TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Environmental Sciences Institute for Cartography

Master Thesis

The effectiveness of uncertainty visualization in a "Coordinated Multiple View" environment using a temporal dataset (casestudy)

submitted by Lisa Clemens

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TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Umweltwissenschaften: Institut für Kartographie

Master Thesis Task Description

Course of Study: Master of Science in Cartography

Candidate Name: Lisa Clemens

Topic: The effectiveness of uncertainty visualization in a "Coordinated Multiple View" environment using a temporal dataset (casestudy)

Zur Effektivität der Visualisierung von Unsicherheiten in „Verknüpften Mehrfensterdarstellungen" unter Verwendung eines temporalen Datensatzes (Fallstudie)

Objectives:

Today we witness in increased availability of spatio-temporal data being displayed in multiple linked views. In these views different (carto)graphic representations in multiple appearances are used.

We are aware how effective individual representation are, and it is assumed this multiple view approach works. However, it is unknown how different designs of the representations support each other in answering specific temporal questions. In addition it is also unknown how data uncertainty in the temporal data (especially accuracy and completeness) might influence the user in answering temporal questions.

Based on a historical data set temporal questions will be formulated to be used in an interactive test environment to evaluate interaction between selective (carto)graphic representations. In the design of the representation indicators to inform about temporal accuracy and completeness will be incorporated to see if it is possible to make the users aware of the uncertainty during their exploration.

There should be submitted two printed versions together with the digital version on CD. The digital version should include the text description and all required data and software to run the prototype. It is encouraged to publish the thesis on the publication server Qucosa of SLUB. The major findings will also be presented in the form of an A2 colour poster.

Supervisor: Prof. Menno-Jan Kraak
Prof. Dirk Burghardt

Delivering date: 15.05.2014
Deadline: 15.10.2014

Statement of Authorship

Herewith I declare that I am the sole author of the thesis named

The effectiveness of uncertainty visualization in a "Coordinated Multiple View" environment using a temporal dataset (casestudy)

which has been submitted to the study commission of geosciences today.

I have fully referenced the ideas and work of others, whether published or unpublished. Literal or analogous citations are clearly marked as such.

Dresden, 02.12.2014 ……………………………………………….

Lisa Clemens

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Abstract

Data are produced constantly and everywhere around the world. In order to explore these huge amounts of data, