a fixed order. Each section is represented by a different hue, saturation varying according to the rank value. When the ranks of several datasets that result from a query are arranged simultaneously in a display, a user can get an overview of the ranks and search visually for the most overall saturated glyph. The authors mention the need for testing how well this approach would communicate the complex set of information to users but, to my knowledge, no user testing is reported. Though this approach does not visualize conventional metadata but case-dependent ranks, it is an interesting example of supporting users in evaluation of datasets by visual means. The visualization is not interactive but the glyphs could act as links to metadata. Beard and Sharma (1998) extend the approach to visualization of collection level metadata by choropleth maps and iconic stacks representing counts of datasets per areal units and distributions of data types (such as maps, satellite images, text documents, videos, etc.), respectively. This approach is included in the Alexandrian Digital Library efforts.

In the context of ADL, the Alexandria Digital Earth Prototype Project (ADEPT-DE, 2004) develops visualizations on two fronts. First, georeferenced visualizations follow the metaphor of the Digital Earth proposing that any georeferenced data could be accessed through an earth simulation interface; starting from a globe representation of the whole earth the user can interactively zoom smoothly to the scale and location of interest. While zooming in, not only the features of the earth become more detailed but also data resources become visible. Current efforts include 3D spatial histograms of dataset counts at the collection level, footprints of maps and images, and a tour of connecting links (Ancona et al., 2002). The other front in ADEPT is visualization of concept spaces (Ancona et al., 2002).

Cai (2002) proposes a retrieval and browsing tool for geographic digital libraries that implements a "document-location frequency" measure. The measure indicates the relevance of a document to a geographic location or region. His approach provides a user interface where a map is used not only for indicating spatial conditions in queries but also for providing an overview of how a collection of documents is related to different parts of the geographic space and a preview of the relevance of a certain document in respect to various locations.

Three approaches to metadata visualization are proposed within the framework of the EU-funded INVISIP project (Information Visualization for Site Planning, IST-2000-29640). First, Klein et al. (2002; 2003) propose an environment for previews and result visualization of queries by CircleSegmentView, SuperTable and scatterplot techniques. The Circle SegmentView aims at preventing zero-hit queries. The SuperTable combines different visualizations, such as bar charts and tile bars, with highlighted texts for presenting the search results. These representations are arranged in columns of a table where each row represents a dataset; users are allowed to change the degree of detail for the whole table or a single row. The latter implies distortion by focused view. The scatterplot is coupled to the SuperTable by brushing and linking. It provides additional information by mouse-over tool tips. Design choices in VisMeB have been confirmed by user testing, though improvements were suggested (Klein et al., 2003). The environment is very advanced as such, but the view of metadata in their examples seems rather mechanistic, and spatial aspects of data are ignored. Second, Göbel et al. (2002) propose use of a visual library metaphor with books, bookshelves, and a map on the floor, coloured blocks in various shapes representing the search results above the map, to improve the understanding of search results. In an earlier paper, Göbel and Jasnoch (2001) evaluated suitability of some visualization techniques, such as box plots, glyphs, cone tree, and tile bars, to metadata without giving any clear recommendations.

As the third approach, Albertoni et al. (2003a; 2003b), Demšar (2004), and Podolak and Demšar (2004) propose metadata visualization for exploration of metadata. Though Albertoni et al. (2003a) mention selection of geographic data as their aim, their approach rather suggests overview level visualizations. However, they make a valid remark that the knowledge coming from metadata patterns helps users in making a compromise between what is needed and what is available To improve users' awareness of available data, they have implemented an environment that provides a pie chart and a histogram for displays of one metadata variable, a parallel coordinate plot for multi-variate displays (Albertoni et al., 2003a), and a snowflake graph for displaying the similarity structure that results from hierarchical clustering of metadata (Podolak and Demšar, 2004). Interaction includes brushing and linking as well as selection by pointing the visual elements.

These proposed visualization approaches aim at use of metadata in discovery and overview rather than selection and evaluation of datasets. Although the usability of the VisMeB design (Klein et al., 2003) has been tested, usefulness of these visualization approaches to users of geographic information has not been confirmed.

1.6 Research questions

The hypothesis of this research was that visualization of geospatial metadata supports users in selecting geographic datasets for an intended use. Because the use of geospatial metadata in evaluation of geographic datasets has not been studied before, the research was aimed at extending understanding about how the evaluation proceeds and what are the characteristics of geographic datasets that gain users' attention. I gathered empirical evidence about the selection process in a visualization environment that combines different representations of geospatial metadata. This was to observe users and assess the usefulness of visualization tools in the selection process.

The questions that aroused from the hypothesis and the aim were the following:

- What are the essential geospatial metadata elements in the evaluation of geographic datasets? What are the feasible visualization techniques for representing these elements?
- How do different forms of metadata representations support the process of evaluation of geographic datasets? Are these different representations easily adoptable and intuitive to users of metadata while comparing datasets?
- What is the role of textual metadata in respect of visual representations?
- What kind of differences are there in the evaluation strategies of users? Do certain representations support particular types of strategies?

According to Fairbairn et al. (2001), the issues of concern in visualization research include characteristics of data to be visualized, purpose and form of representation, impact of form on understanding and task outcomes, and technology to support new forms of representation. These aspects of visualization research are mutually interrelated as shown in Figure 1.1.

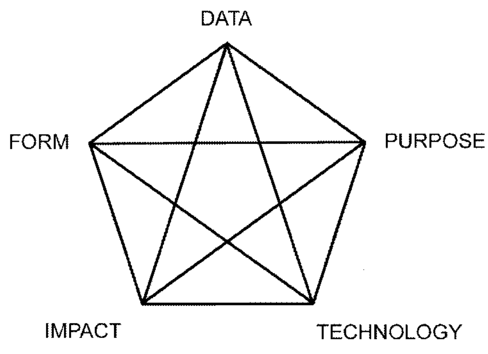

Figure 1.1 The interrelated aspects of visualization research.

In this study, the visualization was for a specific purpose, the evaluation of geographic datasets by metadata in order to select the most suitable one for an intended use. The data to be visualized followed the ISO 19115:2003 metadata standard. The potential forms of representation in this study derived from the semantics and characteristics of metadata as well as the task of evaluation.

Suitability and impact of these representation forms on the task in hand were tested with professional users of geographic data. Technology was out of the scope of this study, and only tools available in the mainstream computing were considered.

The contribution to geographic information science of answering the above questions is increased understanding of the use of geospatial metadata and visualization tools in this context. Results of this research can be used when designing geospatial metadata services as a component of spatial data infrastructures.

1.7 Methods and structure of the research

This study was conducted in the framework of user-centred design (ISO, 1999) that is characterised by early involvement of users and iteration of design solutions. Human-centred design consists of four design activities that are carried out iteratively:

- Understanding the context of use
- Specification of user requirements
- Production of design solutions
- Evaluation of design against requirements

This research did not aim at development of a final product though, but the stages of prototyping and user testing were applied for gaining understanding of users' actions, needs, and preferences. The structure of this research follows the framework of user-centred design and is illustrated in Figure 1.2.

Understanding of the context of geospatial metadata use and drafting of user requirements were based on my knowledge gained in metadata service development projects (e.g. prototyping of the Finnish national geospatial metadata service (Ahonen and Rainio, 1988) and the MEGRIN GDDD (Salgé et al., 1992a)), in metadata standardisation (in Finland (Ahonen-Rainio, in press), in CEN/TC 287, and in ISO/TC 211), and in formal (MADAME, 2000) and informal contacts with users of geospatial metadata. Two examples of the informal contacts are a storytelling session in October 2002 with three users from the Finnish Environment Institute who regularly acquire geographic data for various research projects, and a seminar 'Do we need metadata' with 50 participants representing both users and suppliers of geographic data in March 2003, organised in cooperation by the Finnish Council for Geographic Information and the Institute of Cartography and Geoinformatics of Helsinki University of Technology. The use context of geospatial metadata and the draft requirements of the evaluation task are described in Chapter 2. Chapter 2 also describes the ISO 19115:2003 in respect of the use context of this research.

The first design solution, at the level of concept design, was based on techniques of visualization in cartography and information visualization. The prototype design built on the results that were gained from user testing of the design concepts and extended them with interactivity. Chapter 3 gives a literature review of developments in cartography and geovisualization as well as information visualization.

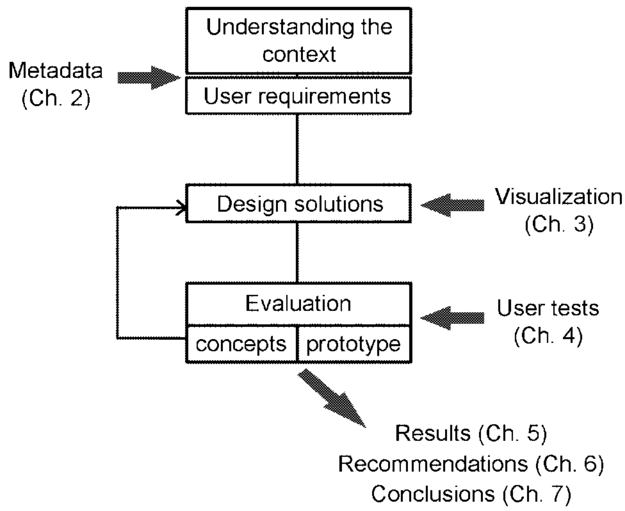

Figure 1.2 The structure of the dissertation in the framework of user-centred design.

Empirical evaluation was conducted in two stages: first, in a concept test of preliminary design ideas, and second, in a user test of an interactive prototype. These two tests are explained in Chapter 4. Results of the tests are introduced and discussed in Chapter 5. Based on the results, Chapter 6 gives recommendations for design of visualization environments for geospatial metadata. Chapter 7 concludes the results of the research and discusses the needs for further research.

2 Geospatial metadata

This chapter discusses the task of selecting geographic datasets by metadata, the expertise of users of geospatial metadata, and the contents geospatial metadata. These issues relate to the aspects of visualization research presented in Chapter 1.5 as shown in Figure 2.1.

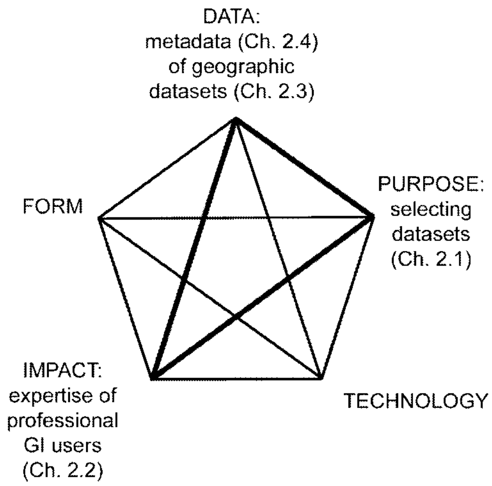

Figure 2.1 Geospatial metadata in the framework of visualization research.

The task of selecting geographic datasets forms an iterative process where specifying requirements, searching, and evaluating datasets iterate. This process is described in Chapter 2.1. After that, expertise of users of geospatial metadata is considered in Chapter 2.2. However, only professional users of geographic information are considered in this research, though use of geographic data is extending to the general public by easy access to geographic information applications in the Internet. Chapter 2.3 discusses the characteristics of geographic data that are of concern to users of metadata and the variation of these characteristics in the array of different geographic datasets. These characteristics set the requirements for the description of geographic datasets. The content of the ISO 19115:2003 metadata standard is studied in this respect in Chapter 2.4. Chapter 2.4 also considers general characteristics and the data types and scales of metadata as they provide a starting point for the visualization considerations. Finally, a summary concludes the Chapter.

2.1 Selecting of geographic datasets by metadata

Theoretically, users looking for datasets for an intended use first specify the requirements for such data. They then make query for potential datasets, and finally, evaluate these datasets to select the best one for an intended use. In practice, the process is highly iterative as users refine the requirements while gaining more insight of available datasets. The main stages of the process are shown in Figure 2.2.

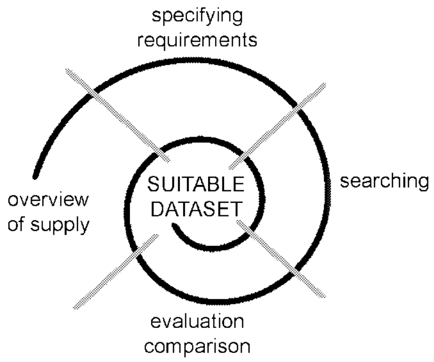

Figure 2.2 The iterative selection process of geographic datasets.

There is no single set of requirements that would guarantee the fitness of data for every use, but users should identify the critical aspect in each case. However, specifying the requirements may be difficult, and users may want to browse metadata first to get an overview of available data resources. If a metadata system is very narrow by scope and includes only a limited number of datasets, users may be able to select a suitable dataset while browsing, and the task is done. This research however considers more extensive metadata systems where the task is not that straightforward.

With the requirements in mind, users then access a metadata system in order to search and evaluate metadata. They now need to translate the requirements into constraints on metadata elements. This implies understanding of metadata elements and their value domains. Users first express the search criteria using the means the system provides, which is typically a query interface. The primary search criteria concern the theme and location of datasets, sometimes also the temporal dimension of data. Further search criteria are possible as far as advanced queries are allowed to users. Users of queries face the dilemma of formulating search criteria that are comprehensive enough to retrieve all relevant datasets but also precise enough to avoid large numbers of irrelevant datasets. However, facilities for advanced queries are not a standard feature in current metadata systems.

While searching datasets, users do not necessarily see the actual metadata but only the user interface that enables search functions; at this stage metadata are entirely in computational use. Only when search results are at hand do users get in touch explicitly with metadata. In this stage, at the latest, users have to transform their requirements into metadata elements. Users evaluate the fitness of each potential dataset by studying metadata and select the most suitable one, if any. The evaluation criteria vary from case to case, depending on the intended application and user's perspective of data. For example, a research analyst may emphasise the currency and reliability of the data whereas an application user may pay most attention to the resolution of data and positional accuracy, and a data administrator may be most concerned by the fees and restrictions upon use.

If searching returns only one or few datasets, users can study the metadata in question and compare the characteristics of each dataset to the requirements in order to accept or reject the dataset. When the requirements are less strict, the process can appear the other way round, as a matching of requirements to the characteristics of an available dataset (Lillywhite, 1991).

When searching results in more than one potential datasets, their mutual comparison becomes relevant. If no single dataset alone meets the primary criteria, then potential combinations of datasets have to be considered. This complicates greatly the comparison. In the context of evaluation of datasets, comparison can occur in three instances:

- **Suitability**: Alternative datasets, all representing the same theme and available from the geographic area of interest, are compared in order to judge which one of them meets the requirements best and is suitable for an intended use.

- **Similarity**: Datasets representing the same theme but available from different geographic areas, are compared in order to judge whether they are similar enough to be integrated and whether they together cover the area of interest.

- **Compatibility**: Datasets representing different themes and available from the geographic area of interest, are compared in order to judge whether they can be integrated to meet the thematic needs of an intended use.

Any combination of these comparisons is possible, but can result in very complex evaluations that require thorough expertise on the effects of data integration. The evaluation criteria and their relative importance direct the comparison, and the suitability has to be considered in any case.

Iteration may be prompted at any stage of the selection process. The requirements may be implicit at the beginning of the process, and users start by a rough search. They browse the search results to gain an idea of potential datasets and only then consider the requirements properly. They may make a new search or proceed to evaluation of alternatives. The evaluation process is iterative as such. Users study metadata in order to determine whether their requirements could be fulfilled, construct knowledge about the alternatives, study their differences, and perhaps reconsider the requirements and start evaluation anew.

2.2 User expertise on geospatial metadata

Longley et al. (2001) estimate that there are about three million people using geographic information systems (GIS) worldwide. Very little is known about their characteristics, although some research efforts have tackled the issue (Medyckyj-Scott and Hearnshaw, 1993; Nyerges et al., 1995). Users are interested in geographic data for various reasons that prompt them to access geospatial metadata. What they seek from metadata is understanding of geographic data. "Proper documentation will provide those unfamiliar with the data with a better understanding, and enable them to use it properly." (ISO, 2003, Introduction) This proper use includes integration, generalization, and manipulation of datasets with understood or predictable results (Guptill, 1999).

2.2.1 Expert and novice users

Understanding relates closely to expertise that is a concept used for explaining individual differences in task performance. Expertise derives from knowledge structures and problem-solving strategies that are closely interrelated when performing tasks (Hakkarainen et al., 1999). Complex knowledge structures and complex problem-solving strategies are characteristic to experts (in contrast to novices).

Eysenck and Keane (2000) describe the different behaviour of novices and experts in problem solving in the following way: First of all, novices and experts classify problems differently; novices tend to group problems on the basis of surface features, such as keywords and objects in the problem, whereas experts classify problems in terms of their deep structures, such as the principles by which they could be solved regardless of the surface features of the problems. Then, experts solve problems faster but spend more time analysing and understanding the problems than novices; experts elaborate the representation of the problem by selecting appropriate principles that apply to it whereas novices tend to wade in to the problems immediately. In respect to strategies, experts tend to work forwards to a solution applying the principles they have selected to generate the unknown quantities needed to solve the problem; novices, who have a poor repertoire of available principles, take the goal and find a principle that contains the desired quantity and usually no more than one unknown quantity, and then, try to find this one unknown hence working backwards to the given problem statement. As Mayer (1997) states, novices focus on getting a solution rather than understanding the problem.

In practice, it is not straightforward to state who are the novice or expert users because the differences form a continuum rather than two classes (McGuinness, 1994). In addition, many tasks require expertise that is multi-dimensional. Nyerges (1995), while outlining a model of GIS user knowledge, distinguishes knowledge in the problem domain and in the tool domain, stating that knowledge in the tool domain can either facilitate or hinder use of the problem domain knowledge. So these two knowledge domains interact when performing tasks. Nyerges (1995) also divides the problem domain knowledge further into conventional spatial knowledge and professional spatial knowledge. The latter varies from one domain to another but is always "deeper and broader" than conventional spatial knowledge that is gained from daily experience with the reality and affected by sensory input. Griffin (2004) lists domain expertise, problem-specific, place-specific, technology-specific, and representation-specific expertises as types of expertise that are relevant in studying geographical visualizations. Mayer (1997) proposes four knowledge categories: syntactic, semantic, schematic, and strategic knowledge. Although he examined differences between experts and novices in the domain of computer programming, his categories seem to be relevant also in the domain of using geographic information system. Syntactic knowledge relates to units and rules of a language. Semantic knowledge refers to a mental model. Schematic knowledge relates to chunks that are information units stored in memory and formed from integrating smaller pieces of information (Eysenck and Keane, 2000). Strategic knowledge relates to problem-solving strategies and is often tacit.

In parallel to the inner characteristics, person's role in an organisation influences on this user's ability to carry out tasks (Nyerges, 1993). In particular, a user's motivation and responsibility depend on the role, and more broadly, the interplay of different roles within an organisation. Nyerges (1993) proposed GIS user roles, such as technical specialist, programmer, analyst, manager, scientist, and executive. A further classification of GIS expertise in respect of educational goals is proposed by Virrantaus (2001). She distinguishes expertise on using a GIS in fixed daily tasks (GIS user), overall understanding of GIS as an information system and the design and implementation process of it (GIS developer), expertise on software development technologies and their application to GIS (GIS engineer), and expertise on spatial modelling and mathematical and computational solutions for application problems (GIS analyst).

Even though users' roles in an organisation reflect their expertise, the roles may shape differently in different organisations. For example, in a research institute a GIS user may need to manage the system alone, whereas in an organisation where GIS is a production tool, users get detailed instructions and all necessary support. In a small organisation a GIS analyst may select and buy data independently, whereas in a large organisation a data administrator may be responsible for coordinated acquisition of data for GIS analysts. However, expertise does not derive from experience only (Hakkarainen et al., 1999), and therefore, users' role and length of experience do not directly indicate their level of expertise.

2.2.2 Dimensions of geospatial metadata expertise

Although the GIS user expertise forms the basis of expertise on use of geospatial metadata, additional components are included in metadata expertise. On one hand, users of geospatial metadata need to be capable in specifying the requirements for data needed in an intended application. On the other hand, they need to be capable in recognizing a suitable dataset when they see one (Flewelling and Egenhofer, 1999). Consequently, the user of metadata needs to take a view one abstraction-level higher than a user of actual data. As such, to users of metadata understanding of the subject matter and the philosophy of the field are more important than skills in using software and data, although practical skills and theoretical knowledge are not mutually exclusive.

The expertise of geospatial metadata users is composed of four dimensions:

- Expertise in the **application domain**. This expertise is vital in identifying the needs for data and, especially, the characteristics that are critical in the intended use. These relate to the subject matter mentioned above, and concern, e.g., the conceptual model and classifications, the spatial approach, and the quality measures. For example, an expert of soils understands the soil classification and the nature of uncertainty in soil data and, on that basis, can specify the requirements for data in a certain application. At the same time, the user should be able to reason whether a potential dataset that represents the intended theme but may originate from a different application domain meats the requirements.

- Expertise in **geoinformation science** (GIScience). This area of expertise is important in reading metadata. Users need to judge how the categorisations and expressions used in metadata correspond to those used in the application domain or what are the implications of quality as described. For example, an expert in GIScience can judge whether the algorithmic interpolation method used in production of a DEM results in an acceptable level of uncertainty in an intended application. Expertise in IT, especially in data modelling and data structures, supports understanding of metadata.

- Skills in using **GIS software**. Practical skills in using GIS software, or application software, are relevant when judging whether a dataset could be transferred to and used in a specific application environment. For example, skills on input formats and data compression methods are needed as well as knowledge about the data structures in the software intended to be used.

- Expertise in **geographic data supply**. This expertise can be gained by experience with datasets and their providers and includes understanding of the peculiarities involved (Flewelling and Egenhofer, 1999). Tacit knowledge dominates this expertise and is hard to be derived explicitly from metadata. Therefore, inexperienced users may choose seemingly suitable datasets that fail to meet their needs. High expertise in geographic data supply seldom occurs without relatively high expertise in the other three dimensions. This expertise reflects on how truthful users' images of data products are, which reflects further on user expectations (Kotler, 1997).

A pattern of expertise with these four dimensions can be drawn to any user of geospatial metadata. Users who are experts in all four dimensions can draw more information from metadata than other kind of users, but they also need detailed metadata to gain real benefit. Users who are novices in all dimensions can use metadata only in learning purposes, and they benefit already from general level metadata. As to selecting of datasets, novice users would need metadata that describe datasets from their application point of use, though that is impossible in objective universal metadata systems (see Chapter 2.5 for discussion of different types of metadata systems). Novice users may lack motivation in studying the numerous details in metadata (that they cannot understand), nor be aware of implicitly expressed limitations or risks of data use, but seek easy answers. Therefore, I do not consider the current metadata approach suitable for the general public when they are looking for geographic data.

2.2.3 Terminology of geospatial metadata

Terminology plays an important role in understanding metadata, especially in universal metadata systems that provide information to users coming from different disciplines and cultures. If metadata include unfamiliar terms the descriptions are meaningless to users, or can lead to misinterpretations. All the four dimensions of geospatial metadata user expertise include mastering the concepts and terminology of that dimension. For example, a skilled user who knows the data structures of a software application but without thorough knowledge of GIScience may find it difficult to properly distinguish the ISO 19115:2003 levels of topology and decide which one of them corresponds to the one in the application system. The emphatic role of domain-specific terminology was clearly demonstrated in a study among professional GIS application users[5], as some of them were not familiar with the Finnish terms of 'geographic dataset' and 'GIS software' even though they use a GIS application frequently.

While metadata tend to provide concise descriptions, there is need to have explanations available to specific terms (MADAME, 2000). These explanations may concern metadata elements as well as enumerations and other value domains of metadata elements. Information about whole value domains instead of individual values provides a context, which can assists users in understanding the descriptions. For example, the meaning of 'map production' as the purpose of a dataset is different when the domain of purposes is divided into three categories than when there are twenty different categories.

2.2.4 Users' motivation and attitude

Users seldom construct their knowledge of geographic datasets on the basis of metadata only. They have previous knowledge gained from education, earlier experiences in using geographic data, colleagues' stories about their experiences, documents from and direct contacts with data suppliers, and advertisements. Earlier use of geospatial metadata also contributes to users' knowledge structures. Previous knowledge sets a level of expectations that controls how users direct their attention and adopt information when using metadata. Evaluation criteria direct users'

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[5] Reported in Louhisola, M., Puolustusvoimien paikkatiedon metadata, Masters thesis at the Helsinki University of Technology, Dept. of Surveying (in Finnish), Espoo 2002.

attention to certain aspects of metadata, but if users have only a vague idea of critical characteristics, their attention on metadata elements is easily directed by the way how metadata are presented as well as the overall design of the user interface of a metadata system.

Motivation of users is based – but only partly – on the task for using metadata. Another important factor affecting the motivation is users' earlier experiences with metadata. High expertise in geographic data supply is valuable in controlling users' expectations on geographic data. On the other hand, expert users are more critical of geospatial metadata and expect detailed and timely information (MADAME, 2000). Experiences of imperfect, out-of-date or faulty metadata set the level of expectations very low and decrease the motivation for using metadata.

2.3 Geographic data as a representation of the real world

Although the criteria by which users evaluate the suitability of datasets for an intended use vary from case to case, the profound criterion in every case is whether the way in which the geographic data represent the real world meets the view of the intended application. Geographic data as a representation of the real world involves different levels of representation. These are the conceptual representation, digital representation (i.e. the data), and visual representation, and all of these are of concern to a user of geospatial metadata. The three-layer model of databases[6] as well as metadata act as a bridge between the conceptual and digital representations, as shown in Figure 2.3. The aim of the visual representation is to display the digital data so that conceptually correct information is perceivable to users.

The conceptual representation is composed of ideas about the objects or phenomena of the real world, their properties and relationships. A conceptual schema, a formal expression of the conceptual representation, is a basis for any data store. All those aspects of the real world ignored in the conceptual representation are excluded from the data. The digital representation is composed of data representing the real world instances, following the conceptual and logical models and implemented in the terms of a database management system. Spatial abstraction of the real world is an essential component of geographic data. Conceptual models for spatial data are implemented in vector and raster data structures (Laurini and Thompson, 1992; Peuquet, 1984; Worboys, 1995) with extended relational, object-relational, and object-oriented data models or following the traditional approach of map layers (Tomlin, 1990).

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[6] This layered model of a generic database architecture presented by ANSI-SPARC in 1970'ies has been widely followed in information system design, also in design of geographic information systems (Laurini and Thompson, 1992; Worboys, 1995).

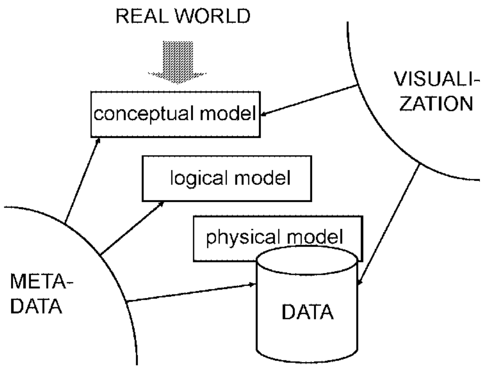

Figure 2.3 The levels of real world representation embedded in geographic data.

In the context of spatial data infrastructures, file formats in data transfer stand for the logical and internal schemata. The digital representation, however, is prone to inaccuracies and errors due to the process of data production. Therefore, information about data quality is essential in the evaluation of the digital representation.

A visual representation is needed for human users to perceive the geographic data. Maps are an established way to represent geographic data visually though other kinds of graphics are used as well. When a portrayal is embedded in or attached to geographic data, the data inherently compose a map. When geographic data are intended for computational use, they are often without predefined portrayal. Though they can be presented as a map, the visual representation is not embedded in the data but up to each user of these data.

In the following, I discuss variation of geographic datasets within these representations as a motivation for extensive metadata content and a demonstration of the complexity of the evaluation task.

2.3.1 Conceptual representation

Within any information community, there is, by definition, an agreement on a shared set of concepts (Kuhn, 2003) but the cross-community concepts can differ remarkably. Burrough and Frank (1995) show the differences of views between users who deal with well-defined crisp and, often, static entities and those who deal with complex dynamic systems that can only be approximated. Mark et al. (1999b) report on personal differences in definitions of geographic terms. Because of the differences in views, categorizations, and meanings of terms that users relate to the real world objects, there is an urgent need for describing the conceptualisations behind datasets, especially when the datasets are available for shared use across disciplinary or cultural boundaries.

Conceptual schemata are conventional means of documenting the conceptualisations in the database design process. A users' view of the real world is captured in a formal conceptual schema that follows an established modelling paradigm, such as entity-relationship or object-oriented modelling. A conceptual schema defines the universe of discourse which is all those objects or phenomena of interest that have been, are or ever might be (ISO, 1987) and the integrity constraints – "the information system cannot be held responsible for not meeting those described elsewhere" (ISO, 1987, p. 17).

Because of its communicative role, a conceptual schema can be seen as a suitable description of the conceptualisation also to users that evaluate the semantics of data extracted from an existing database. But because of their original role, conceptual schemata also have their limitations. Because they serve the database design process, they may leave out concepts or ideas about which the database designers and users have agreed, or which constitute background knowledge about the information system. Complex constraints that govern the geographic data may be documented only to some extent; the expression power of conceptual schemata may be insufficient or expressions, e.g. in predicate logic, are not easily readable to ordinary users. As a result, the conceptual representation documented in a conceptual schema can be incomplete and difficult to capture, especially to users who were not involved in the design process.

Despite the design principles, it is typical that logical data models dominate database design as much as human conceptualisation, and the logical data schema is often the only consistent documentation available for a dataset. In addition, map data originating from digitised paper maps may be stored in a layered model (Tomlin, 1990); the conceptualisation is inherited from the original map and never documented explicitly as a conceptual schema. For this kind of datasets, the specifications of the fieldwork and map compilation may provide the best documentation of the conceptual representation, but these documents are seldom available to users outside the data producer organization. On the other hand, many databases holding topographic map data have evolved dramatically since their origins, hold multi-representation data, and follow a rich conceptual model with tens of object classes (Salo-Merta, 1999). The conceptual modelling approach assumes an object-based view of the real world, whereas some spatial phenomena are continuous and, as such, not dividable into discrete objects. The interest in their conceptualisation lies in how the phenomena are characterized, resulting in the resolution of measures and the value domains. In these cases, the data structure at the logical level is the main interest in the design rather than the traditional conceptual schema with perhaps only a single object class.

While conceptual models have their aims in database design, ontologies are proposed as means of describing the semantics of spatial data both for data retrieval and data integration (Kuhn, 2002; Rodriquez and Egenhofer, 2003). Ontologies – as shared conceptualisations of application domains – can also support sharing of geographic data among different information communities. The need to understand the semantics of data is most urgent for integration of databases as correspondence between the components is critical. Despite studies of automated integration by ontologies, human knowledge of the semantics of data is important in the final decision about the correspondence (Devogele et al., 1998). Kuhn (2003) proposes development of a more extensive semantic reference system that would enable transformations among semantic spaces and projections to sub-spaces, based on stronger formal foundations than most current ontology languages provide. However, extensive domain ontologies that would provide common references for geographic datasets are yet to be developed. For the present, the evaluation of the semantics of geographic datasets is limited to descriptions at the database level or, in some cases, to informal documentation at an application domain level.

2.3.2 Spatial representation

Geographic data can represent almost any kind of object or phenomenon in the real world, the only common factor being the direct or indirect association with a location relative to the Earth[7]. Despite the richness of the real world and conceptual views of it, the representation of geographic data, in practice, is limited to two spatial modelling paradigms, the object-based modelling and the field-based modelling.

These two modelling approaches abstract and generalize the representation of the real world by different means. In the object-based modelling, the 3-dimensional and irregular-shaped objects of the real world are abstracted and reduced in dimensions and generalized in shape into basic geometric objects. Their properties are described by tuples of attributes. In the field-based model, continuous phenomena of the real world are characterized by a set of attributes, each one measured at sample points, and represented as sample points (and attached mathematical functions), regular grids, polygon networks, or triangular irregular networks (TIN). It is assumed that most properties vary smoothly so that attribute values at can be determined from measured values by interpolation.

These modelling paradigms are appropriate when representing objects and phenomena with crisp boundaries and well-defined attributes. Objects of this kind are typically man-made concrete constructions, such as buildings, roads, and utility networks, or abstract objects that exist only in social systems, such as administrative units, parcels, and natural protection areas (Frank, 2001). However, these approaches assume a static invariable world and ignore objects that consist of interacting parts or display variation at many different levels of resolution (Burrough and Frank, 1995); their limitations have been demonstrated with many natural world phenomena that are vaguely defined or with indeterminate boundaries (Burrough and Frank, 1996). Although many solutions are proposed for imprecise data, they are at the processing level and, in practice all transferable data keep to the traditional approaches with crisp geometry and well-defined attributes. However, uncertainty models can be

[7] This follows the terminology used in of the scope of ISO/TC 211, see URL http://www.isotc211.org/Scope (accessed 1.10.2004)

attached to datasets (Horttanainen and Virrantaus, 2004). Standard methods would be needed for describing the interpretation and processing of these data.

2.3.3 Resolution of the representation

The level of detail of representation is an important property of geographic data and one of the primary criteria in the evaluation of datasets. The level of spatial detail is typically expressed in terms of scale (the ratio of distance on the map to distance on the ground) or resolution (the smallest perceivable unit in length, area, or volume). However, the effects of scale or resolution are manifold and not at all self-evident (Tate and Atkinson, 2001).

The choice of geometric objects and the precision of the location coordinates determine at which level the spatial objects represent details of the real world. The number of sample points as well as their location is critical in determining the resolution of field-based representations. A polygon network is an example of the complexity of spatial resolution. It is based on a classification of the phenomenon, such as soil type, forest stand, or land use, assuming homogeneous polygons. Consequently, the level of spatial detail is determined by the classification system rather than any spatial property, though the spatial resolution of observations that are used for the formulation of the polygons affects on the homogeneity of the polygons (Painho, 1995).

While the generalization aims at selecting important features and disregarding unimportant ones in respect to the intended use of the data, separation of the important from the unimportant is a complex mental process involving functions, such as ordering, distinction, comparison, combination, recognition of relations, drawing conclusions and abstraction (Brassel and Weibel, 1988). Because the functions that are appropriate in each case depend on the nature of the represented phenomenon, it is necessary to know something about the general nature of the phenomena to understand the effects of generalization on data (Müller, 1991). Goodchild (2001) emphasizes the spatial dependence in this respect; differences over a short distance can be ignored because they are likely to be small. What this 'short distance' is depends on the phenomenon. Goodchild (2001) mentions slope (function of point spacing), population density, soil types, and land use classes as examples of phenomena that are scale-dependent in the sense that a length measure is inherent in the variable's definition. If the resolution of the representation is higher than appropriate the data can be expected to be noisy; a lower resolution would inhibit perception of significant patterns. This is contradictory to exact objects, where the more accurate measurements mean the better representation.

Taking into account the complexity of the concept of spatial resolution, one value expressing the scale or resolution tells very little of the effects of the abstraction and generalization of the real world.

2.3.4 Cartographic representation

The issue of generalization is faced again when a geographic dataset comprises a map. Though cartographic data are meant for visual use, in practice, these data are extensively used also for computational analyses because many geographic datasets still originate from digitised paper maps. Cartographic processes, especially generalization, effect data quality, but there are few measures that can provide information about these effects. Therefore, the evaluation of map datasets remains highly intuitive.

A map is inherently generalized because of the limited map space available for the representation. Cartographic generalization is by nature irregular and characterized by multiple rules and constraints. It depends not only on the object or feature itself but also on their relations to neighbouring objects, of the same type or other types (Buttenfield, 1985; Buttenfield, 1989; João, 1998). Consequently, an object may be included in the data although a similar object in another location is missing from the data – and in the cartographic sense this may not be an error in the data. Development of automated generalization has produced formal expressions of generalization but typically they form exhaustive collections meant for computers to read. There are no easy or consistent means of describing the generalization process has affected the representation.

When the suitability of data for visual use is evaluated, visual legibility is the primary concern. As the 'errors' such as displacement resulting from cartographic generalisation are mainly unpredictable and difficult to describe, evaluation of the quality of map data is mainly up to the intuition of each user. Contradiction between requirements of visual and computational use becomes evident here. For example, deletion and combining of objects as a part cartographic generalisation may enhance the legibility of a map and increase the quality, but if the same dataset is used for computational analysis, the good cartographic qualities turn to negative quality factors.

2.3.5 Quality of geographic data

The method of collecting or creating data affects the characteristics of the digital representation (Walford, 2002). Therefore, the conceptual or logical schema cannot provide a full description of the contents of geographic data but quality description is required in addition. For data producers, information about source data and production process (lineage) indicates the quality of the resulting data, but the same information may be unintelligible to users of external data sources. Instead, they need to know the quality of the resulting datasets.

Quality is often defined as the ability to satisfy customers' needs (e.g. Gale, 1994). This leads to different quality for different users (Krek, 2002) whereas, in the context of metadata, there is need for objective quality measures that leave the evaluation of satisfaction to each user. The ISO 19113:2002 (ISO, 2002) standard defines data quality elements for objective description of data quality. The standard comprises quantitative quality information and quality overview elements. The quantitative information describes the completeness, logical consistency, positional accuracy, temporal accuracy, and thematic accuracy of geographic data. As each of these composes of several quality elements (ISO, 2002), description of data quality can become extensive. The quality overview elements describe the purpose, usage, and lineage of data.

The ISO 19113:2002 standard defines the structure of the quality elements but not the quality measures. They are defined by a technical specification ISO/PDTS 19138 that is currently under development. Consistent measures are a prerequisite of comparison of quality of different geographic datasets.

Datasets may appear relatively good quality and error-free when examined individually and in terms of their internal consistency and validity. The possibility and need to integrate geographic datasets from different sources issues a challenge for describing data quality, regardless of whether the integration is based on spatial or attribute data. In order to evaluate whether the integration is feasible in each case, consistent quality information would be required. For instance, the quality descriptions in brochures of geographic data suppliers today do not meet this requirement.

2.4 Contents of geospatial metadata

Geospatial metadata should give sufficiently detailed descriptions of datasets so that their evaluation can be carried out and differences between closely similar datasets can be identified. To be effective in use, the content structure of metadata must be the same for each dataset so that the descriptions are comparable. This need was recognized as a mutual interest by the geospatial metadata developers and has resulted now in the international standard ISO 19115:2003 "Geographic Information – Metadata" (ISO, 2003). The standard aims to cover different needs for metadata as far as possible so that a single collection of general-purpose metadata would suffice. This unavoidably leads to compromises between conflicting requirements. Fortunately, the needs of different uses of metadata are not mutually exclusive.

The ISO 19115:2003 metadata standard for geographic information defines a schema and an extensive set of metadata elements for describing the characteristics of geographic data[8]. The metadata elements can be applied to datasets, dataset series, and individual geographic features and their properties. Among the metadata elements, there are conditional elements for alternative descriptions, e.g. for different

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[8] A closely related standard ISO 19131 *Geographic information - Data product specifications* is under preparation and planned to be published in 2006. An extension to the metadata standard, ISO 19115-2 *Geographic information - Metadata - Part 2: Extensions for imagery and gridded data*, is planned to be published in 2007.

types of data (i.e. raster/grid and vector data) and spatial extent. Some of the metadata elements are not meaningful in isolation but only in relation to certain other elements. These structures are defined in the metadata schema. The standard recognizes varying needs for metadata by defining majority of the elements as optional. In addition, it gives rules for defining extensions to or a profile of the standard for communities with special needs.

The standard lists core metadata elements that are required to identify a dataset. The mandatory core elements describe the topic, spatial extent and reference date of a dataset, forming the minimum information for cataloguing purposes and discovery. A point of contact for further information is included in the mandatory core metadata proposing that users would contact the data supplier if they want to know the details of the data; this will, however, be too burdensome if data exchange is to become routine (Beard, 1996). The majority of the metadata elements are optional but it is obvious that they are necessary for many uses of metadata other than discovery.

The standard defines the metadata elements in the following sections (see Figure 2.4):

- Metadata entity set (an aggregate of the other sections)
- Identification
- Constraints
- Data Quality
- Maintenance
- Spatial Representation
- Reference System
- Content (Feature and Attribute Information)
- Application Schema
- Spatial and temporal extent
- Portrayal Catalogue Reference
- Distribution Information

In addition, there are metadata elements for defining possible extensions to the standard description.

By defining the metadata elements the standard also establishes a common set of metadata terminology. It is composed of the names of the elements as well as their enumerated domains. Consistent terminology is a key factor in the comparability of datasets by metadata.

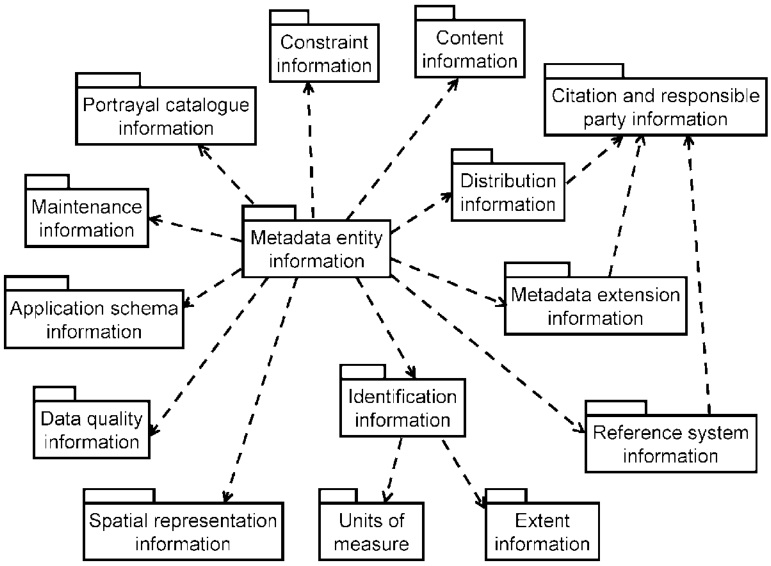

Figure 2.4 The ISO 19115:2003 metadata packages.

2.4.1 Metadata about data contents

The ISO 19115:2003 standard includes the metadata elements *feature catalogue* and *application schema* as the most extensive means of describing the semantics of datasets. An application schema corresponds to the conceptual schema discussed above. It can be provided as an ASCII file, a graphics file, or a software dependent file (with the software). Feature catalogues are derivatives of the application schemata including definitions of objects, attributes, and relationships. The metadata may give a reference to a feature catalogue or description of attributes of grid data.

Metadata elements *keyword* and *topic category* have their main role in discovery by thematic dimension. They provide information about the content at a rough level. In addition, some metadata elements provide contextual information that can support understanding of the semantics, especially the elements *abstract, purpose* and *usage* (ISO, 2003). The context of the data is an important aspect in understanding the limited information of a conceptual schema (Molenaar, 1998). These elements provide informal textual descriptions, which imply that their use is up to the authors of metadata and they may not be comparable. However, the *abstract* as well as the *purpose* can prove to be important pieces of information in the evaluation of a single dataset, but the conventions of using these elements are still to be established. The *usage* element, intended for describing the applications for which the data have been used or for which they are unsuitable, is not easily applicable when data production (including production of metadata) and usage are distributed in different organizations.

The level of detail, as far as this is not evident from the feature catalogue or application schema, is described by the metadata element *spatial resolution*. It is expressed as a representative fraction referring to "the scale of a comparable hardcopy map or chart" (ISO, 2003) or as a ground sample distance. Spatial resolution gives an indication of suitable application scales for data. It can be improved by *browse graphic* that is a visual sample of the dataset.

2.4.2 Metadata about data structures

Information about the logical level of geographic data is conveyed by metadata for *spatial representation* and *format* (ISO, 2003). For grid (or raster) data, the metadata elements of spatial representation give information about the geometry and geolocation of the cells and dimensions of the grid. For vector data, the metadata elements of spatial representation give information about the geometric objects and the level of topology. Closely related to spatial representation is information about the *reference system*[9]. Spatial reference is either by geographic identifiers, such as addresses and place names (ISO 19112:2003 Geographic information – Spatial referencing by geographic identifiers), or by coordinates. In the first case, the reference system is labelled in the metadata. In the latter case, the reference system is labelled or described according to the ISO 19111:2003 Geographic information – Spatial referencing by coordinates. The metadata elements relating to *format* provide "description of the computer language constructs that specifies the representation of data objects in a record file, message, storage device or transmission channel" (ISO, 2003).

2.4.3 Metadata about data quality

The ISO 19115:2003 standard defines five main quality components: *completeness*, *thematic accuracy*, *temporal accuracy*, *positional accuracy* and *logical consistency*. These components are divided further. For example, completeness appears as commission or omission, and logical consistency can be expressed as conceptual, domain, format and topological consistencies. The standard does not predefine measures for the quality components but defines the structure of several elements that allow description of a measure, its evaluation method and procedure, and the result. Commonly used measures are, for example, a classification correctness matrix for thematic accuracy and the root mean square error for positional accuracy of point coordinates.

[9] In addition to spatial reference systems, ISO 19115:2003 defines metadata elements for describing a temporal reference system.

In addition to these quality components, the ISO 19115:2003 standard defines other metadata elements that are relevant in describing data quality. A data production oriented element *lineage* provides information about source data and processing steps, including maintenance, of a dataset. This information is aimed at users who can judge the quality of the data from the lineage description. Whether the data are up-to-date is a crucial matter for some applications. That can be described by temporal validity as part of temporal accuracy together with *maintenance frequency*.

2.4.4 Metadata about visual representation

A bibliographic reference to a *portrayal catalogue* to display the data can be given as a part of metadata. An instant means to show the portrayal is the metadata element *browse graphic* that "provides an illustration of the dataset" (ISO, 2003). The standard does not specify the content of the illustration, and there are various ways how the graphics can add information to metadata. A conventional option is a display of sample data. When the dataset is a digital map, the layout of the sample is inherent, and only the location and size of the sample have to be decided. The display scale also has importance in the interpretation of the graphics. When the dataset is not a map, the layout has to be designed. The rules and conventions of visualization of geographic information (Kraak and Ormeling, 2003) should be followed. The metadata for the browse graphic include the name and format of the graphic file and a text description of the illustration. Several browse graphics can be provided for a dataset.

2.4.5 Other metadata elements

In addition to the above mentioned metadata elements, users evaluating suitability of datasets need to know about the availability as well as access and use restrictions of the data. Availability of the data can be described in respect to geographic and *temporal extent*. Though these are important search criteria, in the evaluation their detailed description can prove to be important. Metadata elements for *geographic extent* are defined for bounding polygon, geographic bounding box and geographical description by identifiers. Each of these has its benefits: the bounding polygon is an exact method, the bounding box is mathematically simple (in the worst case, it conveys very approximate information), and the identifiers are a familiar means for users. For the rare cases, the standard defines metadata elements also for vertical extent. When users are interested not in the whole dataset but a certain location, a valid piece of information is the tiling (or geographic areas) in which the data are available. That is included in the metadata of distribution.

Metadata of *constraints* define use limitations as access, use and security constraints. Metadata about *distribution* includes elements for digital transfer options, distributor and standard order process. These may have value already at the evaluation stage before the actual distribution because, if not the technical aspects, at least the price of data can become a critical factor in deciding on a dataset.

2.4.6 Current supply of geospatial metadata

Geospatial metadata sets and collections are developing in number, and several initiatives have been announced to convert existing metadata collections to conform to the ISO 19115:2003 standard or its profiles. Despite present intentions, most of the current geospatial metadata have been created according to heterogeneous specifications and for data that have been produced a long time ago. Therefore, current metadata mainly are devoid of detailed information, and several metadata elements are lacking values. Furthermore, the accuracy and reliability of these metadata are hardly known. In the long run, when the creation of metadata will be integrated in various phases of data production (Beard, 1996), the extent and quality of metadata should improve. Software tools, such as ArcCatalogue from ESRI, have been developed to help in the creation and management of metadata in the same system environment where data are created and used.

Most geospatial metadata, used for cataloguing purposes, are currently collected at the dataset level (Taylor, 2004). The problem of metadata at the dataset level is the presumption that a dataset is homogeneous. However, that is not always the case. For example, the quality of data may be different for different object classes, or it may vary from region to region or between the periods during which data items have been collected. Especially large nation-wide datasets often are heterogeneous in many respects. For example, in Finland where the population density is very different in the southern and northern parts of the country, the accuracy and currency of data tend to reflect the different intensity of activities in those regions. The wider the internal variation of the dataset the larger is the uncertainty of metadata describing the whole dataset. The ISO 19115:2003 metadata standard provides a mechanism to reduce this uncertainty by defining subsets of the dataset as *scopes* and describing, e.g., quality elements for each scope differently.

Although the importance of geospatial metadata is generally acknowledged, there have been lot of criticism on the usefulness and usability of metadata and related services as they have been implemented until recently. Descriptions of data are considered to be dominated by data producers' view (Frank, 1998) and doubts have been presented on the usefulness of the descriptions (Timpf et al., 1996).

2.4.7 Overall characteristics of geospatial metadata

The general-purpose metadata following the ISO 19115:2003 standard are simply considered to provide objective information about datasets. However, geospatial metadata include both objective and subjective elements. *Objective* metadata are facts about the dataset whereas *subjective* metadata are open to interpretation by the author of metadata. When metadata are implicitly present in data and can (or could) be generated automatically by examining the data, the metadata can be called *implicit* metadata (Jokela, 2001). For example, spatial extent of a dataset can be examined from the actual dataset. Implicit metadata are automatically objective metadata. *Explicit* metadata requires manual work; the author of metadata makes explicit statements about the dataset (Jokela, 2001). For example, an abstract of the content or the distribution information cannot be extracted from the data proper. A majority of current geospatial metadata are explicit even if related data items could be implemented in databases; now most metadata are generated subsequently from external documents that too often are insufficient. Quality information is perhaps the most critical of these items. Explicit metadata are either objective or subjective. Subjective metadata are sensitive to misinterpretation as the mental models of the author and the user may differ.

Metadata can be categorised to *static* metadata and *dynamic* metadata (Jokela, 2001). Static metadata remain valid for the whole life cycle of the dataset. For example, the identification and semantic content of a dataset are not expected to change in time. Dynamic metadata reflect the changes in the dataset and requires updating accordingly. An example of dynamic metadata is the status of the dataset.

Metadata are termed *embedded* metadata when stored and transmitted together with the data. Embedded metadata may be generated as a fixed part of the data during the data production process, or they may be generated separately and then attached to the data. *External* metadata are separate from the data they describe. Embedded metadata are typical in online services of geographic data (Green and Bossomaier, 2002), whereas external metadata are provided in cataloguing services (Guptill, 1999). External metadata satisfy well the needs of searching for suitable datasets. When it comes to accessing and using the data embedded metadata are relevant. But they are not mutually exclusive.

Metadata may provide *qualitative* or *quantitative* information. By their value metadata may be free text, classified (nominal or ordinal data) or metric. ISO 19115:2003 additionally defines elements of graphic form. These are a browse graphic illustrating the data and a conceptual schema of the application. Free text is either nominal, such as the name of a dataset or an object type or a responsible party, or it is descriptive, such as the production history of a dataset. Descriptive textual metadata are flexible adapting to the variation of datasets to be described but inefficient in automated searching. Free text is a typical (but not exclusive) form of subjective metadata. Classified metadata leads to efficient searching but is semantically limited if characteristics of datasets do not properly correspond to the classification. If the metadata classification is not inherently used in the dataset it leads to subjective metadata. Metric metadata give an impression of objective measures. They are exact deterministic measures or stochastic measures, such as percentage of correctly classified items. Metric values are most suitable for automated handling. Most domains of the metadata elements in ISO 19115:2003 are defined as free text.

2.4.8 Effects of metadata systems on the contents of metadata

The extent and openness of a metadata system affects the necessary characteristics of the system. In a *local* system, metadata are targeted at a well-defined community and may be accessible via an intranet or a closed network. The community may be an organisation, such as a consultation company, or a wider institution, such as authorities of a municipality or a military organisation. Metadata in a *universal* system is open to any user through the WWW. In a universal system the target of metadata is certain type of data rather than a defined user group, such as national metadata covering a certain geographic area or a domain related metadata covering, for example, environmental data. A loose specification of target users in practice implies a data suppliers' view of datasets in the metadata and a generic approach instead of definition of contextual user requirements. The extent of both a local and a universal system may vary from small to large, even up to a global system. Small systems can provide more complete and consistent metadata but, on the other hand, a critical mass of data is required to motivate describing data – in a small organisation the need for metadata may be satisfied by mutual communication between professionals who know the data resources.

From a user's point of view the technical difference between the local and the universal system of metadata may be insignificant. Semantically the systems may differ more. All relevant data resources are covered by a local system more probably than by a universal system. In a local system some characteristics of datasets may be constant and considered evident to any user and, therefore, not included in metadata at all. On the other hand, where the data is freely and continuously available users of metadata may request detailed metadata for accessing and using the actual data whereas a user who intends to buy geographic data from a data provider is looking for a different kind of metadata. The terminology used in a metadata system may be more consistent and more familiar to users in a local system than in a universal one. This may also refer to the concepts behind the terms.

There seems to be a trend towards distributed systems. At the level of dataset description, distribution does not make any difference except that it probably results in inconsistent metadata if the culture of describing data is not properly specified or controlled. However, the task of searching becomes more complex because first the appropriate collection has to be found (Goodchild and Zhou, 2003). Collection level metadata summarize the metadata of the objects (typically datasets) in the collection and, in most cases, provide distributions instead of specific values, such as the distribution of collection objects by temporal and spatial extent. If the data in the collection is not fully consistent by types, uncertainty is inherent in collection level metadata.

2.5 Summary

This Chapter discussed the three dimensions that interrelate with the visual representations of geospatial metadata. These dimensions are the task of selecting geographic datasets by metadata, expertise of users, and the geospatial metadata that are to be visualized. The task of selecting datasets is iterative and comprises specification of requirements of data, searching, gaining an overview of metadata, and evaluating of datasets by studying metadata of individual datasets and comparing metadata elements of several datasets. For evaluating datasets, users of geospatial metadata need to have knowledge of the intended application domain and geographic information science, skills in the intended software application, and pragmatic knowledge of geographic information resources available. Geographic datasets that are described by metadata vary conceptually, by spatial representation and resolution, and by data quality. The ISO 19115:2003 standard defines metadata elements for describing these varying datasets. The standard metadata elements include mainly textual data or enumerations. Among the metric value domains are coordinates that show the geographic extent. The browse graphic and application schema elements provide metadata in graphic form.

3 Visualization: approaches and methods

"A graphic is never an end in itself; it is a moment in the process of decision-making." (Bertin, 1981, p. 16)

In this Chapter, I consider the potential of visualization as it is applied in the context of geographic information. Chapter 3.1 explains the understanding of visualization as an active process that involves users' thinking as well as visual displays. I briefly refer to the development of this understanding as far as it enlightens the users' role in the process. Chapter 3.2 continues by discussing visualization methods. Chapters 3.3-3.5 concentrate on the three representation forms that are of special interest in the context of geospatial metadata: maps, multivariate visualizations, and conceptual schemata. Motivation and methods of user studies on visualization are discussed in Chapter 3.6.

3.1 Paradigms of visualization

3.1.1 Stimulus- and concept-driven visualization

Cognitive psychologists consider a human as an active organism that filters information, acts selectively, organises experience, and creates. Based on this view, visualization is a cognitive process that involves visual perception as well as issues such as attention, memory, organization of knowledge (objects, relationships, events, schemata) and knowledge representations (images, propositions) (Eysenck and Keane, 2000; Pinker, 1997). Visualization is thus both stimulus-driven and concept-driven. It has a crucial role in mental activities, such as reasoning, problem solving, creativity, and decision-making. The details of the process are not entirely known, but since 1970's research on cognition has built upon an information-processing paradigm (Eysenck and Keane, 2000). Differences in individual knowledge, experience, emotions, and expectations bring potential differences in how users interpret and use visual information (McGuinness, 1994). It is accepted that already users' perception may be directed by preference, experience, and competence. Although these aspects are accepted their exact mechanisms are far from known.

In cartography, user reactions to symbols as visual stimuli are reasonably well understood as a result of psychophysical studies since the 1950's. These studies coincided with a stimulus-response paradigm in psychological research, which is based on behaviouristic thinking. The essays of Robinson and Petchenick (1976) raised interest in the role of visual cognition in the comprehension of maps and stimulated the shift of research to questions about how users mentally process, learn, and remember maps, combining psychophysical and cognitive research approaches (Gilmartin, 1981; McGuinness, 1994). Although the paradigm of maps as a means of communication that dominated until the 1980's was user-oriented (Griffin, 1983), users of maps were seen as mainly passive receivers of information (McGuinness, 1994).

Alongside the ideas of humans to think visually and the development of computer graphics and tools for interaction, a new visualization paradigm emerged in the early 1990's. It was first applied to scientific computing as well as to geographic data visualization. Visualization is now seen as a complex coupling of how users conceptualise problem domains, how they process visual displays, and how they link mental schemata to actions through interface tools.

The key question about how visualization can stimulate thinking has re-enforced the interest in cognition. In parallel to the development of visualization of geographic data, cognitive research has considered human conception of spatial reality (Mark et al. (1999a) provide a review of this research) and inspired, among other things, studies on human-computer interaction in geographic information systems (e.g., Frank and Mark, 1991; Kuhn, 1995).

3.1.2 Visual presentation, analysis, and exploration

DiBiase (1990) in parallel to MacEachren and Ganter (1990) initiated a new meaning for the term visualization in the context of maps and geographic data. They emphasised the role of cartographic visualization in a scientific process, not only in presenting the results but also in the earlier stages of exploration and confirmation. DiBiase was inspired by Tukey's work (1977) on exploratory data analysis that introduced techniques "for making sense of complex data sets" (DiBiase, 1990, p. 14), as well as the US National Science Foundation's report on scientific visualization (McCormick et al., 1987) that defined visualization as "a method of computing" (p. 3) that facilitates scientists to interact with data by manipulating visual presentations. A whole discipline of scientific visualization has developed since (Nielson et al., 1997) and affected the development of geovisualization (MacEachren and Kraak, 1997).

DiBiase (1990) distinguished *visual thinking* from *visual communication.* Visual thinking happens in a private realm during the exploratory and confirmatory stages of a research process, whereas *visual communication* is a traditional component of synthesis and presentation of research results and happens in a public realm. He anticipated computer-based visualization tools to bring the greatest potential in the private realm. MacEachren and Ganter (1990) stressed the interplay between human cognitive processes and the displays created to facilitate those processes and considered interaction, iteration, and representation of data in variety of modes as the key characteristics of visualization.

MacEachren (1994) takes map use as a defining feature of visualization. His $(\text{cartography})^3$ model, the "map cube" (MacEachren, 1994), has since been widely referred to by geovisualization researchers. The three dimensions of the cube refer to users, tasks, and tools in visualization. The dimension of map users extends from private to public. The tasks extend from presenting known information to revealing unknown. The visualization tools provide high versus low interaction. The opposite corners of the cube relate to the opposite ends of a scientific process; the corner of known data, low interaction, and public audience relates to presentation, and the other corner with unknown data, high interaction, and a private user to exploration (MacEachren (1994) uses the terms communication and visualization, respectively). The model is not limited to scientific use, though.

Basing on the models of DiBiase (1990) and MacEachren (1994), Kraak (1999) characterizes three functions for visualization of geographic data:

- **Presentation** displays known information in well-designed maps that are easily understandable to wide audience.
- **Visual analysis** is answering questions, enabled by processing, manipulation and summaries of known data, and, for example, combination and comparison of two datasets in order to find causal relationships or test hypotheses.
- **Visual exploration** aims at knowledge construction from unknown, probably raw data by extensive interaction and often, dynamic displays.

In Figure 3.1 these three functions are located in the "map cube". However, there are no sharp lines between these functions. MacEachren and Kraak (1997) draw the difference between communication function that uses the term visualization in the sense of making visible and the other visualization functions in which maps facilitate thinking, problem solving, and decision-making. The maps in these contexts tend to have dynamic and interactive components; an ability to prompt instantaneous changes in maps can affect a great difference in the ways users think and may gain information (MacEachren and Kraak, 1997). Taylor (1994) suggests that high interaction is necessary not only for the "private and unknown" but also for the

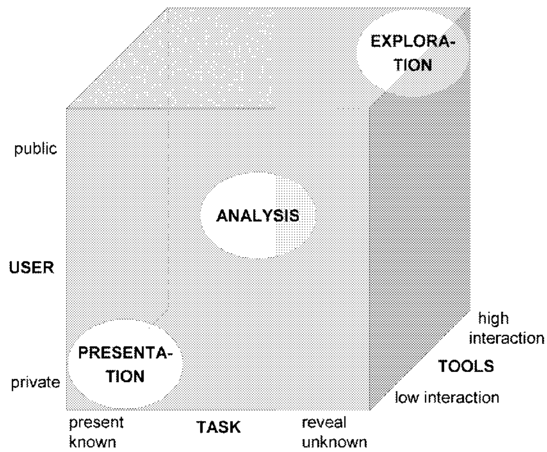

Figure 3.1 Presentation, visual analysis, and visual exploration in the map cube of MacEachren (1994).

"public and known" use of maps, and highly interactive systems even at the "public and known" use can allow a user to analyse and interpret data in ways very different from those "communicating" the information. Wood, on the other hand, (1994a; 1994b) argues for the traditional maps as an effective tool for visualization.

Visualization in the sense of exploration and analysis can be characterized by the iterative nature of successful human interpretation of visual displays (MacEachren, 1995); interactivity in both facilitating the iteration and access to multiple perspectives on information (Dykes, 1997; Kraak, 1998; MacEachren, 1994); and the goal of finding patterns and relationships in data (Dorling, 1992; MacEachren and Ganter, 1990). As such, it is very different from a presentation aiming to communicate. Exploration is also very user-oriented; what is the unknown and what information is revealed depend on individual users' insight and thinking.

3.1.3 Meta-operations of visual thinking

Keates (1982) explained the stages of obtaining information from a map as detection, discrimination, identification and interpretation of a map symbol. Identification leads to understanding, possibly by consulting the map legend, and is a precondition for interpretation. While Keates (1982) was concerned on individual symbols, in accordance to the interests in that time, MacEachren (1995) extends the target of visual thinking to more complex cartographic constructs.

MacEachren (1995) and MacEachren et al. (1999) propose a visualization framework that integrates a cognitive perspective on the process of using visualization methods to facilitate thinking with the formalism of semiotics. The cognitive perspective explains the ways in which users conceptualise problem domains, process visual displays, and link mental schemata to actions through interface tools, and semiotics provides tools for understanding abstract representations of phenomena and processes and methods for explaining how the creators and users bring meaning to the representations. In this framework, three "meta-operations" form the iterative process of examining visual representations, attempting to interpret these representations, and use them as a prompt to insight. These three operations are:

- **Feature identification** for finding instances of identifiable features in data by examining the distribution of data in all its dimensions with an intention to notice any distinct object, regularity, anomaly, hot spot, etc. Attention is at the display's graphic expressions, and emphasis on what is noticed in a display at an abstract level.

- **Feature comparison** extending consideration to multiple objects or patterns and relationships among features. With maps, location is the most obvious focus for noticing spatial co-occurrence but any other attribute such as shape or colour can provide the basis for comparison.

- **Feature interpretation** for connecting the abstract data representations with the user's domain knowledge (and potential knowledge sources external to data displays) in order to relate features, their relationships and behaviour to those among real-world phenomena. In this stage, user's prior knowledge plays a crucial role.

Mental schemata provide a context which guides the interpretation and the iterative cycle of "seeing-that" and "reasoning why". The same process may result to development of new mental schemata (MacEachren, 1995).

3.2 Representations and methods of visualization

3.2.1 Representations for communication and exploration

Mental images are one of the representation forms of human knowledge (Eysenck and Keane, 2000). There is evidence that these representations in memory have analogue qualities but are abstractions, intellectually more like maps than photographs. Graphical images are particularly effective for retrieving information because recognition mechanisms of spatial patterns and groupings seem to be hardwired into the human visual system and allow very rapid recognition (Larkin and Simon, 1987).

One of the key issues of cognitive theory concerns the way that people use external imagery as a support in decision-making. The working memory has a very limited capacity, which can be a limitation in thinking. People can cognitively operate much more effectively with an external artefact than with a purely mental image. In addition to aiding memory with details of complex structures, visual representations affect the way a problem is viewed, as they prompt certain conceptions of the problem, and the ease at which it can be solved. Norman (1993) gives examples of how matching of different representations to different tasks is crucial for supporting cognitive processes.

The concept of knowledge schemata plays an important role in feature identification and interpretation (MacEachren, 1995), as discussed above in Chapter 3.1.3. MacEachren (1995) states, that representations (maps) designed for communication should attempt to automatically invoke users' knowledge schemata. In the context of exploratory use of representation, however, the design principle is different. MacEachren (1995) argues, that representations can prompt discovery only if they break through users' existing knowledge schemata. However, variation of users' knowledge schemata and difficulty of finding out what these schemata are, bring a challenge.

MacEachren and Ganter (1990) argued for visualization systems that stimulate insight by letting users to experience data in a variety of representations, so that they can iteratively look at pieces of information, compare and contrast displays, and confirming or rejecting ideas that arise from pattern recognition. Peuquet and Kraak (2002) give examples of representations that potentially invoke new insights or reveal unexpected properties in displays, such as a space-time cube and variations of the Minard's map (Tufte, 1983). They cite Finke et al. (1992) about preinventive properties that spark imagination by possessing novelty, incongruity (incorporation of components not normally contained in the same image), abstraction (absence of details), ambiguity (whereby an image can be interpreted in a more than one way) or some combination of these.

3.2.2 Representation forms and multiple views

Alternative views to data can be revealing and clarifying because different aspects of data can be conveyed by different representations (MacEachren and Ganter, 1990).

Maps serve as a well-established tradition in representing geographic information, taking the spatial dimensions of data as a standard frame of reference. When data distribution is geographically implicated, maps are a powerful form for exploration (MacEachren, 1995). In advanced forms, dimensionality of maps can be extended to three-dimensional depictions (Fisher et al., 1993; Kraak, 1993), small multiples (Tufte, 1983), spatio-temporal animations (Blok et al., 1999), or geovirtual environments. Dykes (1997) demonstrates use of dynamic symbols on maps for transient data. These advanced forms can stimulate new insight by added realism, or in the other direction, by more abstract representations (Dykes et al., 1999).

More abstract representations result when one or more of the spatial dimensions in a map are used to depict non-spatial attributes. Examples of these approaches are provided by Edsall et al. (2000) who use the third dimension for revealing temporal regularities; Krisp (2004) and Peuquet and Kraak (2002) who demonstrate use of the third dimension for an attribute that is neither spatial nor temporal; and Wise et al. (1995) and Fabrikant (2000) who create ”landscapes” from completely abstract data, such as digital library catalogues or news archives, to illustrate the density, relationships and distribution among the non-spatial data.

Similarly, spatial data can be displayed using inherently non-spatial representations. However, most commonly these representations are still used for attributes of geographic data whereas the location is shown on a linked map. Scatterplot (Cleveland and McGill, 1988) and parallel coordinate plot (Inselberg, 1985; 1997) are popular examples of methods of representation attached with interaction that were developed originally in EDA (exploratory data analysis) for multivariate data. These representations are discussed further in Chapter 3.4.

In exploratory visualization environments alternative representations are most useful when implemented as multiple linked views (Buja et al., 1991; Roberts, 1998). When views are dynamically linked, the selection of objects in one view causes the same objects in the other views to be highlighted. This way, also relationships not directly obvious from any of the single views may become apparent. Alternatively, multiple dimensions of a dataset can be distributed into separate but linked displays and be viewed simultaneously.

But even though alternative views can be revealing, they may as well appear too complex for proper understanding to users not familiar with these non-conventional views. Furthermore, visual representations should be appropriate for not only the data but also the features and phenomena that they represent. For example, Slocum et al. (2000) demonstrate how animations that are considered well suited for representing changes over time can be desirable for representing certain kinds of phenomena and confusing for others. The use of alternative visualization approaches as well as related user studies are stimulated by the geovisualization research agenda (MacEachren and Kraak, 2001).

3.2.3 Exploration by interaction

Interactivity is a fundamental component in a visualization environment, whether the aim is exploratory or communicatory visualization (Dykes, in press). It allows users to select and modify the displays, and immediate reaction in displays to user actions enables users to construct knowledge and insight following their own thinking. Although traditional images and maps can also possess creative thinking and serve exploratory aims (Wood, 1994b), interaction that enables the user to directly and quickly manipulate the properties of visual displays provides the real power for gaining new insights (MacEachren and Monmonier, 1992). Dykes (in press) presents an overview of contemporary approaches to interactivity available in support of geovisualization.

Shneiderman (1998) summarizes the phases of visualization in a visual-information-seeking mantra: *overview first, zoom and filter, then details on demand.* This process implies both interaction and iteration. Roth et al. (1997) propose a variety of related tools. Perhaps the most common and fundamentally powerful interaction mechanism is brushing for interactively selecting a subset of data. It has been used since the early days of dynamic visualization (Cleveland and McGill, 1988), and a variety of brushing techniques has been developed since then. For example, Monmonier (1989; 1994) introduced the geographic brushing for exploring correlations between statistical and geographic patterns. A generic model of brushing techniques is presented by Chen (2004).

Crampton (2002) proposes a typology of interactivity identifying four groups of interactivity types: interaction with data, interaction with data representation, interaction with a temporal dimension, and contextualizing interaction. In a geovisualization environment these types may appear also in combinations. I present this typology here, as it gives a good overview of the potential and variety of approaches in geovisualization environments

The least powerful is the interactivity with data representation (Figure 3.1). It enables different views of data by manipulating the look of displays, e.g. by zooming in and out, or changing symbolization. At the middle level is interactivity with temporal dimension implying that the user can control changes in dynamic maps. Navigation in virtual landscapes or information spaces is one example of this interactivity type. The most powerful level in Crampton's typology (2002) is interactivity with the data and the context. Examples of interactivity with data are brushing, filtering, and focusing; they draw the attention to data rather than just their representation. Crampton (2002) mentions also database queries and data mining as interactivity with data. Interactions that manipulate the context include multiple views, linking, combining data layers, and window juxtaposition. This interactivity is very powerful because the context in which information appears can be critical to analysis and decision-making.

Crampton (2002) bases his typology on a five-level sophistication hierarchy of visualization tasks. At the bottom is examination that involves least sophisticated interaction, i.e. interactivity with the representations. Examination is followed by comparison that requires simultaneous apprehension of two or more displays. The next sophisticated task is (re)ordering or (re)sorting of data which means direct manipulation of data, such as standardising or classifying the data. Data extraction or suppression at the next level implies identification of a subset and highlighting or removing it (i.e. filtering). The most sophisticated task is testing cause and effect by studying the strength and nature of relationships.

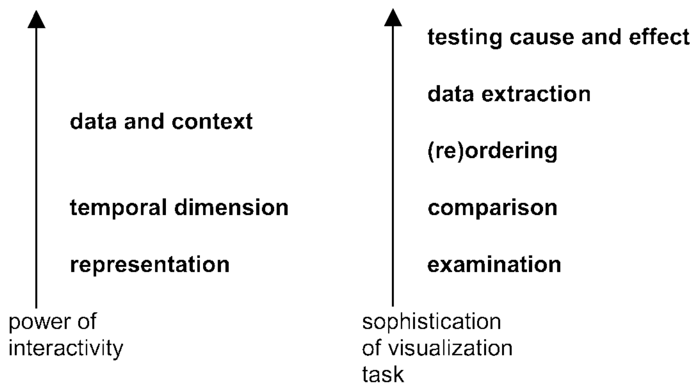

Figure 3.2 Levels of power of interactivity and sophistication of visualization tasks based on the typology of Crampton (2002).

While high-level interactivity opens up possibilities it can also confuse users. Therefore, some guidance or automated help with initial choices may be necessary especially to novice and tentative users (Fairbairn et al., 2001). Monmonier (1994) proposes a narration metaphor as an introduction to new datasets through a "guided tour". A graphic narrative can use an automatically moving brush while the user is a comparatively passive observer. Another example of help is a wizard that results in pre-designed displays, including maps that follow cartographic knowledge incorporated in a program (Andrienko and Andrienko, 1999; Kraak, 1998).

3.3 Maps representing geographic data

Maps provide a simplified representation of the real word by abstracting and selecting what is portrayed. By simplification, maps support comprehension of the complexities of the real word. A map is both a visual image and "a structure that is algebraic in nature" (Peuquet and Kraak, 2002). It is an iconic representation based on a systematic abstraction and ordered according to a system of positional rules of interrelationships. The overall portrayal results from selection, transformation, and arrangement. The process of map compilation is governed by intuition, conventions, and cartographic "rules of grammar"; this means that there is not just a single proper way to depict a certain phenomenon or the data representing it. How far the user of a map shares these intuition, conventions, and rules affects on map interpretation. Also the context of the map has an important role in interpretation as well as cultural factors that work at the cognitive level. As a result, the process of map interpretation is highly complex.

Before the digital era a map served at the same time as data storage and representation of these data. The scale of the map determined how accurate and detailed the data could be. Also the number of attributes in data was limited to those that could be distinguished in the visual representation. As Wood (1993) phrases: "the image *is* the content" (p. 149, emphasis original). Therefore, what could be interpreted from the map was all the information that was available to users. And if there were originally incomplete and uncertain data those were dealt with during the map compilation process, which gave the cartographer a rather authoritative role in respect to users (Kraak, 2001). Similar data exist in digital form in cartographic databases, though implemented in advanced ways, such as with dynamics, interactivity, and multi-scale representation.

Today geographic information is stored in databases, and only seldom is their primary purpose map production. More commonly, these data are collected and maintained for operational systems, decision support, and computational analysis. In this context, maps are intermediate outputs in different stages of data handling and use rather than an end product. Although maps are the most important representation of geographic data, the abstraction of data in geographic information systems is not made from a cartographic viewpoint but from the interests of data use. As such, these databases can comprise much more detailed and versatile data than can feasibly be depicted in a map at a time. Nevertheless, a certain level of abstraction controls also these data collections, as discussed in Chapter 2.3. The accuracy and level of abstraction of the data remain unchanged though a map display of these data can be zoomed in and out on a screen. Therefore, the display scale of digital maps varies at users' will, and more importantly, the resolution of data expresses the level of abstraction and generalization.

When the cartographic design is not embedded in the data, users have a free hand in visualizing the data using the tools provided by the system. However, cartographic expertise in not widely implemented in geographic information system tools, nor are their users cartographers. That users can create a versatility of map displays of the same data emphasizes the arbitrariness of the portrayal. When the cartographic design principles, such as clarity, figure-ground organization, visual contrast, and hierarchy (Robinson et al., 1995), are ignored, displays of data may result in "quick and dirty" maps. This way it is difficult to express the good qualities of a database from a map display; map users tend to pay attention, though not necessarily consciously, to the aesthetic appearance of the map (Keates, 1984; MacEachren, 1995).

3.3.1 Connotations of a map

Semiotics has influenced the understanding of maps, first via Bertin's work on sign systems (Bertin, 1967) and later especially via MacEachren's cognitive-semiotic model (MacEachren, 1995). One of the matters of interest in semiotics is the denotations and connotations of signs. "Maps, due to their melding of scientific and artistic approaches, always involve complex interaction between the denotative and the connotative meanings of signs they contain." (MacEachren, 1995, p. 337). Map legends that specify an explicit meaning have a role at the denotative level, but as a whole, denotation of maps is quite contextual. For connotations, MacEachren (1995) suggests a typology that considers both the map and the topic mapped. In the context of this study, the two connotations about the map are especially interesting, i.e. the connotations of veracity and integrity. The veracity connotation relates to belief that maps are accurate and free from error, and precision of spatial location is interpreted as accuracy not only in location but also in data representation. Wood (1994b, p. 20) states that "a well-produced map can create an impression of accuracy and neutrality far superior to its true quality". The integrity connotation indicates that maps are unbiased, particularly those maps produced by the government or by scientists (MacEachren, 1995). I believe these two connotations apply to geographic datasets as well. Although these connotations are an essential prerequisite for maps to work (MacEachren, 1995; Wood, 1992), it is obvious that they reduce users' motivation in questioning the suitability of maps or datasets for an intended use.

If the quality of geographic data is known it can be shown explicitly to users, not only in figures expressing the results of statistical quality assessment but in visual form. Several methods have been proposed for visualizing the uncertainty of geographic data, typically concentrating on positional accuracy and data classification (e.g., Drecki, 2002; Fisher, 1994; Hootsmans, 1996; MacEachren, 1992; McGranaghan, 1993; Wel van der et al., 1994). Applicability and effectiveness of various methods have been evaluated, for example, by Beard and Buttenfield (1999), Drecki (2002), and Slocum et al. (2003).

3.4 Multivariate information visualization

Information visualization (Card et al., 1999b) focuses on visualization of data that are abstract in the sense that they lack inherent two- or three-dimensional semantics. Information visualization has its roots in visual data exploration and derives from works such as (Tukey, 1977), (Bertin, 1967; 1981) and (Tufte, 1983). It first developed in the wake of scientific visualization, as did geovisualization, and today they share most of their methods and approaches (Rhyne, 2003). However, its applications extend widely outside the scientific world (Spence, 2001). An overview of the approaches and developments in information visualization is given by Card et al. (1999a). More recently, visual exploration has extended to knowledge discovery in databases (KDD) where it is used in parallel to computational methods (Fayyad et al., 2002). In this context, information visualization provides advantages, such as tolerance for inhomogeneous data (Keim, 2001).

Use of information visualization techniques linked to maps in geovisualization environments have been demonstrated by, e.g., Andrienko and Andrienko (2001), Dykes (1997; 1995), Edsall (2003), Gahegan (1998), Haslett et al. (1990), and MacDougall (MacDougall, 1992). Interest in integrating knowledge discovery in geovisualization has been expressed by Gahegan et al. (2001), MacEachren et al. (1999), and Wachowicz (2001).

Multivariate visualization methods make multiple variables of numerous objects visible at a time allowing exploratory studies of the data. Geospatial metadata is multivariate, though the number of variables is relatively low, perhaps around five rather than 20. Also the volume of metadata is relatively small when visualization is focused on evaluation of datasets. As stated in Chapter 1.4, easiness of adoption is a fundamental requirement for the visualization methods for geospatial metadata. Among the most popular multivariate methods are scatterplots and scatterplot matrices, parallel coordinate plot, and some iconic methods. Because of their popularity, I take them as easily adoptable methods. Before studying these methods in detail, a classification framework for information visualization methods is discussed.

3.4.1 Classification of information visualization techniques

Keim (2001) and Keim et al. (in press) propose a classification of information visualization techniques basing on three criteria: the data to be visualized, the technique itself, and the interaction and distortion methods. His classification does not assume disjoint categories but multiple visualization techniques can be used for multiple data types and combined with multiple interaction techniques. The categories of data and visualization techniques are discussed in the following; interaction techniques were considered above in Chapter 3.2.3.

As for the data, Keim (2001) distinguishes one-, two- and multidimensional data as well as text and hypertext, hierarchies and graphs, and algorithms and software. The data in this research falls into categories of two- and multidimensional data, and hierarchies and graphs. In geospatial metadata, extent data and browse graphic maps are two-dimensional data; maps as a representation form are discussed in Chapter 3.3. Metadata elements with numeric and enumerated values compose multivariate data, and relevant representation techniques are discussed below. Conceptual schemata in graphical form belong to hierarchies and graphs; these are discussed in Chapter 3.5 as far as they apply to conceptual schemata. Part of geospatial metadata is in text form, but visualization of these metadata is out of the scope of this work. Before visualization, textual data first have to be transformed into description vectors. A typical transformation is based on word counting but, because geospatial metadata are quite scarce in text mass, that would not be a relevant approach when metadata are used for evaluating suitability of datasets.

Concerning visualization techniques, Keim (2001) considers how they arrange the data on the screen and how they deal with multiple dimensions while displaying multivariate data. He proposes categories of standard 2D/3D displays (e.g., x-y plots, such as maps, and scatterplots), geometrically transformed displays (e.g. parallel coordinate plot), icon-based displays (e.g. star glyphs), dense pixel displays, and stacked displays. Dense displays and stacked displays are developed for detecting local correlations and dependencies, and for hierarchically partitioned data, respectively. They are not applicable techniques in the context of this research and, therefore, I consider further the other three categories.

Gahegan (2001) makes a distinction between different visualization techniques based on the role that a user and a system adopt. In his category of dynamic exploration, a user is an initiator and can change the visual variables in order to shift the focus of attention to different patterns in the data. This category implies interaction techniques such as linking and brushing, and visualization techniques such as scatterplot, parallel coordinate plot, and map-based visualization. It aims at simultaneous pattern discovery within data and proposing of hypothesis by which the pattern might have come to be.

3.4.2 Scatterplot matrix and parallel coordinate plot

A scatterplot matrix is a commonly used method in statistics (Cleveland and McGill, 1988). It is an extension of the conventional approach to the visualization of bivariate data where a two-dimensional plot presents one variable against the other. In a scatterplot matrix of n dimensions all pairs of axes are presented as scatterplots, and these are then arranged in a matrix. Interpretation of the relation of the plots in the matrix requires brushing and linking (Buja et al., 1991). Scatterplots are considered as a simple method of identifying global trends and local features in data. To keep a matrix of scatterplots manageable the number of variables cannot be high; Spence (2001) proposes not more than about five variables in a matrix. Alternatively, three variables can be presented in a three-dimensional scatterplot. Monmonier (1989) present linking of scatterplots to maps, and more recently, Andrienko and Andrienko (1999) and MacEachren et al. (1999) demonstrate use of 2D and 3D scatterplots, respectively, in geovisualization environments.

A parallel coordinate plot (Inselberg, 1985; 1997) is a popular technique in exploratory visualization. It organizes the axes of a multidimensional space in parallel and thus enables assess to a large number of variables concurrently. Filtering and focusing are often attached for interaction. A parallel coordinate plot is a useful method for identifying relationships between groups of similar data items across a range of variables. Dykes (1997) and MacEachren et al. (1999) give examples of the implementation of a parallel coordinate plot in a geovisualization context.

These methods treat the whole set of variables equally because each of the variables has the same graphic representation. However, in the parallel coordinate plot the ordering of the axes influences the nature of the plot and so possibly its interpretation. Therefore, it is important that users can control the ordering of axes during interactive exploration so that the variables of interest can be studied adjacently.

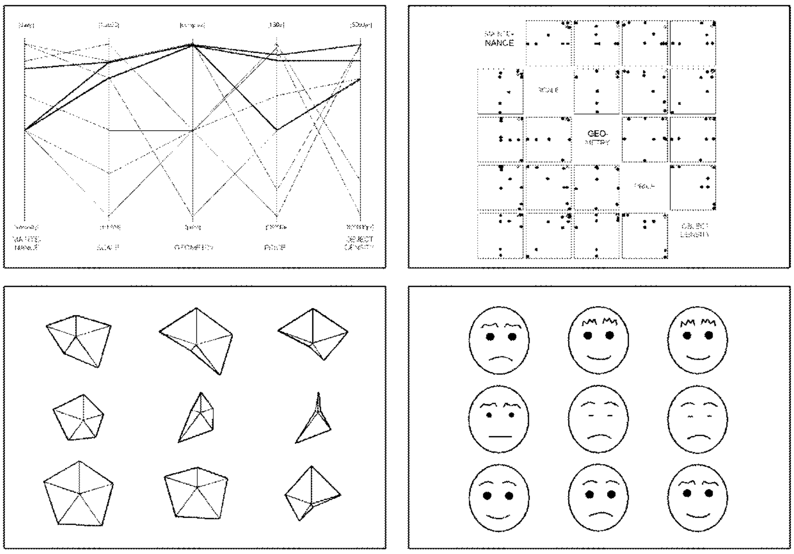

Figure 3.3 Examples of multivariate visualization methods: a parallel coordinate plot (upper left), a scatterplot matrix (upper right), star glyphs (lower left), and Chernoff faces (lower right).

Edsall et al. (2001), in a usability assessment comparing the use of parallel coordinate plots and scatterplots in a case of geovisualization, came to a conclusion that a visualization environment is most effective for data exploration when a variety of tools are present. Significant differences between the effectiveness of these two visualization methods were not identified in their study that used researchers as subjects.

3.4.3 Icons

Iconographic techniques use complex symbols to encode many data dimensions simultaneously. The aim of iconographic displays is to promote perception of the whole while also allowing some differentiation of individual variables. Icons can be looked at on an individual basis as well as in groups of icons. The latter is for discovering patterns, especially if the icons have a natural location in relation to each other, such as a geographic location that can be shown on a map. Ward (2002) presents a taxonomy of glyph placement strategies and reviews the strengths and weaknesses of these strategies. Two examples of iconographic techniques, star glyphs and Chernoff faces, are discussed below.

In a star glyph (Chambers et al., 1983), the axes for variables radiate in equal angles from a common origin. A line segment is drawn along each axis starting from the origin and the length of the line representing the value of the related variable. An outline connects the end points of the line segments, thus creating a star shape.

Although, in principle, the variables are displayed equally in stars, the ordering of the individual axes influences the star shape. However, the order of the axes is usually not under users' control, whereas user-control of parallel coordinate axes is a rule. For a rapid classification of star glyphs, Ware (2000) recommends using not more than about three orientations. He also warns about collinear orientations because these would be visually confounded. Interactive mouse-over legends can be used for checking the meaning of the individual dimensions of star glyphs.

Chernoff faces (Chernoff, 1973) are multi-part glyphs in the shape of a human face, and the individual parts, such as eyes, ears, mouth, and nose represent the data variables by their shape, size, and orientation. The idea of the use of the faces is related to the fact that humans easily recognize faces and can see small changes in them without problems, but according to Morris et al. (1999), faces are not necessarily superior to other multivariate techniques. Examples of the application of Chernoff faces in the visualization of geographic data are the mapping of UK-census data by Dorling (1994; 1995).

Chernoff faces depict each data variable differently. Chernoff (1973) originally designed faces to portray up to eighteen variables. However, many face features are interrelated, and combinations of the variables can visually cancel each other. For example, the shape of eyes is hardly distinguishable if their size is reduced to minimal. De Soete (1986) found in his studies of the relevance of each facial feature that only three or five variables are among the perceptually salient face features, including mouth curvature, eye size, density of eyebrow. Because different face features effect viewers differently in a visual search even if only few features are included, e.g. in (Nelson et al., 1997), the way in which the variables are mapped to the features is very critical. Therefore, in an exploratory environment, users should be allowed to set the priorities to the data variables, and the high-priority variables should be visualised by the most salient face features.

3.4.4 Transformations and scaling of values

Information visualization methods, such as those above, are designed to present numeric variables. If nominal, or merely ordinal, variables are to be visualized, their values first have to be mapped or transformed to numeric values. Simplistic mapping methods do not take order or spacing among the values into account and, thus, do not convey semantic relationships. Methods for pre-processing nominal values have been proposed (Rosario et al., 2004), but allowing users to interactively modify the organisation of values is a valid option. More generally, data preparation for the visualization may be needed for the data analysis purposes, and transformations, such as counting, aggregating, sorting (e.g. of nominal values), and filtering, are used (Tang et al., 2004).

Values on a coordinate axis are typically organized so that the ends of the axis represent the minimum and the maximum values of the corresponding variable. Keim et al. (in press) propose that the axes are linearly scaled from the minimum to the maximum value but that is not always feasible; for example, logarithmic scaling can perform better is some cases. Andrienko and Andrienko (2001) suggest scaling of the axes based on the medians and quartiles of the variable values. However, then the variables must be comparable. Individual metadata elements are not comparable but could be made comparable in a transformation process.

The minimum and the maximum values typically are among the data to be visualized. However, they could as well refer to the potential minimum and maximum values in the domain, and in that way provide a contextual view.

Visualization of realistic data sets, such as geospatial metadata, faces the problem of incomplete data. Missing of single values is a typical case. Depending on the purpose of visualization the missing values may be indicated as such in displays or substituted by plausible values.

3.5 Visualization of concepts and concept structures

3.5.1 Visualization of conceptual schemata of databases

Conceptual schema techniques have developed outside the visualization community as a part of development efforts in database design. However, interaction with databases has gained interest also in information visualization, especially in query interfaces.

A conceptual schema has a communicative role between users and designers of an information system (Date, 1981). The layered model of generic database architecture distinguishes the conceptual level from the logical and implementation levels. This is to allow definition of the database using concepts that are familiar to users without regard to data structures and database management techniques. However, a conceptual model will be later implemented at a logical level, and therefore, modelling paradigms and formal languages are used. Conceptual schema languages provide a formal notation that enables both unambiguous human communication and translation to the logical schema.

Graphical notations are typically used in human communication. They show the whole at one glance, and relationships of components are easily perceivable. However, their expression power is more limited than that of lexical notations and, for example, constraints are typically expressed in a natural language. Lexical notations are not easily readable but used for tasks that can be performed by computers. In respect to spatial components, conceptual schemata are not very intuitive. Laurini (2001) has developed a method where icons are added to concepts.

In the past, the most common approach for conceptual modelling was the entity-relationship modelling (Chen, 1976) resulting in an ER-schema which occurs in many slightly varying graphical notations. Currently, UML (Unified Modeling Language) (Rumbaugh et al., 1999) is gaining ground as a standard modelling language. However, the standard covers only the graphical language; lexical notations are CASE tool dependent.

Although a formal language provides a means for unambiguous communication, knowledge of conceptual schema languages cannot be anticipated in ordinary users of geographic data. In regard to evaluation of geographic datasets, comparison of very complex conceptual schemata is not very easy. On the other hand, formal schemata can be computer-interpretable, but then the problem of inconsistencies in terminology and definitions is faced. Formal ontologies can provide solutions in this respect.

Component of a conceptual schema include the object classes (or entity types, depending on the modelling paradigm), their attributes, and relationships, as well as value domains of attributes and, in object-oriented modelling, methods of the object classes. The object orientation also allows complex objects that are defined in terms of sub-objects and define fully the relationships of objects.

3.6 User studies of geovisualization

User studies of visualization aim at understanding users and their performance to ensure development of better tools for users in their different tasks. This is needed, and happens, both at the level of single visualization applications and at a wider discipline level (Fuhrmann et al., in press; Slocum et al., 2001). In the latter case, studies aim at building theories that, on their behalf, provide basis for design rules applicable throughout the field of visualization, such as the perceptual and cognitive theories (Loshe, 1997; Ware, 2000). However, Kosara et al. (2003) remind that basic perception experiments are not sufficient to ensure efficient visualization tools because visualization applications have important aspects that have to be studied within the application's context.

The need for experimental evaluation of visualization techniques is emphasised both in information visualization (Chen and Czerwinski, 2000) and in geovisualization (MacEachren and Kraak, 2001), and the number of reported studies is slowly increasing. Chen and Yu (2000) argue for standard approaches in testing visualizations so that tests would be comparable and their results extendable. On the other hand, visualization is very contextual depending on both the semantics of data (Fuhrmann et al., in press) and users and tasks (Cartwright et al., 2001). Differences in individual knowledge, experience, emotions, and expectations bring potential differences in how users interpret and use visual information (McGuinness, 1994). Therefore, as Fairbairn et al. (2001) point out, especially in exploratory use it can be hard to find out whether insight results from the individual expertise of the user or the effective rendering and use of visualization.

Methods of user-centred design and usability engineering are starting to gain ground in development of geovisualization tools and systems. Furhmann et al. (in press) provide an overview of these methods and research questions on user-centred design of geovisualization. Geovisualization often implies aspects that divert from ordinary software engineering; user studies may aim not only at achieving users' acceptance to what is developed but also at better understanding of users' knowledge construction, decision-making, or problem solving in the case study. This brings exploratory characteristics, such as hypothesis generation, into user studies in the geovisualization context (Elzakker van, 1999). User studies in geovisualization have been reported by, e.g., Andrienko et al. (2002), Fabrikant (2001), Fuhrmann (2003), Fuhrmann and MacEachren (2001), Griffin (2003; 2004), Harrower et al. (2000), Slocum et al. (2003), and Tobón (2002).

3.6.1 Interaction with users

Users are involved in two roles in user-centred system development, such as in the development of visualization tools. Firstly, studies are made for the specification of user requirements using approaches such as task analysis (Hackos and Redish, 1998) and contextual design (Beyer and Holtzblatt, 1998). These approaches apply methods such as observation of users in their activities, diaries, interviews, and questionnaires. The aim of these studies is to understand the tasks and context in which the system will be used so that the design specifications are not based on what is technically possible but rather on what is useful and usable to users. When the tasks are not easily definable, which is often the case in exploratory visualization, or the use context is unpredictable, like when the development is based on some new technology, more abstract methods are due. These methods, such as storytelling, approach the requirements indirectly and leave more responsibility to designers' interpretation. Alternatively, domain experts can be involved in specifying the design requirements. In these cases, user assessment should start in early stages of design, preferably already when product concepts are designed (Kankainen, 2003; Slocum et al., 2003; Ulrich and Eppinger, 2003).

Secondly, users are involved in assessing the design during different development stages. The methods of user assessments vary on the basis of how the design is communicated to users and how users' reactions are collected. For example, the design can be communicated to users by scenarios, storyboards, demonstrations, mock-ups, or prototypes (Erickson, 1995; Kuutti, 1995; Nielsen, 1995). Combinations of these methods are used as well; Buttenfield (1999) proposes an evaluation strategy based on convergence of different methods in unstable, long-lasting development projects. Users' reactions can be collected while observing users in carrying out predefined tasks, by focus group discussions, interviews, or questionnaires. User assessments may concentrate on revealing whether a tool is useful for a specific task, or whether it is more effective than an earlier tool. This may imply users' subjective acceptance or specific usability measures (Nielsen, 1993). A more fundamental goal of user studies is to seek insight into why a particular technique is effective, or to show that an abstract theory applies under certain practical conditions or how they should be modified to function for real-world data and tasks (Kosara et al., 2003).

3.6.2 User groups and test subjects in geovisualization

For the validity of user testing, it is important that the subjects represent the real users (Hackos and Redish, 1998; Nielsen, 1993). Often students of the disciple in question or colleagues act as test subjects. While usability problems can be detected with less specific groups of users – for example, when analyzing two focus group discussions, one between experts and one between novices, Harrower et al. (2000) discovered that users' ability to identify usability problems was at a similar level though experts could better back up their opinions – the subjects representing proper users is especially important for the validity of the results when the study aims at understanding how users work with the tools. For example, Griffin (2004) travelled to professional users in different organizations to test whether and how different expertise affects use of visual tools in time-space process modelling.

Geovisualization tools are most often targeted at professional users who are used to working with large and complex datasets. User studies among less experienced users show the importance of training. In their usability test assessing learnability of a set of geovisualization tools, Andrienko et al. (2002) noticed that those users who received an introductory demonstration and brief training of the system before carrying out tasks performed much better than those subjects who did the test via the Internet with only written instructions and some illustrations. In the latter group there were significant differences between individual users, and the level of performance correlated strongly with the behaviour of reading the instructions. In the study of Harrower et al. (2000), one tool (temporal brushing) gained positive reactions from users in the focus group sessions, where users could interact with the instructor, but task-sessions showed that the tool was difficult to understand to some users. Their findings also indicate that users, when presented with tools that they do not fully understand, are likely to perform more poorly than when not provided with any special tools.

The number of subjects that gives sufficiently reliable results depends on the measures and the goal of testing. If detecting usability problems for practical development purposes is the main goal, 3-5 subjects already reveal the majority of problems (Nielsen, 1993); increasing the number of subjects above this adds to the results very slowly. Beyer and Holtzblatt (1998) propose 6-10 subjects when studying requirements for detailed user interfaces and 10-20 subjects for collecting information about overall working processes.

3.6.3 Collecting user reactions in geovisualization

In geovisualization, evaluation typically concerns concept or prototype implementations rather than fully functional systems. In system development, it has been noticed that rough prototypes draw users' attention to concepts and functionality more easily than well-finalized implementations that tend to provoke comments on surface design instead (Erickson, 1995). Collecting users' reactions in real-world tasks in real-world context is recommended (Hackos and Redish, 1998) but, in practice, such user studies are rare. Davies and Medyckyj-Scott (1996) give an example of such a study, though not in the context of geovisualization but a geographic information system. They observed users performing their daily work using their geographic information systems in different organizations. This type of a study, however, can measure only overall qualities, as in the case of Davies and Medyckyj-Scott (1996), the poor response times and general under-use of the functions of geographic information systems. Testing of prototypes is typically organized in a somewhat simulated situation where use scenarios communicate the task context to test subjects.

Typically, in a user study subjects carry out predefined tasks. This allows comparison of performance between users using measures, such as response times (Fabrikant, 2001; Harrower et al., 2000), correctness of answered questions after performing a task (Andrienko et al., 2002), or improvement in the answers while performing (Harrower et al., 2000). Well-defined tasks and quantitative measures in the context of exploratory use of tools may prove difficult if not impossible. Fuhrmann and MacEachren (2001) as well as Lucieer and Kraak (2004) instructed participants in focus group sessions to freely explore the data in question, only limiting the time participants worked with the prototypes (15 and 45 minutes, respectively). Tobón (2002) in her focus group session allowed free exploration before predefined tasks. Although this kind of free performance does not support formal analysis it gives users valid experience with the tools, which then reflects in their verbal reactions either during the performance or afterwards in discussions or interviews.

When the design interest is in improved insight, a thinking aloud protocol is commonly used to reveal users' cognitive processes. Van Elzakker (1999) gives a review of the thinking aloud protocol discussing its pros and cons in geovisualization studies. Thinking aloud approach implies video (or audio) recording the task performance and, afterwards, analysing the recordings (Fuhrmann, 2003; Griffin, 2004), or observing and making notes throughout the sessions (Fabrikant, 2001). This can be very time consuming, which is perhaps the main drawback of the approach.

One of the great benefits of user studies is hearing the voice of users. Comments from participants are often more important than other data collected as they provide valuable hints about what is happening during the experiment (Kosara et al., 2003). For example, observation of users can offer information about experiment details that were possibly not taken into account in the original hypothesis – this is one of the exploratory aspects of user studies. Erickson (1995) argues for the subjective and ambiguous views of individual users, as they may reveal valuable considerations in the design process instead of "objective" quantitative measures; quantitative measures though can reveal valuable differences in efficiency or error rates.

As a practical limitation, user studies are time-consuming to implement, run, and analyse. Therefore, studies have to be limited in scope and results can answer only small questions; wider conclusions rely on generalizations that may not be valid. Also test sessions cannot extend to a long time period; typically two hours is recommended as a maximum length, or otherwise the fatigue of test subjects may affect the results. Consequently, this limits the time available for the introduction to tools and their use as well as collecting background information about users, such as their visual abilities, prior knowledge, attitudes etc.

4 User tests of metadata visualization

According to the principles of human-centred design, users shall be involved in the design process for designers to gain understanding of the context of use and specify users' requirements, and for evaluation of the design at different stages of the process.

In this Chapter, I describe the two user tests that were carried out in order to gain insight of how visualization of geospatial metadata would support users in evaluating geographic datasets and what type of details in the design would affect the usability of such a visual environment. The tests were limited to a case where a user selects a dataset from among alternatives that all represent the same theme and are available from the intended location. I chose a road theme for test materials because it is one of the themes that are available in several data products on the market. Therefore, I could use real metadata instead of synthetic material that may not reveal the details of real world cases. A road theme is also familiar and important to many users of geographic information, and so the theme did not restrict too much the selection of potential test subjects.

The visualization methods included in the tests were samples maps (as browse graphic of ISO 19115:2003) with potential reference maps and multivariate visualization methods (a scatterplot matrix, a parallel coordinate plot, star glyphs, and the Chernoff faces) for representing metadata elements that could be easily transferred to numeric values. The conceptual schemata were left outside the testing, as it appeared to be difficult to get sufficient information for producing the conceptual schemata; schemata were not available from data suppliers.

The first one of the tests was a concept test, the other one was a prototype test. The concept test was carried out in an early stage of design when only first ideas of visualization approaches were at hand. By communicating the ideas of metadata visualization to users, the test was seeking users' attitude towards and preferences within the visualization approaches that included sample maps and four multivariate visualization methods. The results of this test were then taken into account when building a prototype of a visualization environment.

The interactive prototype environment included sample maps, two multivariate visualization methods, and textual metadata. It was tested with users whose interaction with the prototype and thinking aloud were recorded and who afterwards commented on the process and the prototype in a semi-structured interview.

4.1 The concept test

Concept testing is a communication process between designers and potential users about the form, function and features of a product (Ulrich and Eppinger, 2003). Testing comprised communicating the ideas to the test users and collecting feedback from them. Several methods and techniques can be used for communicating the ideas, such as use scenarios, storyboards, paper prototypes and physical mock-ups (Erickson, 1995; Kuutti, 1995). Because of the early stage of the design process and the provision of parallel design proposals, the effort in implementing the ideas for testing is kept to a minimum.

In this study, design concepts were communicated to users by static displays. While interactivity is a core element of an exploratory visualization environment, interaction possibilities were introduced to users by use scenarios and verbal explanations.

Collecting of feedback from users can be done, for example, by an interview, a questionnaire, or focus group discussion, or by recording the thinking aloud when users study the ideas or use a prototype. It is important to hear the voice of real users; the subjective and ambiguous views of the users may reveal valuable consideration in the design process (Erickson, 1995) rather than the generalized, "objective" results of quantitative research methods. In this concept test users were thinking aloud when studying the displays. In addition, a semi-structured interview was carried out throughout the test.

The concept test concerned two different visual approaches, first, the browse graphic metadata element (ISO, 2003) that was representing sample maps, and second, multivariate metadata that represented multiple metadata elements for several datasets in one display. In respect of sample maps, I sought to know what meta-information users could derive from sample maps and how different reference images could add that information. In respect of multivariate visualization methods, I sought to know whether the proposed methods would be easily understandable to users, whether they would convey metadata efficiently for the case of selecting a dataset, and whether users considered these methods useful.

4.1.1 Test materials and displays

Sample maps

The sample maps were produced from three vector datasets: two road datasets and a dataset of coastlines. The road datasets originate from different data suppliers and have slightly different definition of the content. The coastline dataset was included in order to see whether the theme caused any differences in the sample maps. The coastline data originates from a 1:250 000 map. All the samples are from Kotka town on the coast in South Eastern Finland. The sample area of about 2 km x 2km includes a dense housing area, streets, an uneven seashore and a small forested outdoors area. The area was selected randomly, only checking the versatility of feature types. It appeared later that many curiosities worthy of detection were included in the sample data. The sample maps presented the data without any added marks that could have signalled the curiosities or potential errors in the data.

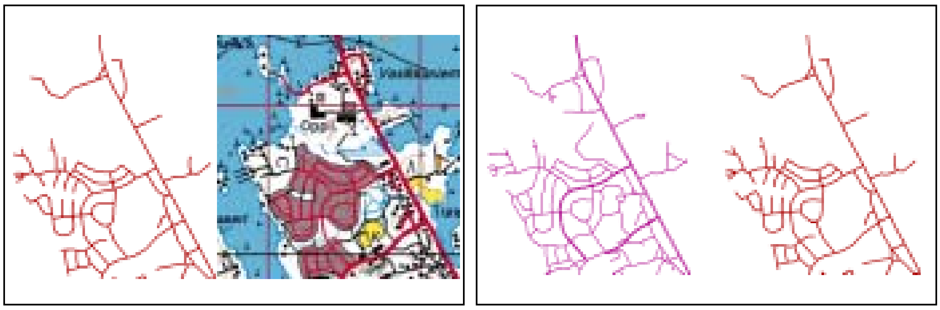

Figure 4.1 Examples of the displays in the concept test: a sample map of a road dataset in parallel to a topographic map (left) and sample maps of two road datasets in parallel (right).

In addition to sample maps, reference images were included in the displays. The role of the reference images was to represent the real world, and the idea was to support users in assessing characteristics of the data by allowing comparison with the reference. Because the real world is continuous and infinite in its details the representation can never be more than an approximation. Therefore, a reference image at its best can only give a more detailed approximation than what the data do. The reference images in the test were a city map, a topographic map, and an orthophoto (see Figures 4.1 and 4.2). They have different limitations in respect to the level of detail and currency.

The sample maps were displayed individually, in parallel to each reference image, and overlaid on the orthophoto. In addition, the two road data samples were displayed in parallel to and overlaid on each other, and the coastline data sample was displayed with a sample of coastline data from the national topographic dataset that corresponds to map scales 1:20 000 - 1:50 000. After a pilot test, the display of an individual coastline was removed as a distraction, because it was impossible for the test subject to figure out which side of the coastline was water and which one land. Examples of the test displays are given in Figures 4.1 and 4.2.

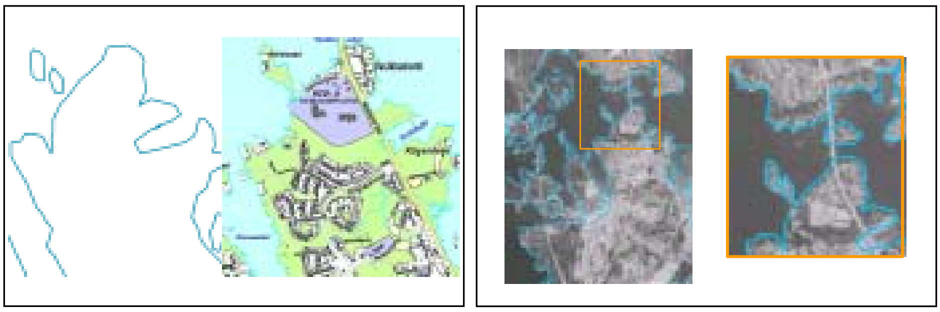

Figure 4.2 Examples of displays in the concept test: a sample map of a coastline dataset in parallel to a city map (left) and overlaid on an orthophoto and presented in two different scales (right).

Multivariate visualization methods

Four multivariate visualization methods were tested, i.e. scatterplot matrix, parallel coordinate plot, star glyphs, and Chernoff faces (see Figures 4.3-4.5). Reasoning for the selection of these methods is given in Chapter 3.4. A set of geospatial metadata was compiled for the production of realistic displays. The set was composed of five metadata elements for eight road datasets, namely updating frequency, scale (or reference scale), geometric structure, price, and number of geometric objects (i.e. road segments). Metadata were collected from data suppliers' brochures and in direct contact with them. Still some single values remained missing, which reflects the reality of metadata being incompletely available.

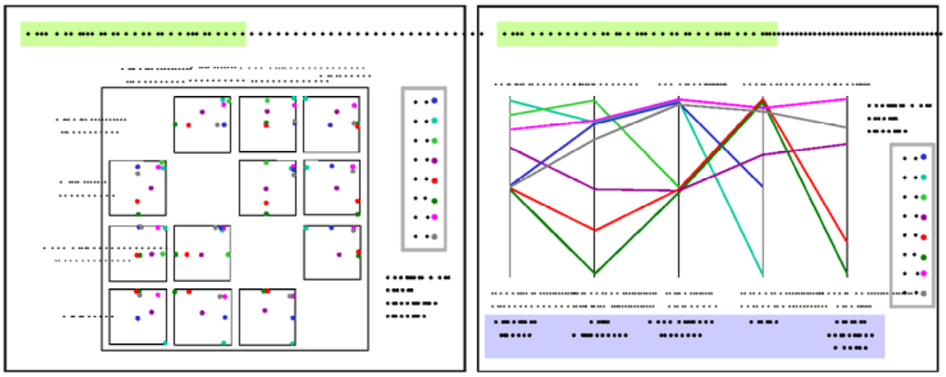

Figure 4.3 Examples of multivariate visualization displays in the concept test: a scatterplot matrix (left) and a parallel coordinate plot (right).

In enumeration of metadata values, the ISO 19115:2003 standard was followed. The metadata values were then manipulated as ordinal data and coded to numeric values for the displays. In the scatterplot matrix, parallel coordinate plot, and star glyphs displays datasets were colour coded, and the colours were linked to datasets (called A-H) in each display. This was necessary to make datasets distinguishable without interactive brushing. In the scatterplot matrix and parallel coordinate plot names of the metadata elements were given at the axes. In the parallel coordinate plot also minimum and maximum values were displayed. In the displays of star glyphs and Chernoff faces, explanation of the elements was given in each display. For the Chernoff faces, the metadata values were classified into tree classes to keep the face features clearly distinguishable.

Alternative displays were created for the parallel coordinate plot and the star glyphs. In the other parallel coordinate plot, two "most suitable" (according to the use scenario) datasets were removed in order to test how users interpret the display when there are no such obvious choices as those two. For the star glyphs, an alternative display with star axes in full length was created (on the right in Figure 4.4); the plots with several missing values were left out from this display. Another display of star glyphs presented four star glyphs overlaid.

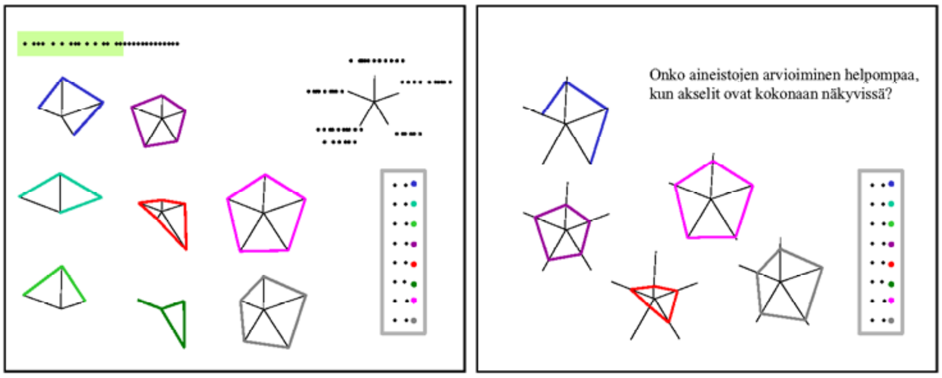

Figure 4.4 Examples of multivariate visualization displays in the concept test: star glyphs.

Missing values did not cause any problem when creating the scatterplot matrix, as only dots were missing in related scatterplots. In the parallel coordinate plot, order of axes was such that missing values occurred only in the last two variables. Therefore, lines representing datasets with missing values just ended at the axis of the last know value. This solution had not worked if the parallel coordinate plot had been interactive and users could have changed the order of the axes. Also in star glyphs, the missing values caused a break in the outline. Actually, one missing value caused two segments missing. The three variables displayed in Chernoff faces were selected so that values were not missing.

The face features in the Chernoff faces were selected so that there would be a relation between favourable metadata values (according to the use scenario) and satisfied face features.

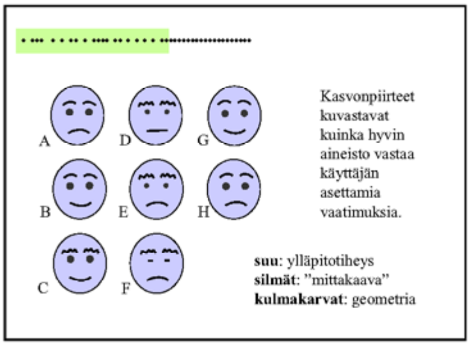

Figure 4.5 An example of multivariate visualization displays in the concept test: Chernoff faces.

4.1.2 Subjects and test sessions

For the validity of usability testing, it is important that the test subjects represent the potential users and their number is significant. As was discussed above in Chapter 3.6.2, when working processes are being studied, the number of subjects should be 10-20 (Beyer and Holtzblatt, 1998). The concept test was carried out with 12 subjects from the Finnish Defence Forces. In addition, a pilot test was conducted before the actual test sessions. All the test subjects were professionals working with geographic data, either as application developers, data administrators or application users. Their working experiences with GIS varied from two years to over 15 years. Therefore, they represented well the professional users of geospatial metadata. Individual differences in experience of evaluating datasets as well as in motivation and attitude were obvious during the test sessions.

The concept testing was carried out in December 2002 and January 2003 in individual test sessions. Eight sessions were organised in the offices of the subjects, four sessions were organized at Helsinki University of Technology for those subjects who work outside the metropolitan area but regularly visit Helsinki for meetings. The test sessions took from 50 to 90 minutes. During the sessions, thinking aloud protocol and semi-structured interview alternated, and the sessions were audio recorded.

After an introduction that covered the purpose of the test and its general structure, I gave the subject the first displays that were organized in a set of PowerPoint slides on a portable PC and instructed the subject to proceed at their own pace and return to previous displays when convenient. I asked the subject to study each display of sample maps and consider what he or she could perceive about the contents and quality of the presented data. Some questions where written in the displays, such as which one of the two or three successive displays the subject finds the most useful. I made further questions on the basis of subject's comments or to prompt thinking aloud if the subject remained silent for a longer while.

In the second phase, I gave the subjects a use scenario that described a need to select a dataset for an intended use from eight alternative road datasets. The use scenario explained that the user had already selected the criteria (they concerned the five metadata elements explained above) and the favourable values for each metadata element. So the evaluation criteria were fixed for the subject. The favourable values and the organization of metadata were such that higher values in the displays were the most favourable. This is a rough simplification of ordinary cases of evaluation but I thought that such a case could result if the data manipulation tools in a visualization environment were advanced enough. The subject then studied each of the multivariate displays, one at a time. I first explained the principles of the method, and then the subject, thinking aloud, tried to identify the most suitable dataset following the use scenario. While talking about the displays, subjects referred to datasets by colour or the identifying letter (A-H). Two of the subjects were colour blind but they could distinguish the objects by differences in brightness if not by hue.

After the subject had finished with a display, I explained how interaction techniques, such as ordering of axes, brushing and filtering, and multiple linked views, would be implemented with the method. Displays provoked many comments from the subjects, also about how they would use the interaction possibilities when working with metadata, and they compared various methods without request.

At the end of the test session, I asked the subject's opinion of the visualization approach on geospatial metadata, what tools seemed to be most useful (and why), and in which situations the subject could benefit from visualization of metadata.

4.1.3 Analysis method

Afterwards I transcribed the recordings and made a qualitative analysis. I compared positive and negative remarks of the subjects on different displays and collected the opinions they expressed on individual methods and the process of using metadata. The results are explained in Chapter 5. Some of the findings affected the prototype that was used in the second test, as explained in the following.

4.2 The prototype test

The other test in this research was carried out with an interactive prototype that implemented some of the ideas that were present in the concept test, whereas some ideas were ignored because of the results of the test. The prototype simulated a real geospatial metadata visualization environment in the respect that it was implementable, and partly implemented, in the Internet.

The prototype test aimed at gaining understanding about the process in which users select a dataset for an intended use and how different representations of metadata would support this process. Therefore, it was important to observe users in a situation that simulated a real selection case and with tools that provided feel of a real environment. Furthermore, the subjects had to represent real users of geospatial metadata.

4.2.1 Test prototype and materials

The test prototype was composed of three forms of geospatial metadata describing six road datasets. The forms were sample maps, a parallel coordinate plot and star glyphs as forms of multivariate visualization, and structures text files. These were implemented in two separate software environments.

The sample maps and textual metadata files

For the prototype test, a sample map environment (see Figure 4.6) was established on Paikkatietolainaamo (a geographic data lending facility) that is a pilot service relating to the national geographic information strategy process in Finland. The pilot service has provided geographic data samples of 14 private and government data providers since Autumn 2003 for the purposes of research, education, and product development. The pilot service has been financed by the Ministry of Environment and implemented on an ArcIMS platform in the Department of Geography of University of Turku[10]. It provides an environment for browsing of maps with functions for displaying sample data, zooming and panning, and a collection of background datasets. Sample maps can be overlaid mutually or with background data. The prototype for this test was implemented in Paikkatietolainaamo with six road datasets and a selection of background maps. A sample site in Tammela in Southwest Finland was selected because all the road datasets already implemented in Paikkatietolainaamo had sample data for that area.

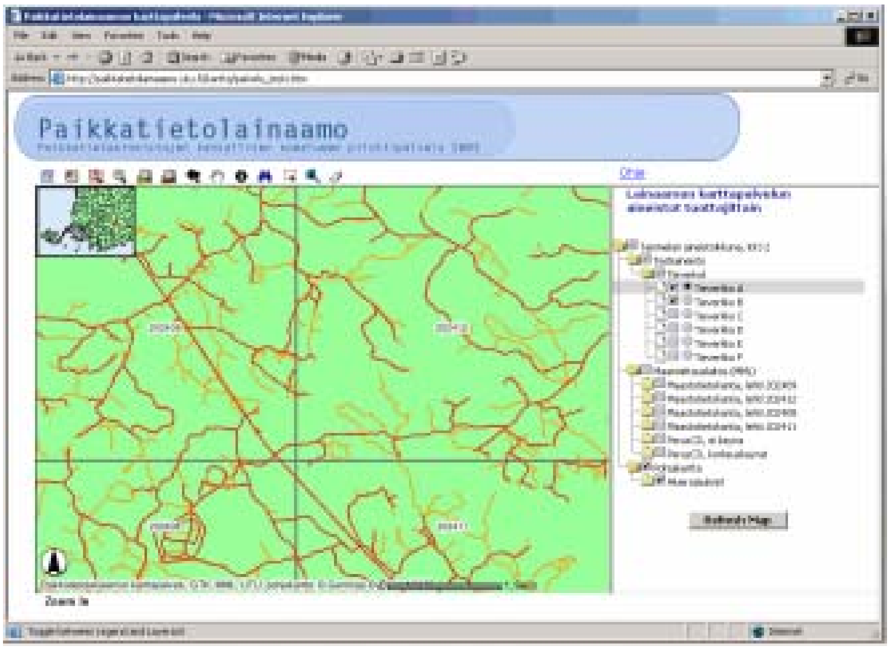

Figure 4.6 The test environment for sample maps. In the example, road data A and B are displayed without a reference map.

Four of the road datasets used in the test were already included in the Paikkatietolainaamo environment, one additional road dataset was provided by a data supplier on request, and one was created for the test. This last one represents a new dataset that is in an early production stage and initially has the same geometry with

[10] Kalliola, R. and Toivonen, T., Paikkatietolainaamo kansallisen koealueen pilottina. UTU_LCC Publications 6, University of Turku, Laboratory of Computer Cartography, Turun yliopisto, Turku 2004. (In Finnish, English summary) ISBN 951-29-2618-0. URL http://paikkatietolainaamo.utu.fi/linkit/PTL_loppur_UTULCC6.pdf (accessed 27.9.2004)

one of the other datasets. So a copy of this other dataset sample served as a sample of the new dataset. The order in which datasets are drawn when overlaid is fixed in the environment, and users cannot change it. Therefore, the order of the datasets was predefined according to the scale of datasets, the largest scale on the top. Also the colours of maps in the environment are predefined. Different shades of red were selected, as red is a conventional road colour in Finnish road maps. Because the colours had to be distinguishable from each other, the shades extended from yellow and brownish red to purple.

Background maps were selected from among the datasets already implemented at the Tammela sample site. The background maps in the test environment included a topographic map at 1:20 000 scale in raster form in two versions, that is with and without contour lines, and the building and land cover themes of the topographic database, all from the National Land Survey. The road datasets were named as Road network A–F to keep them anonymous. However, the alphabetical order of the datasets followed their order of scale.

The files of textual metadata were linked to the names of road datasets. Clicking a road name opened a window with metadata for that road dataset (Figure 4.7). I defined a structure for the metadata files following the ISO 19115:2003 standard but concentrating on metadata elements that are relevant when evaluating datasets.

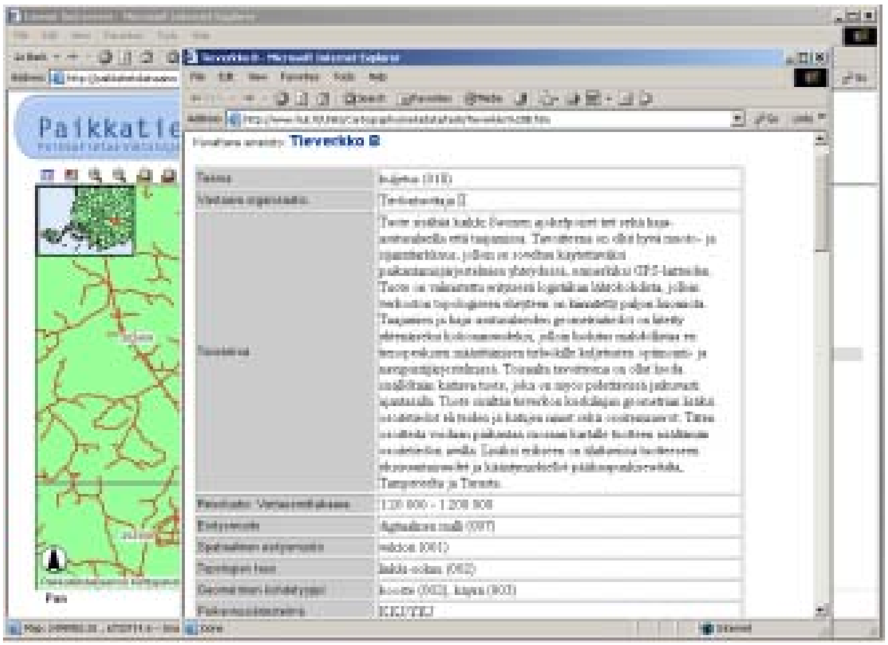

Figure 4.7 The test environment for textual metadata. In the example, the text window of road data B is open.

Therefore, for example, contact information was ignored but classification of datasets was described in detail. I gathered the metadata from web pages, brochures, and other materials of data suppliers and asked for some datasets directly from data suppliers. Lack of quality descriptions was common, but otherwise metadata were quite complete. Because of anonymity, data suppliers were named as Supplier I–III. An example of a metadata file, translated from Finnish, is in Annex 1.

As the sample map environment was implemented on a server at Turku University and the textual metadata files on a server at Helsinki University of Technology, in the test, this part of the prototype was used over the Internet.

Parallel coordinate plot and star glyphs

In the concept test, a parallel coordinate plot and star glyphs proved to be suitable for visualization of metadata in the evaluation of datasets. Therefore, these two methods were implemented as a software component in the prototype test environment (Figure 4.8). The aim was interactive software with an easy to use interface. A geoinformatics student at Helsinki University of Technology programmed the software as a part of his special assignment. The software was based on the Java Bean code of the Parallel Coordinates applet of VixCraft[11]. Modifications to the original software included an additional window displaying star glyphs, linked to the parallel coordinate plot, enhancements to the user interface, and translation of the user interface into Finnish.

The software reads the variable names and values from a Simple Tabular Format file and draws a parallel coordinate plot in one and star glyphs in another window. Interaction by mouse pointer in the parallel coordinate plot includes changing the order of coordinate axes by drag and drop, zooming in (i.e. filtering out) on a coordinate axis, and focusing on a value. The latter function both displays the value of the pointed variable and highlights the line(s) in question. One of the axes can be divided in 1-3 equal sections that determine the colour of the lines representing the datasets. Users can change the number of these sections any time during the exploration.

The star glyphs are drawn in two alternative ways; users can change the style any time during the exploration. One of the styles is the traditional star outline from one axis point to the next one. In the other style, the star outline starts from a root point between two axes near the star centre and goes to an axis point, then via the next root point to the next axis point etc. resulting to a more star-like shape (see Figure 4.8). In the latter style, the minimum values become detectable more easily than in the traditional style in which the minimum values distort the shape badly. The parallel coordinate plot and the star glyphs were linked so that changing the order of axes or

[11] URL http://www.amitgoel.com/pcoord/

highlighting of datasets in the parallel coordinate plot reflected to the star glyphs. Interaction or linking vice versa was not possible.

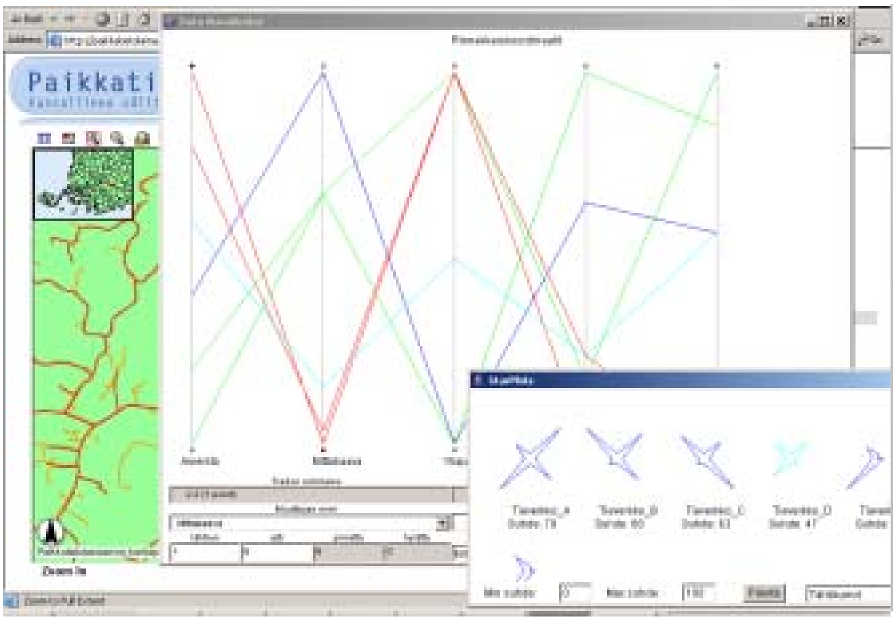

Figure 4.8 The test environment for a parallel coordinate plot and star glyphs. In the example, all the six test datasets are displayed.

The metadata represented in the parallel coordinate plot and star glyphs was collected with the other metadata. The test file included four metadata elements that were the scale (spatial resolution of vector data), updating interval, number of road classes, and price. An additional element provided the names of the datasets. These metadata are shown in Table 4.1. The original values for scale (ranging from 1:10 000 to 1:1.6 million) were transformed to a logarithmic scale (resulting to values 10-0.8). Updating intervals were collected according to the ISO 19115:2003 classification as ordinal/nominal values and transformed to metric values. The numbers of road classes ranged from 9 to 28 and prices of the datasets from 100 to 7000 euros. The transformed values were explained on a paper that was available to subjects during the test.

Table 4.1. Metadata for the multivariate visualization in the prototype test.

Dataset name	**Scale (cf. spatial resolution)**	**Updating interval**	**No of road classes**	**Price (in euros)**
A	1:20 000	One year	13	7000
B	1:20 000	Continuous	27	6000
C	1:10 000	Continuous	21	4000
D	1:200 000	One month	14	4000
E	1:800 000	One year	10	100
F	1:1 600 000	One year	14	100

4.2.2 Subjects

The test was carried out with 18 test subjects. Of the subjects, 6 were female and 12 were male. They all worked regularly with geographic information, their experience with geographic information extending from 1 to over 15 years. Of the subjects 14 had a master's degree: 7 in geography, 3 in engineering (geoinformatics), 2 in other geosciences, 2 in engineering (transportation). They came from the following organizations: Finnish Defence Forces, Finnish Environment Institute, Finnish Road Administration, University of Turku, and VTT Research Centre.

Four of the subjects were geoinformatics students at Helsinki University of Technology working for their master's thesis or other research project at Helsinki University of Technology. Three of them had made a project relating to metadata management, each one in a different organisation.

The subjects made the test individually, except for two subjects who made the test together. One of the subjects participated in both the concept test and the prototype test, and two other subjects of the prototype test were familiar with the concept test results.

Originally there was one more subject but his test was interrupted by a virus attack on the Internet server which disabled access from his organization to external sites including Paikkatietolainaamo.

4.2.3 Test session

The test session were carried out in June-July 2004. Most of the test sessions were organised in the working places of the subjects, either in an office or a meeting room. Three subjects came to the University for the test. The multivariate visualization software, related data files, and introductory slides were copied to a computer with an Internet connection. A video camera was set up so that it recorded the computer screen or, in two locations, the projected display on a wall. A minidisk with a microphone was located near the keyboard.

At the beginning of the test session, the subject read three slides on the screen that explained the objective and structure of the test and the role of subjects. When the subject had read the slides I repeated verbally that the test is not targeted to subject's knowledge and skills and gave reasoning for the importance of thinking-aloud.

The test comprised four phases with the following aims and tasks:

Phase I: Orientation to the use case

First the subject read a brief case scenario: the subject participates in a development project for a transportation system and is responsible for selection of suitable data for the system. Then the subject got two tasks asking the subject to consider what kind of data would be suitable in this case. The subject answered in writing but was encouraged to think aloud. This was to familiarize the subjects in thinking-aloud, which was new to all but two subjects. The orientation phase was audio recorded. The two tasks were the following:

Task 1: The subject is asked to list the characteristics of data that (s)he would consider when selecting a dataset for this case.

Task 2: The subject is asked to give relative weights, ideal values, and limits to non-acceptable values for the following four characteristics (i.e. metadata elements) in this case

- Scale (representing the spatial resolution of the data)
- Maintenance interval
- Number of road classes
- Price (for the extend of Finland)

Phase II: Orientation to the tools

Two tasks were introducing the subject to the visualization tools of the prototype environment and let them train with the tools before the actual test task. The order of these tasks was varied to avoid biased results in the next phase. The tasks were video recorded.

Task 3: The subject was asked to select the most suitable dataset from among alternatives that were described by those four metadata elements that were considered already in task 2. The actual test metadata were not yet in use in this task but synthetic metadata that were slightly modified; for example, there were only five alternative datasets. The metadata were represented in a parallel coordinate plot and in start glyphs. I first explained briefly the principles of both representations and the implemented interactivity, and the subject tried to interact with the visualization while I explained. Written instructions were available throughout the test. After the introduction the subject made the selection thinking-aloud while interacting with the displays.

Task 4: The subject was provided with a set of linked displays that represented a sample map of two road datasets from the same location and at the same scale. The displays represented the sample maps individually, in parallel, overlaid, and on a topographic map (in grey scale). The sample maps were drawn one in orange and the other one in brown. There were two different overlays: the orange sample map on top and the brown one on top. The sample maps were presented on the topographic map both individually and overlaid in the two ways. The links at the bottom of each display allowed browsing of the displays in any order.

The subject was asked to study the sample maps in order to gain an insight how they differ and to think aloud while studying the displays.

When the subject had finished the task, we accessed Paikkatietolainaamo. I introduced the basic functionality of zooming and panning and asked the subject to study briefly some maps in another location than the one used in the test. Those five subjects that were familiar with Paikkatietolainaamo skipped this task.

Phase III: Use of the visual metadata environment

While the subjects now were familiar with the use case and the tools available they proceeded to the actual test task. The task was video-recorded.

Task 5: The subject was asked to select the most suitable dataset in the use case from among six alternative datasets. Metadata about these datasets was available as sample maps in Paikkatietolainaamo, as text files linked to dataset names in Paikkatietolainaamo, and in parallel coordinate plot and star glyphs. The multivariate representation included the four metadata elements as above in tasks 2 and 3.

Thinking-aloud of the subjects varied from fluent to non-existing during the exploration. Often, a non-word sound of was a sufficient prompt to make them continue aloud. Obviously an intensive thinking stage is not easily pronounced without disturbing concentrated thinking. However, when the subjects got a solution, either their final choice or an interim selection of the most potential datasets, they voiced their reasoning of the solution without prompting.

When the task was done, the subject moved away from the computer.

Phase IV: User profile

At the end, the subject filled in a form that asked experience with geographic information, metadata, Paikkatietolainaamo, and parallel coordinate plot technique, possible colour-blindness, and educational background.

The test sessions took from 45 minutes to 90 minutes.

In addition to the test session, 14 subjects participated in a semi-structured discussion in groups of 3-4 subjects. These were hold in the same day than the test sessions when each participant had made the test. The discussions took 20-30 minutes. The other four subjects gave a semi-structured interview immediately after their test session. These discussions and interviews were audio recorded.

4.2.4 Analysis method

Transcription was done for the orientation part (tasks 1 and 2) and the use task (task 5) as well as for the discussions and interviews. The use task was analysed from the transcription in respect of the use of representation forms (time and number), stages of filtering datasets out (incl. reasoning why), interaction with sample maps (incl. zooming, panning, and use of reference maps), and interaction with the parallel coordinate plot. Remarks of the subjects that expressed their satisfaction or critics were analysed.

5 Results of user tests

The subjects of both the concept test and the prototype test gave positive feedback about the visual representation of geospatial metadata. In the concept test, the subjects considered sample maps useful for users at any skills level and multivariate visualization methods very useful if alternative datasets are available. However, most subjects of the concept test had no experience about selecting a dataset because of the coordinated supply of geographic data in their organization. In the prototype test, the subjects unanimously commented that sample maps and a parallel coordinate plot would be useful components in a geospatial metadata service. They believed that users would be motivated to put effort in using a parallel coordinate plot if they were to select a dataset.

The results of the two user tests are reported in more detail in the following subchapters. Chapter 5.1 introduces the results concerning how users set the requirements for the selection in the use case and the presumptions that users seem to have about geographic datasets. Chapter 5.2 describes the process of selection and how the subjects used the component of the prototype environment. Chapters 5.3 and 5.4 explain the results in respect of the visualization methods, first the use of sample maps and then the multivariate visualization methods.

5.1 Results concerning user approaches

5.1.1 Specifying the requirements

The first part of the prototype test indicated the difficulty of specifying the requirements for evaluation.

In the task 1, the subjects listed the characteristics that they would need to consider when evaluating datasets according to the use case. Subjects' knowledge of what characteristics matter when selecting datasets – both in general and in this use case, especially – were good, although most of the subjects are not involved in transportation applications in practice. The subjects gave comprehensive lists of relevant characteristics. There was no evident difference between the 3 subjects who are working daily with road data and the other subjects, or between the most and the least experienced GIS users. In that respect the subjects formed a homogeneous group of experts.

Table 1 summarizes the characteristics that the subjects of the prototype test mentioned to be of concern when selecting a dataset, and the number of references of each characteristic.

Table 5.1. The characteristics of concern when selecting a geographic dataset.

Characteristic of datasets	No of references
Up-to-dateness or maintenance of data	16
Classification of data (or semantics)	14
Geographic extent	13
Geometry	8
Topology	7
Positional accuracy	6
Data producer	5
Price	5
Format (or technical characteristics)	4
Suitability to use without processing	4
Scale or level of generalization	3
Copyright and use rights	3
Quality	2
Consistency with other datasets	2
Original purpose of use	2
Availability of metadata	2
Availability of test data	1
Time of delivery	1

In task 2, the subjects first gave relative weights to four given characteristics (i.e. metadata elements). There was some variation in the weights given, but each subject gave a valid reasoning for their decision in thinking aloud. Half of the subjects gave the highest weight to the number of road classes (semantic resolution). Almost as many subjects gave the highest weight to the scale (spatial resolution). The lowest weight was given to the price of data with only a few exceptions.

Specifying the ideal values for these four metadata elements proved to be much more difficult than weighting. The subjects commented that it would be easier in a real case, because the requirements could be derived from practical constraints. But more importantly, the subjects recognized correlations between different characteristics that complicate the task and requirements that vary, e.g., between urban and rural areas. This part of the results clearly shows that it would not be possible to formulate the data needs in a query language at an exact level. However, only two subjects set such limits for acceptable metadata values that none of the datasets in the test would have met them, one in respect of scale and the other in respect of price.

The number of road classes appeared to be the most curious metadata element. The subjects typically listed the relevant classes in their mind and ended up to 3-7 classes (one subject up to 10 classes), whereas the test datasets included 10-27 different road classes. It was only in task 5 when the subjects could see the metadata and compare how their ideas about the needed classification fit with the classifications of the datasets. In addition, price values provoked most comments from the subjects, such as "I don't really know" and "it really depends on... ". This part of the results emphasises users' need to get on overview and to interact with metadata before they specify their requirements in detail.

5.1.2 Presumptions about data

The concept test showed that users have certain presumptions about characteristics of datasets. For example, high price is commonly linked to good quality. One subject confirmed this presumption when he reasoned in thinking aloud that, because a dataset is more accurate than another one, it must be too expensive, and he will not consider it further. However, the display he was looking at showed that the price ratio of those two datasets was not what he assumed. This shows that communicative presentation is not sufficient to break through and change users' existing knowledge structures if the presumptions are strong. In the prototype test where the subjects used the displays interactively, they made no similar comments. This suggests that interactivity encourages users to consider the information available more carefully.

Another presumption relates data quality to the amount of spatial details in data. In the concept test, while studying sample maps, the subjects gave comments such as "this road dataset with more details is more accurate" though there was no explicit information about the quality. The same happened in the orientating task 4 in the prototype test when the subjects were studying individual maps. Some subjects in the concept test, however, considered that the road dataset with more detailed data must be "raw data" still requiring consistency checking and geometric cleaning because the lines were "uneven". (The sample represented a final data product.)

In the concept test, subjects also thought that those road segments in the data that could not be found in the reference image indicated that the dataset is more current than the reference image. Nobody expressed a concern that the data might include roads that do not exist in the real world, i.e. commission errors. However, several subjects in both tests noted that they would need additional information to properly evaluate the sample maps, especially the reference date of the datasets.

The dominating presumption seems to be the link between data producers and data quality. The datasets in the prototype test were anonymous, but several subjects in some stage of the test stated that if they knew the data producers, it would be easier to decide which dataset to select. This is in accordance with the theory of marketing management that customers base their decisions on images rather than facts of products, and the producer is one of the factors forming the image (Gale, 1994). The images of test subjects, at least partly, base on their knowledge and experiences of the products of certain data producers and, therefore, may this presumption may be well-founded.

5.1.3 Users' attention and terminology

In the concept test, the most experienced (in years of working with geographic data) subjects made more consistent remarks than the least experienced subjects. However, there were also personal differences that affected on how concentrated observations the subjects did. The more concentrated subjects recognized probable errors and obvious inconsistencies in the samples more often than those who appeared to be less motivated or who were willing to proceed quickly. Some of the subjects often lacked terms when thinking aloud about the quality of data represented in the sample maps. They obviously perceived more than they could verbalize.

In the prototype test, some metadata elements and terms used in the descriptions were not familiar to the subjects. For example, positional accuracy is a commonly known quality term, but the meaning of completeness aroused questions among the subjects. The problem involves two levels: first, many concepts of geospatial metadata are unfamiliar and, second, the terms used for these concepts are not known. The problematic terms may differ from one language to another. For example, at the moment there are no well-established Finnish terms for 'lineage' and 'completeness' although the concepts as such are unambiguous. A project has now been launched for the Finnish terminology of metadata and quality standards of geographic information in cooperation with the Finnish Terminology Centre TSK. Although the work is based on the terms of the ISO 19100 series, it starts by concept analysis instead of just translating the English term. This illustrates the complexity of the terminology issues.

5.2 Results concerning the selection process

The selection strategies of the most suitable dataset varied greatly between the subjects in the prototype test. From the 18 subjects that made the selection task, 3 did not end up to a final selection. They evaluated datasets and filtered out several alternatives, but together with the orientating tasks they used a long time and started to get tired or otherwise feel that they wanted to finish. Because 2 subjects made the selection task together, there were 14 completed selection tasks. The time used in the tsak varied from 6:45 to 28:30 minutes, which means that the longest process took about four times the shortest time.

Figure 5.1 represents the time used in the task and the use of the three representation forms. The subjects are presented in the order of time they used for the task. Use of star glyphs was minimal (as reported in Chapter 5.4.3), and it is here combined with the parallel coordinate plot. Figure 5 clearly shows that the use of representation forms varied from very short to very long sections. There is no common trend in the length or rhythm of the sections from the beginning of the task towards the end.

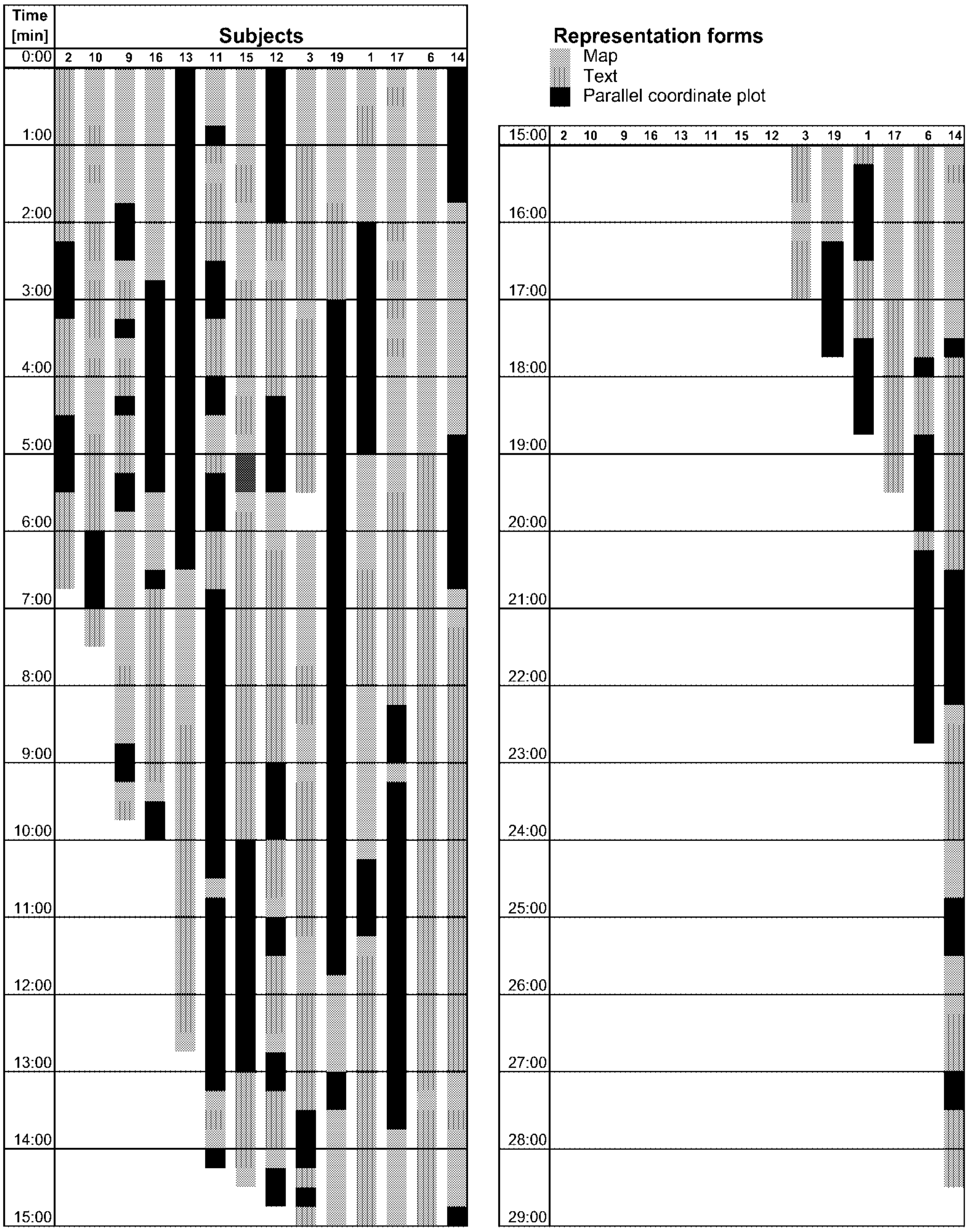

Figure 5.1 Use of time and different representation forms for each test subject in the prototype test.

Regardless of the used representation forms, the subjects started the task by forming an overview of the alternatives. Most of the subjects made the first filtering out of 2-3 alternatives already within the first 3-5 minutes, mainly based on too rough scale, whereas other subjects concentrated on studying those datasets that looked most promising before filtering out any alternatives. Typical strategies of approaching the selection task were the following:

- Check each one of the sample maps at a time and take a look at the related text. When all datasets have been checked, filter out the 2-3 datasets of the smallest scale. Then continue comparison of the remaining alternatives.

- Check the six sample maps, all overlaid, and filter out the 2 smallest scale datasets. Then continue the comparison of the remaining datasets by different means.

- Look at the datasets in a parallel coordinate plot and filter out the three smallest scale datasets. Then read the texts and check the maps comparing the remaining datasets.

The use pattern of the different representation forms in the selection process varied between the subjects.

Each subject used the parallel coordinate plot (PCP in Figures 5.1 and 5.2) in some stage of the process. The total time of using the parallel coordinate plot during the task varied from 1:00 to 10:30 minutes (average 4:45) and the ratio to the time used for the task from 6 to 61 %. Two subjects accessed the parallel coordinate plot only once, 2 subjects 7 times. The length of the parallel coordinate plot use sections varied from 5 seconds to 8:45 minutes. As the number of road classes of each dataset was much higher than the subjects expected, the maximum price was tolerable, and maintenance intervals were either acceptable or good, the subjects put the main attention on the scale axis. So 10 subjects filtered out datasets on the bases of the scale values; 3 subjects made the filtering out on other axes in addition. Only 2 subjects changed the order of the axes, they both moved the number of classes next to the scale.

Scale, in the sense of the amount of spatial details, was the main concern also when the subjects were studying the sample maps. Three subjects first checked sample maps for all the datasets. One subject did not look at the sample maps at all. The total time of using the sample maps during the task varied from 1:00 to 9:00 minutes (average 4:15) and the ratio to the time used for the task from 11 to 54 % (except the subject who used 0 %). The shortest use sections were only some seconds (not visible in Figure 5.1) when a subject gave a glance to a map before starting to read the related textual metadata. The longest section of map use took 5:00 minutes. The subjects typically overlaid 2-3 maps.

The total time of using the textual metadata during the task varied from 1:15 to 13:30 minutes (average 6:15) and the ratio to the time used for the task from 7 to 70 %.

While reading the textual metadata, the subjects put attention on the abstract, the classification of data, and the quality elements. Four subjects compared systematically textual metadata of two or more datasets. They asked for a display where they could have had the texts in parallel, element by element.

The medians of the time that the subjects used with each of the representation forms were each around 5 minutes. However, in average more time was used with textual metadata than with sample maps or the parallel coordinate plot. The subjects who used the longest time for the task also used the longest time with textual metadata.

Use strategies observed in this test suggest that with a larger number of alternatives multivariate visualization gets more weight. Browsing the textual descriptions for overview and filtering caused overload in memory and need to mark the findings. The subjects who started by browsing first all the text files gave remarks such as "did I already look at this dataset".

The time used for each representation form in proportion to the total task time is shown for each subject in the triangle in Figure 5.2. The subjects distributed evenly in the triangle in respect of the total task time, the number of sections during the process, and their education. However, those three subjects who used the parallel coordinate plot more than 50 % of the total task time (S11, S13, S19) had 5 or less years of experience with geographic data and were male. But among those who used the parallel coordinate plot less than 50 % of the total task time were also subjects of the same level of experience (S2, S9, S14, S16). Those three subjects who had over 10 years of experience with geographic data (S3, S6, S12) each used textual metadata more than 50 % of the total task time.

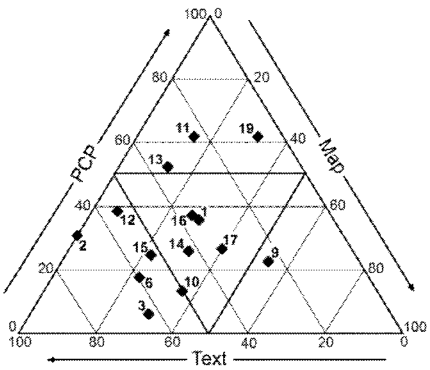

Figure 5.2 Use of different representation forms (time spent per total task time) for each subject in the prototype test.

5.3 Results concerning the sample maps

5.3.1 Usefulness of sample maps of vector data

As a summary of the results of using sample maps, the subjects got very little metainformation by looking at an individual sample map. They could easily identify what kind of road network was represented, i.e. whether it was an urban or rural area, etc., but about the level of detail or data quality they could only give guesses. However, the thinking aloud of the subjects revealed that they assumed good quality if the data displayed looked reasonably clean; they did not question the details of the semantics, positional accuracy, completeness, or consistency of the data. Only when the subjects saw samples of two or more datasets (representing the same theme) differences between datasets became obvious and the subjects became aware of the possibility that the data were not what they assumed them to be. The thinking aloud revealed that the subjects became more critical when they started to compare samples.

In the concept test, the subjects first studied displays of a road dataset that looked fine but did not include all the smaller roads. Only few subjects commented that some minor roads were missing when they compared the data with reference images. When the second road dataset was shown in parallel to the first one, the difference in the level of details was clearly visible and the subjects started to comment on the lack of minor roads in the first dataset. When the two sample maps were overlaid, the differences could be seen in detail. The second dataset included many more roads, but some roads that were included in the first dataset were missing from the second one. Half of the subjects considered this as confusing, whereas the other half just disregarded that observation. In the prototype test, an orientating task (task 3) again asked the subjects to compare sample maps of two road datasets. Now they interactively switched different displays (individual samples, overlaid samples, and samples overlaid with a topographic map) and the observation pattern was repeated. However, when the differences became obvious in the overlay displays, each subject started to actively search for an explanation by switching between the displays. As the instruction was the same in both tasks, the different behaviour between the subjects of these tests suggests that interactivity stimulates users' attention also in the context of sample maps.

During this same task, about half of the subjects reasoned that the less detailed dataset that still included some roads that were missing from the other dataset (including bike lanes and walkways) must be more up-to-date, and one subject remembered a recently build-up housing area in that location. However, the two subjects who were somewhat familiar with the sample area did not evaluate the datasets differently from the other subjects.

In the task of using the full prototype environment (task 5), the subjects put less attention to the sample maps than in the orientating task. Instead of detailed studying they seemed to use the sample maps for getting an overview of the spatial resolution. Only those subjects who ended up making the final selection between two spatially closely similar datasets were checking more carefully the differences between those two samples.

5.3.2 Use of reference images with sample maps

In the concept test, a hypothesis was that comparison of graphic samples to a reference image helps users in evaluating data quality. This proved to be true if the reference image is suitable, but selecting of an appropriate reference image is a complex issue. The subjects working a lot with aerial photographs and used to aerial photo interpretation preferred the orthophoto as a reference image. However, the orthophoto was useless for those subjects who were not accustomed to photo interpretation, and they preferred a map. This is not surprising, as successful use of aerial photographs requires training (Albertz, 2001).

Comments from the subjects indicate that to be useful, a reference map shall present the theme in question most clearly. All the subjects preferred the topographic map as a reference for the road data; the roads were difficult to detect in the city map because the road names made the image fuzzy and no distinguishable colour was used. Several subjects mentioned that the topographic map is a natural reference for military people as they use it frequently and consider it as a kind of standard. However, the city map appeared to be the better reference when the shoreline was in question. The shoreline in the city map was a continuous line in bright colour without disturbing elements, whereas in the topographic map rock symbols cut in the shoreline here and there, and occasionally the shoreline changed from a continuous to a dotted line indicating reeds on the shore. To summarise the results, both the theme of the data and the expertise of the users affect on what is the most suitable reference in each case.

In the prototype test, all but one of the subjects used the sample maps, and they all zoomed the maps in some stage. Eight subjects used a reference map, mainly the topographic map without contours. Two subjects used buildings (from the topographic database) as a reference. When opening a reference map, the subjects without exception also zoomed in the map. Only the subjects who used a reference map used pan to move on the map. They moved especially to find a location where the road network had been denser.

In the discussions afterwards, the subjects stated that a reference map is not necessary with a road network. This suggests that the subjects were more concerned about the spatial resolution of the representation than the positional accuracy (supposing that a reference map would be sufficiently good quality to give an indication about the accuracy).

5.4 Results concerning multivariate visualization methods

The overall attitude of the subjects towards the multivariate visualization methods was positive both in the concept test and the prototype test. In the concept test, the parallel coordinate plot and star glyphs gained the most positive reactions. Several subjects found the scatterplot matrix a difficult method to adopt and Chernoff faces aroused emotions that may disturb their use. Therefore, only a parallel coordinate plot and star glyphs were implemented in the prototype environment. The prototype test proved that a parallel coordinate plot is very useful when comparing datasets, but star glyphs would require a different implementation to be of benefit to users of metadata. The results are introduced for each of the four methods in the following.

5.4.1 Scatterplot Matrix

In the concept test, half of the subjects considered the scatterplot matrix a very complex and non-easily approachable method, even though they could detect the best datasets from the matrix in a reasonable time. Only one fourth of the subjects gave the method their unreserved approval. Two subjects lost their motivation after some attempts of interpreting the display. The strategies of studying the display varied among the subjects. Only few subjects seemed to gain benefit of the expression power of the whole matrix, i.e. of more than the top row plots. This result emphasises the importance of guidance in exploratory strategies.

The scatterplot matrix is not a favourable method for occasional users nor does it support building of a holistic view of a dataset. Though each scatterplot is simple to read as such, users have to keep in mind the various plots while they are not really supported in constructing knowledge of the whole dataset. Pair-wise relationships that the scatterplot matrix presents very well are not the main interest in comparison of metadata. Brushing and linking in an interactive environment would help somewhat in this respect; in the concept test, the displays were static, but on the other hand, each dataset was identifiable by a different colour. In addition, the subjects easily ignored a dataset completely if it was missing (because of a missing value) in the scatterplot that they studied first.

5.4.2 Parallel Coordinate Plot

Results from the concept test

A parallel coordinate plot provides a holistic view of datasets as several metadata elements can be shown in the same plot. In the concept test, the subjects considered a parallel coordinate plot more explicit and faster to interpret than a scatterplot matrix. Half of the subjects clearly preferred a parallel coordinate plot to a scatterplot matrix. Subjects also made remarks that perceiving the range of values of each metadata element was intuitive in the parallel coordinate plot.

In the concept test, the use case and the organization of metadata values on the axes were such that the more favourable a value the higher it was on an axis (similar organization was implemented in the scatterplot matrix and the star glyphs). The subjects found this very useful and intuitive, and it was easy to recognise the line of an overall satisfactory dataset in the plot (see Figure 4.3). When no unambiguously good dataset was available in another display, the interpretation of the plot was not as straightforward, but the subjects still felt confident when selecting the most suitable dataset. The subjects commented on the complex outlook of the plot because of several crossing lines and favoured the idea of reorganizing the axes. The subjects considered also the datasets with missing values, though the way of handling missing values by just ending the lines before the last axes is not a sustainable solution. However, in this case a parallel coordinate plot did not "hide" the datasets of missing values.

Results from the prototype test

In the prototype test, the subjects unanimously considered a parallel coordinate plot as an efficient tool for comparison of metadata. However, especially during the orientating task (task 3), each subject used a considerable amount of time in finding out how the values were set on the axes. Because the values were not organized according to the preferences in the use case, as they were in the concept test, the subjects had to sort out whether they were looking for low or high values for each axis or possibly something in the middle. The subjects commented that pointing in order to highlight a line (representing a dataset) or to check a value on an axis should be easier; the active pointing area around the intersection of a dataset line and an axis was very small. The pointed value was shown in a dialog box under the parallel coordinate plot; the subjects would have preferred that the value had been displayed at the side of the axis. That way, users would not need to move their attention away from the graphical features. The software has originally been designed for cases were there could be much larger number of items than in this test. Although the design solutions may be necessary in those cases, they are annoying to users of geospatial metadata because overload of display space is not constraining a parallel coordinate plot representing geospatial metadata.

Ten subjects used filtering during the exploration, but only three subjects filtered datasets out in more than one step. One subject commented afterwards that he was afraid that he would make a mess of the display and dared not to filter out datasets. Only two subjects changed the order of axes. They both moved the axis for the number of road classes next to the scale axis. This corresponded to the weighted order of the metadata elements (task 2) for the two highest weights by one of the two subjects (the other had an equal weight on each element). Five subjects had given the highest weights on scale and maintenance interval (in this order), so the original order of axes corresponded their weights. The other subjects did not study the axes in the weighted order of the metadata elements. The main reason may be the small number of axes, which made the reading of the plot easy in that respect.

5.4.3 Star Glyphs

Results from the concept test

In the concept test, the subjects favoured star glyphs, commenting that the glyphs are an intuitive and expressive method that gives an impression of the "overall goodness" of each dataset. Again here the organization of metadata values on the star axes was such that the more favourable a value the longer the corresponding axis. So the size of a star indicated the "overall goodness". Only one subject considered star glyphs as an inferior method. However, the test indicated that, even if each star glyph provides a clear representation of an individual dataset, the glyphs are not easy to compare if the differences between the glyphs are minor or in different axes. In general, the subjects considered that star glyphs would best provide the first impression of datasets. Then users would select the most potential datasets and study them further in a parallel coordinate plot. An overlay of star glyphs was also displayed to the subjects, but they considered that it would not really add anything to a parallel coordinate plot. Rather it would easily result in over plotting.

In the concept test, two subjects commented that the star glyphs showed the missing values more clearly than the other methods. However, when comparing datasets, most of the subjects intuitively completely ignored those star glyphs that had values missing. A display with axes in their full length balanced the star glyphs so that it was easier to distinguish which values were missing and which values were dissatisfactory (i.e. close to the origin).

Results from the prototype test

In the prototype test, only three subjects considered the star glyphs at all during the selection task. As the organization of the values did not relate the size of a star to the "overall goodness", the majority of the subjects saw no value in using the star glyphs, especially when a parallel coordinate plot was available. However, one subject used the star glyphs in several staged during the selection process. He figured out in his mind how an ideal star glyph would look like and then compare this shape to the star glyphs displayed. He made quick reasoning about how the datasets differed from what he was looking for and which were the most closely similar. His action suggests that to be useful in the selection process the display should include not only the star glyphs representing the datasets but also a star glyph for the ideal dataset. In one stage, when he had chosen two potential stars, he moved to the parallel coordinate plot to check on one of the axes what is the exact difference between the two.

5.4.4 Chernoff Faces

In the concept test, Chernoff faces aroused emotions among the subjects. Some of the subjects were very amused when studying the faces; some found the faces irritating and not a suitable method for providing serious information. Regardless of their emotional reactions, the subjects could easily identify those faces that visualized a coherent set of either satisfactory or dissatisfactory metadata values. But when the faces represented a mixture of satisfactory and dissatisfactory values or values between these extremes the subjects made confusing interpretations. This happened even though the faces represented only three variables.

In addition, it appeared that the features interact. The even eyebrow curve that indicated a satisfactory value and was easily attached to that value in a happy face was interpreted as a dissatisfactory value when in the face where the mouth was a downward curve (see faces A and B in Figure 4.5). In general, the eyebrow caused most confusion, whereas the mouth curvature was interpreted without mistakes.

The subjects seemed to interpret the faces very quickly. A face is an icon that gives an immediate impression that the user does not question further. Therefore, the Chernoff faces should be applied only when sure of the correct interpretation.

5.5 Limitations of the user tests

The user tests dealt only with road datasets. It is obvious that sample maps of other kind of datasets, especially raster data, need to be handled differently. Most importantly, raster maps cannot be overlaid in the same way, which affects on the comparison process.

The use case always has its limitations as an artificial task. In this research, the use case presented an application that most of the subjects are not working with. However, the subjects dealt well with this shortcoming.

A real environment of geospatial metadata would allow users to select freely the metadata elements for studying. In this research, the subjects worked with pre-selected metadata elements, which enabled easier comparison of user performance. However, it added the artificial nature of the test situation and may have affected on the users' interest and attitude.

The number of metadata elements in the multivariate visualization was small as was the number of datasets that could be selected. Larger numbers could change the use pattern of different representations, as the comparison would become more demanding.

Individual differences as well as differences between user groups could be recognized in the research but not explained. Studying of users' knowledge structures in respect to metadata was outside of the capacity of this research.

6 Recommendations for designing visualization of geospatial metadata

In this Chapter, I discuss the components and characteristics of a visualization environment for geospatial metadata that would support users in evaluating datasets, comparing them, and selecting the one that best fits for an intended purpose. The discussion is divided into four sections: support for concepts of metadata, comparison by sample maps, comparison by multivariate visualization, and textual metadata.

Figure 6.1 illustrates the levels of user tools that would support users in the evaluation. The core components, the textual metadata, sample maps, and multivariate visualization tools, would need to be interactive and mutually linked. Around the core is the level that would enable users in specifying which metadata elements to be considered and how they would be transformed to the visualization. These would reflect users' preferences in respect of the intended uses of datasets. On the outmost level is a concept map that would support users in understanding the metadata elements and how they link to each other. Also user guidance would be available.

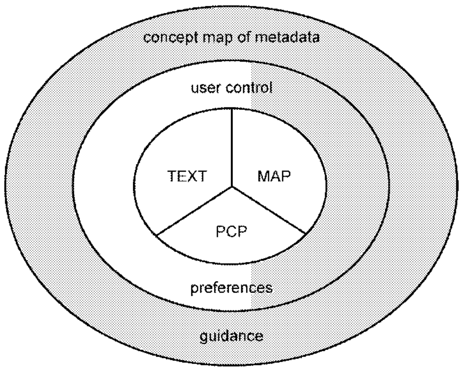

Figure 6.1 Levels of tools that would support users in evaluation by metadata.

6.1 Support for users

6.1.1 Concepts and concept structures in metadata

A concept map of the metadata elements would support users in understanding the meaning of different metadata elements and how they relate to each other. An insight of the overall structure of the metadata could support users in deciding what characteristics they should consider when evaluating datasets and how to weight the different components. Explanations of the metadata elements should be linked to the concept map as well as description of the value domain of each metadata element. Users could then use the concept map and the domain descriptions also in detailing their requirements; Ruth et al. (1997) propose that description of a set is easier by enumerating set members than by explicitly defining the criterion for inclusion.

6.1.2 Guidance for the selection process

The tests confirmed that users of geospatial metadata prefer easily adoptable visualization methods, such as a parallel coordinate plot. However, a parallel coordinate plot is not self-explanatory, and users need guidance when first accessing the method. As the use of a parallel coordinate plot is interactive, an animated guidance (cf. Monmonier's (1994) guided tour) could help users in gaining full benefit from the interactive functions. However, such guidance is hardly neutral in respect of the selection strategy as the use of a parallel coordinate plot in the visualization environment of geospatial metadata is closely linked to other representation forms of metadata. The design of the guidance should be based on knowledge about how different strategies best meet the needs and knowledge of different users. This research provides first indications about how users use and benefit from different presentations of geospatial metadata but the differences between users of metadata need to be tackled in more detail.

Guidance could also support novice users by drawing their attention to relevant details when studying metadata, especially sample maps. A checklist of items that might be relevant could be a generic solution, though different checklist would be needed for different types of data. A checklist would be transparent and, as such, support novice users in learning of geographic information.

6.2 User control and interactivity

6.2.1 Selection and preprocessing of metadata elements

Users of geospatial metadata should be allowed to select the metadata elements they want to explore in a parallel coordinate plot. However, the number of standard metadata elements that are suitable as such for the visualization is very low. Therefore, the visualization environment for geospatial metadata should provide tools for users to transform the metadata values they want to visualize into numeric values. In general, transformations should maintain the semantic relationships between the values (Rosario et al., 2004), but when visualization is used for selecting datasets, the transformation should rather enable users to create semantic relationships for the metadata values. That way, the semantics would correspond to the preferences of the user, and the resulting visual displays would be far more intuitive than when displaying original values that require efforts from users to be correctly interpreted.

6.2.2 Interactivity for textual metadata

Textual metadata is an essential component of any metadata environment because it provides information that is difficult if not impossible to express by other means. However, textual metadata should not be a static file of numerous elements that overloads the working memory of users if they want to compare datasets. First of all, users should be able to (or even asked to) select which elements they study. Secondly, it should be possible to view textual metadata elements from several datasets in parallel. Thirdly, the textual metadata should be linked to other representation forms. Even linking and brushing at the metadata elements level could be considered.

However, in addition to limiting their attention to those metadata elements that are the most relevant in each case, users should also be encouraged to browse metadata more widely. Browsing of information may draw users' attention to metadata elements that open up a new perspective and further comparison. This was demonstrated several times during the prototype test. Especially novice users may benefit from browsing.

6.3 Design of sample maps

Comparison of sample maps is an essential function in a visualization environment of geospatial metadata. To work efficiently, users should be able to decide the order in which the samples are overlaid and to change the order easily, because the order of displays can reveal differences or hinder their perception. In addition, users should be able to control the colours used in the display so that any combination of samples would be easily distinguishable, also to colour vision impaired users. However, the selection of colours or other visual variables is not only a mechanical matter to distinguish the samples from each other, as the visual design of the sample affects on the impression that users get from a dataset.

Although it is essential that users can zoom in and out the sample maps, it is also important that some indication is given about the intended application scale of each dataset. While printed maps provided experienced users a sense of scale, level of generalization, and usability of data, a digital display does not support this sense. Instead, comparison of datasets on a screen may tempt to favour larger scale data while smaller scale data start to look sparse when zooming in. If users cannot compare datasets visually in the scale that corresponds to the resolution of their intended application, they easily consider a dataset the better the higher the resolution, and they may end up selecting a dataset that is too detailed.

The environment should provide a selection of reference maps and ortophotos that fit in scale and content for comparison of the datasets. For example, topographic features should be selectable theme by theme; it is important that a reference map is not too crowded and the comparison not too complex. The reference should always include (at least) as current data as the dataset that it is compared with. Although this requirement is self-evident, it is not easy to meet the requirement in practice.

6.4 Multivariate visualization methods

Multivariate visualization methods provide an essential tool for users of geospatial metadata, as these methods enable users to study and compare multiple metadata elements of multiple geographic datasets at a time. A parallel coordinate plot is an easily adoptable method to users who need it only occasionally and who thus require intuitive tools. The amounts of metadata studied at a time are typically small compared to numbers of data items in many other information visualization applications. This benefit should be taken into account in the design of tools. For example, pointing of values does not need to be too exact when the display is not overcrowded.

Multivariate visualization methods support users' cognitive processes by providing a view of the whole and enabling interaction with individual data items, at the same time. Indicating clearly where various values of metadata locate on the axes of a parallel coordinate plot can lessen the cognitive load further.

Although multiple visualization methods are recommended to enable different views of data (e.g., Edsall et al., 2001), in the case of geospatial metadata, implementation of a parallel coordinate plot as the only multivariate visualization methods seems to be feasible. It meets the primary needs and the other now tested methods do not provide additional functionality that would be useful in this case. Concentrating on one method only may be feasible also in order to minimize the load of learning new tools when accessing geospatial metadata.

7 Conclusions

7.1 Summary of the results

In this dissertation I studied how visualization of geospatial metadata can support users in selecting geographic datasets for an intended use. The results of user tests demonstrated that in comparison of datasets both sample maps and a parallel coordinate plot help users in evaluating the differences between closely similar datasets. Individual sample maps, however, provide little value, but two or more samples overlaid provoke users in studying metadata. The parallel coordinate plot gained users' acceptance as a multivariate comparison approach, but the tests did not examine how users would cope if they accessed the method without interactive guidance at the beginning of a session. The results also indicated the important role of textual metadata in a visualization environment. However, the interpretation of textual metadata seems to be very sensitive to the phrasing of descriptions.

The difficulty of specifying exact requirements for the selection was evident, and seemed to depend on the complex dependencies between different characteristics of geographic datasets. Users, however, proceeded smoothly in the evaluation when they had metadata available. They had different strategies of using the metadata representations, although all users aimed at reducing the number of potential datasets stepwise. Different strategies in the selection could not be explained by the differences in user profiles.

These findings lead to the conclusion that metadata services in the context of spatial data infrastructures should provide visualization tools for users to gain better insight to geographic datasets that are available to shared use. However, the guidance for using these tools should be considered carefully.

7.2 Visualization of metadata in the field of visualization

This research proposes that visualization of geospatial metadata does not fit in only one of the use categories of visualization (Kraak, 1999) but spreads across the diagonal of the "map cube" (MacEachren, 1994), as it comprises presentational, analytical, and exploratory characteristics.

The primary setting of selecting a geographic dataset by geospatial metadata relates the task to exploration. A user has to get an overview of data supply before being able to specify the criteria for the selection and, therefore, needs to browse metadata. An overview implies a view of a whole, which in the case of metadata means a view of several metadata elements of multiple datasets at a time. For example, a parallel coordinate plot is an efficient method for this purpose. As the process continues, the user may change the evaluation criteria and viewpoint according to the increasing knowledge and insight, which is typical in exploration.

Comparison is a common task in analysis, as it aims at answering a specific question (Kraak, 1999). While studying geospatial metadata, users generate new questions throughout the process and use comparison to answer them. However, comparison can also deepen users' insight and provoke new questions, even hypothesis, and as such, comparison belongs to an exploratory process, as well. In the selection of a geographic dataset for an intended use, comparison of metadata elements is an essential subtask.

However, a parallel coordinate plot or any other multivariate visualization method cannot support users of geospatial metadata in comparison of the spatial elements of geographic datasets. Browse graphics (ISO, 2003) that present sample maps of geographic datasets provide means for gaining an insight and comparing of spatial characteristics of datasets. Sample maps are clearly presentational graphics (Kraak, 1999; MacEachren, 1994). They are used in a public realm by any professional user of geospatial metadata with interactivity that is limited to the lowest level of the interactivity (Crampton, 2002), typically to zooming and panning.

Use of multiple representations is another characteristic of geospatial metadata that is typical in exploratory environments. Metadata is necessary in both textual and visual forms.

7.3 Needs for further research

Although the findings of this research supported the hypothesis that visualization of geospatial metadata supports users in selecting geographic datasets, the differences between use strategies of different representations could be investigated further. The impact of sample map design on users' assessment of datasets was not covered in this study, but should be examined in the future. Furthermore, the use of browse graphics for other than sample maps should be considered; the urgent need to understand better the quality of data calls for visualization of quality information also in the context of metadata. How these illustrations should be designed and produced are questions for future research.

The parallel coordinate plot seems to be a suitable method for visualizing elements of geospatial metadata. Usability of parallel coordinate plots should be studied in order to find the simplicity in the design that is optimal to the occasional users of geospatial metadata, to the relatively low numbers of datasets, and to the task of comparison.

Implementation of visualization environments requires further research on the management of metadata elements and their automated transformation to the visualization. This implies the question of how to deal with missing values of multivariate data so that users get proper understanding of the characteristics of geographic datasets.

This study considered only selection of an individual dataset. The case of integration of several datasets and evaluation of their compatibility or similarity (cf. Chapter 2.1) should be explored. It is a wide topic close to interoperability of geographic information (systems) (Bishr, 1998) and combines spatial, semantic, syntactic and quality aspects of geographic data.

The ISO 19115:2003 metadata standard includes application schemata as an element of geospatial metadata. Applicability of these schemata in a visualization environment should be studied, supposing that application schemata of geographic datasets will be widely available as a part of geospatial metadata in the future.

User-orientation in the development of geospatial metadata services is a wide issue. As the process of selecting a dataset starts from the specification of requirements on data, even though at a draft level, tools are needed that support users in this task and integrate in the visualization environment. Especially interesting prospect is transformation of metadata values so that they reflected user's preferences. This would result to more intuitive visual displays, as users could then compare visually representations of available datasets to what they are looking for. However, further research is needed about the types of preferences and how they relate to types of metadata.

Another interesting prospect in user-orientation is distribution of creation of metadata to users (not ignoring data producers as authors of basic metadata elements). The metadata element *usage* (ISO, 2003) could be the first one of the means for users in communicating about their experiences of geographic datasets. Knowledge management systems in industries would provide a starting point for this research. The research should be manifold targeting social aspects because of cultural change both among users and data producers, metadata management including moderation of open universal metadata environments, and issues of user interfaces.

The datasets that metadata currently describe are limited in many respect; they are static and their uncertainties are not properly known. When research on these issues leads to new kind of datasets to be available as a part of spatial data infrastructures, also metadata have to reach a more advanced level and provide means for describing, for example, dynamic data with uncertainty models. This will set totally new requirements for the visualization of metadata. For example, comparison of dynamic sample maps and combinations of different quality displays need to be regarded. This kind of development requires both data-oriented development of representation forms and user-oriented research on visualization tools that support users' in gaining insight on geographic data via metadata.

References

ADEPT-DE, 2004. Alexandria Digital Library Project: Digital Earth. http://www.alexandria.ucsb.edu/research/de/index.htm (accessed 6.9.2004).

ADL, 2004. Alexandria Digital Library Project. http://www.alexandria.ucsb.edu/research/index.htm (accessed 6.9.2004).

Ahonen, P. and Rainio, A., 1988. Developing a query system for joint use of spatial data in Finland. In: J.-C. Müller (Editor), EuroCarto Seven: Environmental Applications of Digital Mapping. ITC, Enschede, The Netherlands, pp. 77-86.

Ahonen-Rainio, P., in press. JHS 137 Data Product Description. In: H. Moellering, H.J.G. Aalders and A. Crane (Editors), World Spatial Metadata Standards. Elsevier.

Akervall, L., Degerstedt, K. and Rystedt, B., 1991. Spatial metadata systems at the National Land Survey of Sweden. In: D. Medyckyj-Scott, Newman I., Ruggles C., Walker D. (Editor), Metadata in Geosciences. Group D Publications, Leicester, pp. 153-170.

Albertoni, R., Bertone, A., De Martino, M., Demšar, U. and Hauska, H., 2003a. Visual and Automatic Data Mining for Exploration of Geographical Metadata, 6th AGILE Conference, Lyon, France, pp. 479-488.

Albertoni, R., Bertone, A., Demšar, U., De Martino, M. and Hauska, H., 2003b. Knowledge Extraction by Visual Data Mining of Metadata in Site Planning, Proc. 9th Scandinavian Research Conference on Geographical Information Sciences, Espoo, pp. 155-166.

Albertz, J., 2001. Einführung in die Fernerkundung: Grundlagen der Interpretation von Luft- und Satellitenbildern, Wissenschaftliche Buchgesellschaft, Darmstadt, 249 pp.

Ancona, D., Freeston, M., Smith, T. and Fabrikant, S., 2002. Visual Explorations for the Alexandria Digital Earth Prototype. In: K. Börner and C. Chen (Editors), Visual Interfaces to Digital Libraries. Lecture Notes in Computer Science Vol. 2539. Springer-Verlag, Heidelberg, pp. 199-213.

Andrienko, G. and Andrienko, N., 2001. Exploring spatial data with dominant attribute map and parallel coordinates. Computers, Environment and Urban Systems, 25: 5-15.

Andrienko, G.L. and Andrienko, N.V., 1999. Interactive maps for visual data exploration. International Journal of Geographical Information Systems, 13(4): 355-374.

Andrienko, N. et al., 2002. Testing the Usability of Interactive Maps in CommonGIS. Cartography and Geographic Information Science, 29(4): 325-342.

ANZLIC, 1995. Core Metadata Elements: Guidelines Draft 7. Australia and New Zealand Land Information Council: Working Group on Metadata, Sydney.

Awad, E.M. and Ghaziri, H.M., 2004. Knowledge Management. Pearson, New Jersey, 480 pp.

Beard, K., 1996. A Structure for Organizing Metadata Collections, 3rd International Conference on Integrating GIS and Environmental Modeling. NCGIA, Santa Fe, NM.
Beard, K. and Sharma, V., 1997. Multidimensional ranking for data in digital spatial libraries. International Journal of Digital Libraries, 1(1): 153-160.
Beard, M.K. and Buttenfield, B.P., 1999. Detecting and evaluating errors by graphical methods. In: P.A. Longely, M.F. Goodchild, D.J. Maguire and D.W. Rhind (Editors), Geographical Information Systems: Principles and technical Issues. John Wiley & Sons, Inc, New York, pp. 219-237.
Beard, M.K. and Sharma, V., 1998. Multilevel and Graphical Views of Metadata, Advances in Digital Libraries Conference. IEEE Computer Society, pp. 256-265.
Bédard, Y., Merrett, T. and Jiawei, H., 2001. Fundamentals of spatial data warehousing for geographic knowledge discovery. In: H.J. Miller and J. Han (Editors), Geographic Data Mining and Knowledge Discovery. Taylor & Francis, pp. 53-73.
Bertin, J., 1967. Sémiologie Graphique. Mouton, Den Haag.
Bertin, J., 1981. Graphics and Graphic Information Processing. Walter de Gruyter & Co, Berlin, 273 pp.
Beyer, H. and Holtzblatt, K., 1998. Contextual design: defining customer-centered system. Morgan Kaufmann, San Francisco, CA, 496 pp.
Bishr, Y., 1998. Overcoming the semantic and other barriers to GIS interoperability. International Journal of Geographic Information Science, 12(4): 299-314.
Blok, C., Köbben, B., Cheng, T. and Kuterema, A.A., 1999. Visualization of Relationships Between Spatial Patterns in Time by Cartographic Animation. Cartography and Geographic Information Science, 26(2): 139-151.
Brandt, S.A. (Editor), 2004. Proceedings of the 12th International Conference on Geoinfirmatics. Geospatial Information Research: Bridging the Pacific and Atlantic. Gävle University Press, Gävle, Sweden, 826 pp.
Brassel, K.E. and Weibel, R., 1988. A review and conceptual model of automated map generalization. International Journal of Geographic Information Science, 2(3): 229-244.
Bucher, B., 2002. L'aide à l'accès à l'information géographique: un environnement de conception coopérative d'utilisations de données géographiques. Doctoral Thesis, L'Universite Paris 6, Paris, 207 pp.
Buja, A., McDonald, J.A., Michalak, J. and Stuetzle, W., 1991. Interactive data visualization using focusing and linking, Proc. Visualization '91, IEEE Conference on Visualization, San Diego, CA, pp. 156-163.
Burrough, P.A. and Frank, A.U., 1995. Concepts and paradigms in spatial information: are current geographical information systems truly generic? International Journal of Geographic Information Science, 9(2): 101-116.
Burrough, P.A. and Frank, A.U., 1996. Geographic Objects with Indeterminate Boundaries. GISDATA. Taylor & Francis, 345 pp.
Buttenfield, B., 1999. Usability Evaluation of Digital Libraries. Science and Technology Libraries, 17(3/4): 39-59.

Buttenfield, B.P., 1985. Treatment of the cartographic line. Cartographica, 22(2): 1-26.
Buttenfield, B.P., 1989. Scale-dependence and self-similarity in cartographic lines. Cartographica, 26(1): 79-100.
Cai, G., 2002. GeoVIBE: A Visual Interface for Geographic Digital Libraries. In: K. Börner and C. Chen (Editors), Visual Interfaces to Digital Libraries. Lecture Notes in Computer Science Vol. 2539. Springer-Verlag, Berlin Heidelberg, pp. 171-187.
Card, S.K., MacKinlay, J.D. and Shneiderman, B., 1999a. Information Visualization. In: S.K. Card, J.D. Mackinlay and B. Shneiderman (Editors), Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann, San Francisco, pp. 1-34.
Card, S.K., Mackinlay, J.D. and Shneiderman, B., 1999b. Readings in Information Visualization: Using Vision to Think. Morgan Kaufmann, San Francisco.
Cartwright, W. et al., 2001. Geospatial Information Visualization User Interfaces Issues. Cartography and Geographic Information Science, 28(1): 45-60.
CEC, 2004. Proposal for a Directive of the European Parliament and of the Council establishing an infrastructure for spatial information in the Community (INSPIRE), Commission of the European Communities, Brussels.
CEN, 1998. ENV 12657 Geographic Information - Data Description - Metadata. Comité Européen de Normalisation, Brussels.
CGSB, 1994. The Canadian Directory Information Describing Digital Geo-referenced Data Sets. Canadian General Standards Board, Ottawa.
Chambers, J.M., Cleveland, W.S., Kleiner, B. and Tukey, P.A., 1983. Graphical Methods for Data Analysis. Wadsworth Press, Belmont (CA).
Chen, C. and Czerwinski, M.P., 2000. Empirical evaluation of information visualizations: an introduction. International Journal of Human-Computer Studies, 53(5): 631-635.
Chen, C. and Yu, Y., 2000. Empirical studies of information visualization: a meta-analysis. International Journal of Human-Computer Studies, 53(5): 851-866.
Chen, H., 2004. Compound brushing explained. Information Visualization, 3(2): 96-108.
Chen, P., 1976. The entity-relationship model: toward a unified view of data. ACM Transactions on Database Systems, 1(1): 9-35.
Chernoff, H., 1973. The use of faces to represent points in k-dimensional space graphically. Journal of the American Statistical Association, 68(342): 361-368.
Cleveland, W.S. and McGill, M.E., 1988. Dynamic graphics for statistics. Wadsworth & Brooks, Pacific Grove, California.
Clinton, W., 1994. Executive Order 12906 of April 11, 1994. Coordinating Geographic data Acquisition and Access: The National Spatial Data Infrastructure. Federal Register, 59(71).
Crampton, J., 2002. Interactivity Types in Geographic Visualization. Cartography and Geographic Information Science, 29(2): 85-98.

Crompvoets, J., Bregt, A., Rajabifard, A. and Williamson, I., 2004. Assessing the worldwide developments of national spatial data clearinghouses. International Journal of Geographic Information Science, 18(7): 665-689.
Danko, D., 1997. Perspectives in the Development of ISO Metadata Standards, Earth Observation (EO)/GEO World Wide Web Workshop 97, Washington DC.
Date, C.J., 1981. An Introduction to Database Systems. Addison-Wesley, Reading, Massachusetts, 574 pp.
Davies, C. and Medyckyj-Scott, D., 1996. GIS users observed. International Journal of Geographical Information Systems, 10(4): 363-384.
De Soete, G., 1986. A perceptual study of the Flury-Riedwyl faces for graphically displaying multivariate data. International Journal of Man-Machine Studies, 25(5): 549-555.
Demšar, U., 2004. Exploring geographical metadata by automatic and visual data mining. Licentiate in Geoinformatics Thesis, Royal Institute of Technology (KTH), Stockholm, 93 pp.
Devogele, T., Parent, C. and Spaccapietra, S., 1998. On spatial database integration. International Journal of Geographic Information Science, 12(4): 335-352.
DiBiase, D., 1990. Visualization in the Earth Sciences. Earth and Mineral Sciences, 59(2): 13-18.
DoE, 1987. Handling of Geographic Information: Report of the Committee of Enquiry chaired by Lord Chorley, Her Majesty's Stationary Office (Department of the Environment), London.
Dorling, D., 1992. Streching Space and Splicing Time: From Cartographic Animation to Interface Visualization. Cartography and Geographic Information Systems, 19(4): 215-227.
Dorling, D., 1994. Cartograms for visualizing human geography. In: H.M. Hearnshaw and D.J. Unwin (Editors), Visualization in geographical Information Systems. John Wiley & Sons, Chichester, pp. 85-102.
Dorling, D., 1995. A New Social Atlas of Britain. John Wiley and Sons, U.K.
Drecki, I., 2002. Visualisation of Uncertainty in Geographical Data. In: W. Shi, P.F. Fisher and M.F. Goodchild (Editors), Spatial Data Quality. Taylor & Francis, London, pp. 140-159.
Dykes, J., 1997. Exploring spatial data representation with dynamic graphics. Computers & Geosciences, 23(4): 345-370.
Dykes, J., in press. Facilitating Interaction for Geovisualization. In: J. Dykes, A.M. MacEachren and M.-J. Kraak (Editors), Exploring Geovisualization. Elsevier.
Dykes, J., MacEachren, A.M. and Kraak, M.-J., in press. Exploring Geovisualization. Elsevier.
Dykes, J.A., 1995. Cartographic Visualization for Spatial Analysis, Proceedings 17th International Cartographic Conference, Barcelona, pp. 1365-1370.
Dykes, J.A., Moore, K.E. and Fairbairn, D., 1999. From Chernoff to Imhof and Beyond: VRML and Cartography, 4th Symposium on Virtual reality modeling language. ACM Press, Paderborn, Germany, pp. 99-104, 179.
Edsall, R.M., 2003. The parallel coordinate plot in action: design and use for geographic visualization. Computional Statistics & Data Analysis, 43: 605-619.

Edsall, R.M., Harrower, M. and Mennis, J.L., 2000. Tools for visualizing properties of spatial and temporal periodicity in geographic data. Computers & Geosciences, 26: 109-118.

Edsall, R.M., MacEachren, A.M. and Pickle, L.J., 2001. Case Study: Design and Assessment of an Enhanced Geographic Information System for Exploration of Multivariate Health Statistics. In: K. Andrews, S. Roth and P.C. Wong (Editors), Proceedings of the IEEE Symposium on Information Visualization, San Diego, pp. 159-162.

Elzakker van, C.P.J.M., 1999. Thinking Aloud about Exploratory Cartography. In: C.P. Keller (Editor), 19th International Cartographic Conference, Ottawa, Canada, pp. 559-569.

Erickson, T., 1995. Notes on Design Practices: Stories and Prototypes as Catalysts for Communication. In: J.M. Carroll (Editor), Scenario-Based Design: Envisioning Work and Technology in System Development. John Wiley & Sons, New York, pp. 37-58.

Eysenck, M.W. and Keane, M.T., 2000. Cognitive Psychology: A Student's Handbook. Psychology Press Ltd, East Sussex, 631 pp.

Fabrikant, S.I., 2000. Spatialized Browsing in Large Data Archives. Transactions in GIS, 4(1): 65-78.

Fabrikant, S.I., 2001. Evaluating the Usability of the Scale Metaphor for Querying Semantic Spaces. In: D.R. Montello (Editor), Spatial Information Theory: Foundations of Geographic Information Science (COSIT'01). Lecture Notes in Computer Science 2205. Springer Verlag, Berlin, pp. 156-171.

Fairbairn, D., Andrienko, G., Andrienko, N., Buziek, G. and Dykes, J., 2001. Representation and its Relationship with Cartographic Visualization. Cartography and Geographic Information Science, 28(1): 13-28.

Fayyad, U., Grinstein, G.G. and Wierse, A., 2002. Information Visualization in Data Mining and Knowledge Discovery. Morgan Kaufmann, San Francisco, 407 pp.

FGDC, 1994. Content Standard for Geospatial Metadata (revised 1998). Federal Geographic Data Committee (FGDC), Washington, DC.

FGDC, 2004. Metadata. http://www.fgdc.gov/metadata/metadata.html (accessed 10.9.2004).

Finke, R.A., Ward, T.B. and Smith, S.M., 1992. Creative cognition: Theory, Research, and Applications. The MIT Press, Cambridge, MA, USA, 205 pp.

Fisher, P. (Editor), 2004. Developments in Spatial Data Handling. 11th International Symposium on Spatial Data Handling. Springer Verlag, 676 pp.

Fisher, P., Dykes, J. and Wood, J., 1993. Map design and visualization. The Cartographic Journal, 30(2): 136-142.

Fisher, P.F., 1994. Animation and sound for the visualization of uncertain spatial information. In: H.M. Hearnshaw and D.J. Unwin (Editors), Visualization in Geographical Information Systems. John Wiley & Sons, Chichester, pp. 181-185.

Flewelling, D.M. and Egenhofer, M.J., 1999. Guest Editorial: Using digital spatial effectively. International Journal of Geographical Information Science, 13(1): 1-8.

Foresman, T.W., Wiggins, H.V. and Porter, D.L., 1996. Metadata Myth: Misunderstanding the Implications of Federal Metadata Standards, First IEEE Metadata Conference, Maryland.
Frank, A.U., 1998. Metamodels for Data Quality Descriptions. In: R. Jeansoulin and M. Goodchild (Editors), Data Quality in Geographic Information: From Error to Uncertainty. Hermès, Paris, pp. 15-29.
Frank, A.U., 2001. Socio-Economic Units: Their Life and Motion. In: A.U. Frank, J. Raper and J.-P. Cheyland (Editors), Life and Motion of Socio-Economic Units. Gisdata 8. Taylor & Francis, London, pp. 21-34.
Frank, A.U. and Mark, D.M., 1991. Language issues for GIS. In: D.J. Maguire, M.F. Goodchild and D.W. Rhind (Editors), Geographical Information Systems: Principles and Applications. Longman, Harlow, pp. 147-163.
Frank, S., 1994. Cataloging Paradigms for Spatial Metadata. Unpublished Ph.D. Thesis, University of Maine. Dept. of Surveying Engineering.
Fuhrmann, S., 2003. Facilitating wayfinding in desktop geovirtual environments - Concept, design, and usability engineering. IfGI prints, Bd. 15, Institut für Geoinformatik, Westfälische Wilhelms-Universität Münster, Münster.
Fuhrmann, S., Ahonen-Rainio, P., Edsall, R.M., Fabrikant, S., Koua, E., Tobón, C., Ware, C., Wilson, S, in press. Making Useful and Useable Geovisualization: Design and Evaluation Issues. In: J. Dykes, A.M. MacEachren and M.J. Kraak (Editors), Exploring Geovisualization. Elsevier.
Fuhrmann, S. and MacEachren, A.M., 2001. Navigation in desktop geovirtual environments: Usability assessment, 20th International Cartographic Conference - Mapping the 21st Century, Beijing, pp. 2444-2453.
Gahegan, M., 1998. Scatterplots and scenes: visualisation techniques for exploratory spatial analysis. Computers, Environment and Urban Systems, 22(1): 43-56.
Gahegan, M., 2001. Visual exploration in geography: Analysis with light. In: H.J. Miller and J. Han (Editors), Geographic Data Mining and Knowledge Discovery. Taylor & Francis, London, pp. 260-287.
Gahegan, M., Wachowicz, M., Harrower, M. and Rhyne, T.-M., 2001. The Integration of Geographic Visualization with Knowledge Discovery in Databases and Geocomputation. Cartography and Geographic Information Science, 28(1): 29-44.
Gale, B.T., 1994. Managing Customer Value: Creating quality and service that customers can see. The Free Press, New York, 424 pp.
Gilmartin, P.P., 1981. The Interface of Cognitive and Psychophysical Research in Cartography. Cartographica, 18(3): 9-20.
Goodchild, M., 1998. The Geolibrary. In: S. Carver (Editor), Innovations in GIS 5. Taylor and Francis, London, pp. 59-68.
Goodchild, M.F., 2001. Models of Scale and Scales of Modelling. In: N.T. Tate and P.M. Atkinson (Editors), Modelling Scale in Geographical Information Science. John Wiley & Sons, pp. 3-10.
Goodchild, M.F. and Zhou, J., 2003. Finding Geographic Information: Collection-Level Metadata. GeoInformatica, 7(2): 95-112.

Gould, M., Laurini, R. and Coulondres, S. (Editors), 2003. Proceedings of the 6th AGILE Conference on Geographic Information Science. Lyon, April 24-26, 2003. Presses Polytechniques et Universitaires Romandes, Lausanne, Switzerland, 787 pp.
Green, D. and Bossomaier, T., 2002. Online GIS and Spatial Metadata. Taylor & Francis, London, 222 pp.
Griffin, A.L., 2003. An empirical study of interactive maps in the context of a geographical simulation model, 21st International Cartographic Conference: Cartographic Renaissance. ICA, Durban South Africa, pp. 358-363.
Griffin, A.L., 2004. Understanding How Scientist Use Data-Display Devices for Interactive Computing with Geographical Models. Doctor of Philosophy Thesis, Pensylvania State University, 284 pp.
Griffin, T.L.C., 1983. Problem Solving on Maps - the Importance of User Strategies. The Cartographic Journal, 20(2): 101-109.
Groot, D. and McLaughlin, J. (Editors), 2000. Geospatial data infrastructure: Concepts, cases, and good practice. Spatial information systems. Oxford University Press, Oxford, 320 pp.
Guptill, S.C., 1999. Metadata and data catalogues. In: P. Longley, M.F. Goodchild, D.J. Maguire and D. Rhind (Editors), Geographical Information Systems, Volume 2, Management Issues and Applications. John Wiley & Sons, Cambridge, pp. 677-692.
Günther, O. and Voisard, A., 1998. Metadata in Geographic and Environmental Data Management. In: A. Sheth and W. Klas (Editors), Managing Multimedia Data: Using Metadata to Intergrate and Apply Digital Data. McGraw Hill, pp. 57-87.
Göbel, S., Haist, J., Reiterer, H. and Müller, F., 2002. INVISIP: Usage of Information Visualization Techniques to Access Geospatial Data Archives, DEXA 2002. Lecture Notes in Computer Science Vol 2453, pp. 371-380.
Göbel, S. and Jasnoch, U., 2001. Visualization techniques in metadata information systems for geospatial data. Advances in Environmental Research, 5(4): 415-424.
Hackos, J.T. and Redish, J.C., 1998. User and task analysis for interface design. John Wiley & Sons, New York, 512 pp.
Hakkarainen, K., Lonka, K. and Lipponen, L., 1999. Tutkiva oppiminen: Älykkään toiminnan rajat ja niiden ylittäminen. WSOY, Helsinki, 295 pp.
Harrower, M., MacEachren, A. and Griffin, A.L., 2000. Developing a geographic visualization tool to support earth science learning. Cartography and Geographic Information Science, 27(4): 279-293.
Haslett, J., Wills, G.J. and Unwin, A.R., 1990. SPIDER: An interactive statistical tool for the analysis of spatially distributed data. International Journal of Geographical Information Systems, 4(3): 285-296.
Hootsmans, R.M., 1996. Fuzzy Sets and Series Analysis for Visual Decision Support in Spatial Data Exploration. Doctor's Thesis, University of Utrecht, Utrecht, 168 pp.

Horttanainen, P. and Virrantaus, K., 2004. Uncertainty Evaluation of Military Terrain Analysis Results by Simulation and Visualization, 12th International Conference on Geoinformatics. University of Gävle, Gävle, Sweden, pp. 473-480.
Inselberg, A., 1985. The Plane with Parallel Coordinates. The Visual Computer, 1: 69-91.
Inselberg, A., 1997. Multidimensional Detective, IEEE Information Visualization '97. IEEE, pp. 100-107.
ISO, 1987. ISO/TR 9007:1987 (E) Information processing systems - Concepts and terminology for the conceptual schema and the information base. International Organization for Standardization.
ISO, 1999. ISO 13407:1999 (E) Human-Centred Design Processes for Interactive Systems. International Organization for Standardization.
ISO, 2002. ISO 19113:2002 (E) Geographic information - Quality elements. International Organization for Standardization, 140 pp.
ISO, 2003. ISO 19115:2003 (E) Geographic information - Metadata. International Organization for Standardization, 140 pp.
João, E.M., 1998. Causes and consequences of map generalisation. Taylor & Francis, London, 266 pp.
Jokela, S., 2001. Metadata Enhanced Content Management in Media Companies. Acta Polytechnica Scandinavica, Ma 114. Finnish Academies of Technology, Helsinki.
Kankainen, A., 2003. UCPCD - User-Centered Product Concept Design, Designing for User Experiences (DUX 2003). ACM, San Francisco, CA.
Keates, J.S., 1982. Understanding Maps. Longman, London, 139 pp.
Keates, J.S., 1984. The cartographic art. Cartographica, 21(1): 37-43.
Keim, D.A., 2001. Visual Exploration of Large Data Sets. Communications of the ACM, 44(8): 39-44.
Keim, D.A., Panse, C. and Sips, M., in press. Information Visualization and its Application to Geography Related Data. In: J. Dykes, A.M. MacEachren and M.-J. Kraak (Editors), Exploring Geovisualization. Elsevier.
Klein, P., Mueller, F., Reiterer, H. and Eibl, M., 2002. Visual information retrieval with the SuperTable+Scatterplot, Sixth International Conference on Information Visualization (IV'02). IEEE Computer Society, pp. 59-66.
Klein, P., Reiterer, H., Müller, F. and Limbach, T., 2003. Metadata Visualisation with VisMeB, Seventh International Conference on Information Visualization (IV '03). IEEE, pp. 600-605.
Koivunen, H., 1995. Kirjasto merkityksen tuottajana tietoyhteiskunnassa. Kirjastopalvelu Oy, Helsinki.
Kosara, R., Healey, C.J., Interrante, V., Laidlaw, D.H. and Ware, C., 2003. User Studies: Why, How, and When? IEEE Computer Graphics and Applications(July/August): 20-25.
Kotler, P., 1997. Marketing Management: Analysis, Planning, Implementation and Control. Prentice Hall International, New Jersey.
Kraak, M.J., 1998. The cartographic visualization process: from presentation to exploration. The Cartographic Journal, 35(1): 11-15.

Kraak, M.J., 1999. Visualising spatial distributions. In: P.A. Longely, M.F. Goodchild, D.J. Maguire and D.W. Rhind (Editors), Geographical Information Systems: Principles and Technical Issues. John Wiley and Sons, Inc, New York, pp. 157-173.

Kraak, M.-J., 1993. Three-dimensional map design. The Cartographic Journal, 30(2): 188-194.

Kraak, M.-J., 2001. Trends in Cartography. In: M.-J. Kraak and A. Brown (Editors), Web Cartography: Developments and Prospects, London, pp. 9-19.

Kraak, M.-J. and Ormeling, F., 2003. Cartography: Visualization of Geospatial Data. Pearson Education, Harlow, 205 pp.

Krek, A., 2002. An agent-based model for quantifying the economic value of geographic information. Doctor of Technical Sciences Thesis, Vienna University of Technology, Vienna, 150 pp.

Krisp, J.M., 2004. Three-dimensional visualization of ecological barriers. Applied Geography, 24: 23-34.

Kuhn, W., 1995. 7+/-2 Questions and Answers about Metaphors for GIS User Interfaces. In: T.L. Nyerges, et al. (Editor), Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems. Series D: Behavioural and Social Sciences. Kluwer Academic Publishers, Dordrecht, pp. 113-122.

Kuhn, W., 2002. Modeling the Semantics of Geographic Categories through Conceptual Integration. In: M.J. Egenhofer and D.M. Mark (Editors), GIScience 2002. Lecture Notes in Computer Sciences 2478. Springer-Verlag, Berlin, pp. 108-118.

Kuhn, W., 2003. Guest Editorial: Semantic reference systems. International Journal of Geographic Information Science, 17(5): 405-409.

Kuutti, K., 1995. Work processes: Scenarios as a preliminary vocabulary. In: J.M. Carroll (Editor), Scenario-based design: Envisioning work and technology in system development. John Wiley & Sons, New York, pp. 19-36.

Larkin, J.H. and Simon, H.A., 1987. Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11: 65-99.

Laurini, R., 2001. Information Systems for Urban Planning. Taylor & Francis, London, 349 pp.

Laurini, R. and Thompson, D., 1992. Fundamentals of Spatial Information Systems. Academic Press, London, 680 pp.

Lillywhite, J., 1991. Identifying available spatial metadata: the problem. In: D. Medyckyj-Scott, Newman I., Ruggles C., Walker D. (Editor), Metadata in Geosciences. Group D Publications, Leicester, pp. 3-11.

Longley, P.A., Goodchild, M.F., Maguire, D.J. and Rhind, D.W., 2001. Geographic Information Systems and Science. John Wiley & Sons, 454 pp.

Loshe, G.L., 1997. Models of Graphical Perception. In: M. Helander, T.K. Landauer and P. Prabhu (Editors), Handbook of Human-Computer Interaction. Elsevier, Amsterdam, pp. 107-135.

Lucieer, A. and Kraak, M.-J., 2004. Interactive and visual fuzzy classification of remotely sensed imagery for exploration of uncertainty. International Journal of Geographical Information Science, 18(5): 491-512.

MacDougall, E.B., 1992. Exploratory Analysis, Dynamic Statistical Visualization, and Geographic Information Systems. Cartography and Geographic Information Systems, 19(4): 237-246.
MacEachren, A.M., 1992. Visualizing Uncertain Information. Cartographic Perspective(13): 10-19.
MacEachren, A.M., 1994. Visualization in Modern Cartography: Setting the Agenda. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier Science Ltd, Oxford, pp. 1-12.
MacEachren, A.M., 1995. How Maps Work: Representation, Visualization, and Design. The Guilford Press, New York, 513 pp.
MacEachren, A.M. and Ganter, J.H., 1990. A pattern identification approach to cartographic visualization. Cartographica, 27(2): 64-81.
MacEachren, A.M. and Kraak, M.-J., 1997. Exploratory Cartographic Visualization: Advancing the Agenda. Computers & Geosciences, 23(4): 335-343.
MacEachren, A.M. and Kraak, M.-J., 2001. Research Challenges in Geovisualization. Cartography and Geographic Information Science, 28(1): 3-12.
MacEachren, A.M. and Monmonier, M., 1992. What's special about Visualization? Cartography and Geographic Information Systems, 19(4): 197-200.
MacEachren, A.M., Wachowicz, M., Edsall, R., Haug, D. and Masters, R., 1999. Constructing knowledge from multivariate spatiotemporal data: integrating geographical visualization with knowledge discovery in database methods. International Journal of Geographical Information Science, 13(4): 311-334.
MADAME, 2000. Comparative Evaluation of On-line Metadata Services and User Feedback, Deliverable D2 of INFO2000 Project: PUB1108-MADAME Methods for Access to Data and Metadata in Europe, 110 pp.
Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley & Sons, New York, 392 pp.
Mark, D.M., Freksa, C., Hirtle, S.C., Lloyd, R. and Tversky, B., 1999a. Cognitive models of geographical space. International Journal of Geographical Information Systems, 13(8): 747-774.
Mark, D.M., Smith, B. and Tversky, B., 1999b. Ontology and Geographic Objects: An Empirical Study of Cognitive Categorization. In: D.M. Mark (Editor), Spatial Information Theory: A Theoretical Basis for GIS. Lecture Notes in Computer Science. Springer-Verlag, Berlin, pp. 283-298.
Mayer, R.E., 1997. From Novice to Expert. In: M.G. Helander, T.K. Landauer and P.V. Prabhu (Editors), Handbook of Human-Computer Interaction. Elsevier, Amsterdam, pp. 781-796.
McCormick, B., DeFanti, T.A. and Brown, M.D., 1987. Visualization in Scientific Computing. Computer Graphics, 21(6): special issue.
McGranaghan, M., 1993. A cartographic view of spatial data quality. Cartographica, 30(2-3): 8-19.
McGuinness, C., 1994. Expert/ Novice Use of Visualization Tools. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier Science Ltd, Oxford, pp. 185-199.

McLaughlin, J., 1991. Towards National Spatial Data Infrastructure, The 1991 Canadian Conference on GIS. Canadian Institute of Geomatics, Ottawa, Canada.
Medyckyj-Scott, D., Cuthbertson, M. and Newman, I., 1996. Discovering Environmental data: metadatabases, network information resource tools and the GENIE system. International Journal of Geographical Information Systems, 10(1): 65-84.
Medyckyj-Scott, D. and Hearnshaw, H.M. (Editors), 1993. Human Factors in Geographical Information Systems. Belhaven Press, London, 266 pp.
Medyckyj-Scott, D., I., N., C., R. and D., W., 1991. Metadata in Geosciences. Group D Publications, Leicestershire, 233 pp.
Moellering, H., Aalders, H.J.G.L. and Crane, A. (Editors), in press. World Spatial Metadata Standards. Elsevier.
Molenaar, M., 1998. An introduction to the theory of spatial object modelling for GIS. Taylor & Francis, London.
Monmonier, M., 1989. Geographic brushing: Enhancing exploratory analysis of the scatterplot matrix. Geographical Analysis, 21(1): 81-84.
Monmonier, M., 1994. Graphic Narratives for Analysing Environmental Risks. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier Science Ltd, Oxford, New York, Tokyo, pp. 201-213.
Morris, C.J., Ebert, D.S. and Rheingans, P., 1999. An experimental analysis of the effectiveness of features in Chernoff faces, Applied Imagery Pattern Recognition `99: 3D Visualization for Data Exploration and Decision Making.
Müller, J.C., 1991. Generalization of spatial databases. In: D.J. Maguire, M.F. Goodchild and D.W. Rhind (Editors), Geographical Information Systems: Principles and Applications. Harlow, Longman/New York, John Wiley & Sons, pp. 457-475.
Nebert, D. (Editor), 2004. Developing Spatial Infrastructures: The SDI Cookbook. GSDI, 171 pp.
Nelson, E.S., Dow, D., Lukinbeal, C. and Farley, R., 1997. Visual Search Processes and the Multivariate Point Symbol. Cartographica, 34(4): 19-33.
Nielsen, J., 1993. Usability engineering. Academic Press, Boston, 362 pp.
Nielsen, J., 1995. Scenarios in Discount Usability Engineering. In: J.M. Carroll (Editor), Scenario-Based Design: Envisioning Work and Technology in System Development. John Wiley & Sons, New York, pp. 59-83.
Nielson, G.M., Hagen, H. and Müller, H., 1997. Scientific Visualization: Overviews, Methodologies, and Techniques. IEEE Computer Society, Washington.
Norman, D.A., 1993. Things that make us smart. Perseus Books, Massachusetts, 290 pp.
Nyerges, T.L., 1993. How do people use Geographical Information Systems? In: D. Medyckyj-Scott and H.M. Hearnshaw (Editors), Human Factors in Geographical Information Systems. Belhaven Press, London, pp. 37-50.

Nyerges, T.L., 1995. Cognitive Issues in the Evolution of GIS User Knowledge. In: T.L. Nyerges, D.M. Mark, R. Laurini and M.J. Egenhofer (Editors), Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems. Kluver academic Publishers, Dordrecht, pp. 61-74.
Nyerges, T.L., Mark, D.M., Laurini, R. and Egenhofer, M.J. (Editors), 1995. Cognitive Aspects of Human-Computer Interaction for Geographic Information Systems. NATO Advanced Science Institutes Series D: Behavioral and Social Sciences. Kluwer Academic Publishers, Dordrecht, 448 pp.
OED, 2001. Oxford English Dictionary Online. www.oed.com (accessed 10.9.2004).
Painho, M., 1995. The effect of generalization on attribute accuracy in natural resource maps. In: J.C. Müller, J.P. Lagrange and R. Weibel (Editors), GIS and Generalization - Methodology and Practice. Taylor & Francis, London, pp. 194-206.
Peuquet, D., 1984. A conceptual framework and comparison of spatial data models. Cartographica, 21(4): 66-113.
Peuquet, D.J. and Kraak, M.J., 2002. Geobrowsing: creative thinking and knowledge discovery using geographic visualization. Information Visualization(1): 80-91.
Pinker, S., 1997. How the mind works. W. W. Norton & Company, Inc, New York, 565 pp.
Podolak, I. and Demšar, U., 2004. Discovering Structure in Geographical Metadata, 12th International Conference on Geoinformatics, Gävle, Sweden, pp. 805-811.
Rhyne, T.-M., 2003. Does the Difference between Information and Scientific Visualization Really Matter? IEEE Computer Graphics and Applications, 23(3): 6-8.
Roberts, J.C., 1998. On Encouraging Multiple Views for Visualization, IEEE Conference on Information Visualization 1998 (London, UK). IEEE Computer Science Press, Washington, pp. 8-14.
Robinson, A.H., Morrison, J.L., Muehrcke, P.C., Kimerling, A.J. and Guptill, S.C., 1995. Elements of Cartography. John Wiley & Sons, New York, 674 pp.
Robinson, A.H. and Petchenik, B.B., 1976. The Nature of Maps: Essays toward Understanding Maps and Mapping. The University of Chicago Press, Chicago, 138 pp.
Rodriquez, M.A. and Egenhofer, M.J., 2003. Determining Semantic Similarity among Entity Classes from Different Ontologies. IEEE Transactions on Knowledge and Data Engineering, 15(2): 442-456.
Rosario, G.E., Rudensteiner, E.A., Brown, D.C., Ward, M.O. and Huang, S., 2004. Mapping nominal values to numbers for effective visualization. Information Visualization, 3(2): 80-95.
Roth, S.F., Chuah, M.C., Kerpedjiev, S., Kolojejchick, J.A. and Lucas, P., 1997. Toward an Information Visualization Workspace: Combining Multiple Means of Expression. Human-Computer Interaction, 12: 131-185.
Rumbaugh, J., Jacobson, I. and Booch, G., 1999. The Unified Modeling Language Reference Manual. Addison-Wesley, 576 pp.

Salgé, F., Ahonen, P. and Smith, N., 1992a. Megrin Business Plan. Supporting Document I: Development of the Geographical Data Description Directory, CERCO PTG, Paris.
Salgé, F., Smith, N. and Ahonen, P., 1992b. Towards harmonized geographical data for Europe: MEGRIN and the needs for research. In: P. Bresnahan, E. Corwin and D. Cowen (Editors), The 5th International Symposium on Spatial Data Handling. IGU Commission of GIS, Charleston, SC, pp. 294-302.
Salo-Merta, L., 1999. Object-Oriented Modeling Approach on Geo-Databases and Cartographic Products, The 19th International Cartographic Conference, Ottawa, Canada, pp. 1423-1431.
Shneiderman, B., 1998. Designing the User Interface: Strategies for Effective Human-Computer Interaction. Addison-Wesley, Reading, Massachusetts, 639 pp.
Simon, H.A., 1960. The New Science of Management Decision. Harper, New York, 50 pp.
Slocum, T.A. et al., 2001. Cognitive and Usability Issues in Geovisualization. Cartography and Geographic Information Science, 28(1): 61-75.
Slocum, T.A., Cliburn, D.C., Feddema, J.J. and Miller, J.R., 2003. Evaluating the Usability of a Tool for Visualizing the Uncertainty of the Future Global Water Balance. Cartography and Geographic Information Science, 30(4): 299-317.
Slocum, T.A., Yoder, S.C., Kessler, F.C. and Sluter, R.S., 2000. MapTime: Software for Exploring Spatiotemporal Data Associated with Point Locations. Cartographica, 37(1): 15-31.
Smith, T., 1996. A Digital Library for Geographically Referenced Materials. IEEE Computer, 29(5): 54-60.
Spence, R., 2001. Information Visualization. Addison Wesley / ACM Press, Harlow, 206 pp.
Tang, D., Stolte, C. and Bosch, R., 2004. Design choices when architecting visualizations. Information Visualization, 3(2): 65-79.
Tate, N.T. and Atkinson, P.M., 2001. Modelling Scale in Geographical Information Science. John Wiley & Sons, Chichester, 277 pp.
Taylor, D.R.F., 1994. Perspectives on Visualization and Modern Cartography. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier Science Ltd, Oxford, pp. 333-341.
Taylor, M., 2004. Metadata: Describing geospatial data. In: D. Nebert (Editor), Developing Spatial Infrastructures: The SDI Cookbook. GSDI, pp. 24-38.
Timpf, S., Raubal, M. and Kuhn, W., 1996. Experiences with Metadata, 7th International Symposium on Spatial Data Handling, SDH'96, Delft, The Netherlands, pp. 12B.31-43.
Tobón, C., 2002. Usability testing for improving interactive geovisualization techniques. CASA Paper 45, Centre for Advanced Spatial Analysis, University College London, London, 25 pp.
Tomlin, D., 1990. Geographic Information Systems and Cartographic Modelling. Prentice-Hall, 249 pp.

Tufte, E.R., 1983. The Visual Display of Quantitative Information. Graphics Press, Cheshire, Connecticut, 197 pp.
Tukey, J.W., 1977. Exploratory Data Analysis. Addison-Wesley, Massachusetts.
Ulrich, K.T. and Eppinger, S.D., 2003. Product Design and Development. McGraw-Hill, Boston, 464 pp.
Wachowicz, M., 2001. GeoInsight: An approach for developing a knowledge construction process based on the integration of GVis and KDD methods. In: H.J. Miller and J. Han (Editors), Geographic Data Mining and Knowledge Discovery. Taylor & Francis, London, pp. 239-259.
Vahala, M., 1986. Data standardization of the integrated LIS in Finland. In: M. Blakemore (Editor), Auto Carto London: Hardware, Data Capture and Management Techniques, London, pp. 323-332.
Walford, N., 2002. Geographical Data: Characteristics and Sources. John Wiley & Sons, Chichester, 274 pp.
Ward, M.O., 2002. A taxonomy of glyph placement strategies for multidimensional data visualization. Information Visualization, 1(3-4): 194-210.
Ware, C., 2000. Information Visualization : Perception for Design. Morgan Kaufmann Publishers, San Francisco, 438 pp.
Wel van der, F.J.M., Hootsmans, R.M. and Ormeling, F., 1994. Visualization of Data Quality. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier Science Ltd, Oxford, pp. 313-331.
Widom, J., 1995. Research Problems in Data Warehousing, 4th International Conference on Information and Knowledge Management.
Williamson, I., Rajabifard, A. and Feeney, M.E., 2003. Developing Spatial Data Infrastructures: From concept to reality. Taylor & Francis, London and New York, 316 pp.
Virrantaus, K., 2001. From GIS to Geographic Information Science in University Education, International Conference on Spatial Information for Sustainable Development. FIG, Institution of Surveyors Kenya and UN-HABITAT, Nairobi, Kenya, pp. PS3.2:1-11.
Wise, J.A. et al., 1995. Visualizing the Non-Visual: Spatial analysis and interaction with information from text documents, IEEE 1995 Symposium on Information Visualization. IEEE, Atlanta, Georgia, pp. 51-58.
Wood, D., 1992. The Power of Maps. The Guillford Press, New York, 248 pp.
Wood, M., 1993. The map-users' response to map design. The Cartographic Journal, 30(2): 149-153.
Wood, M., 1994a. The traditional map as a visualization technique. In: H.M. Hearnshaw and D.J. Unwin (Editors), Visualization in Geographical Information Systems. John Wiley & Sons, Chichester, pp. 9-17.
Wood, M., 1994b. Visualization in Historical Context. In: A.M. MacEachren and D.R.F. Taylor (Editors), Visualization in modern cartography. Elsevier, Oxford, pp. 13-26.
Worboys, M.F., 1995. GIS: A Computing Perspective. Taylor & Francis, London, 376 pp.

Annex 1 Example of textual metadata

In the prototype test, metadata was available for each dataset with the content and in the form of the example below.

Dataset: **Road data B**

Topic category	transportation (018)
Responsible organisation	Data producer II
Abstract	The dataset includes all drivable roads in both rural and urban areas. The aim has been good shape and positional accuracy, so that the data are compatible with positioning systems, for example, GPS devices. The dataset has been produced especially from the starting point of logistics, and therefore, special attention has been put on topological consistency. The road geometries for urban and rural areas have been integrated, which enables specification of different speeds for different road classes in the optimisation and navigation systems of transportation. On the other hand, the aim has been a dataset that is content-wise complete and can be continuously updated. The dataset includes the centre line geometry of the road network as well as address information by street names and numbers. Thus addresses can be located on the map directly by the address information of the dataset. In addition, one-way information and turning restrictions can be ordered separately for the Helsinki metropolitan area, Tampere, and Turku.
Spatial resolution: Equivalent scale	1:20 000 - 1:200 000
Presentation form	digital model (007)
Spatial representation	vector (001)
Topology level	Topology 1D: chain-node (002)
Geometric objects	composite (002), curve (003)

Reference system		KKJ/YKJ (Finnish national grid/uniform coordinates)
Data content: Features and classifications		**Road segment:** road name in Finnish road name in Swedish first house number on the left side last house number on the left side first house number on the right side last house number on the right side road class* * Classes: Motorway Other double carriageway Motor-traffic way … Walkway Market place or square Road under construction Connection over water Ferry route Tunnel, public roads Tunnel, main roads in urban areas Tunnel, streets **Turning restrictions:** ID of the segment, from which turning is forbidden ID of the segment, to which turning is forbidden At which end of segment the turning restriction is valid (for the segment, from which turning is forbidden)
Geographic extent		Finland
Temporal extent	Scope	Road geometry and address data
	Date	2004
Temporal extent	Scope	Turning restrictions
	Date	Metropolitan area 1996, Tampere 1998, Turku 2001
Maintenance frequency		continual (001)
Status		continually updated (004)

Data quality: Lineage		On the rural areas, the road centre lines have been digitised from the maps of Road data D in 1:200 000 scale. On the urban areas, the road centre lines have been digitised from the maps of the local authorities in 1:4000 - 1: 20 000 scales. After digitising, the data have been transformed according to field-measured control points in order to gain sufficient positional accuracy.
Data quality: Completeness Commission	Scope	Geometry
	Measure	The amount of road kilometres
	Evaluation method	unknown
	Result	355 000 km
Data quality: Completeness Commission	Scope	Address data
	Measure	Proportion of road segments in Finland (the goal is 70%, as some private roads do not have any address)
	Evaluation method	unknown
	Result	65 %
Data quality: Correctness of classification		unknown
Data quality: Positional accuracy	Scope	Urban areas
	Measure	unknown
	Evaluation method	unknown
	Result	5-10 metres
Data quality: Completeness	Scope	Rural areas
	Measure	unknown

	Evaluation method	unknown
	Result	50-100 metres
Data quality: Consistency	Logical	unknown
	Topological	unknown
	Format	unknown
Use restrictions		copyright (001); intellectual property rights (006)
Distribution	Format and version	MapInfo .tab; turning restrictions file in MIF
	Units of distribution	All roads with addresses; Main roads with addresses; All roads without addresses; Main roads without addresses; Turning restrictions data have to be ordered separately.
	Transfer size	unknown
	Media/ on-line	cdRom
Distribution: Fees		unknown
Metadata maintenance:	Author	Paula Ahonen-Rainio, paula.ahonen@hut.fi
	Date	26.5.2004
	Date of next update	No updating
	Standard	ISO 19115:2003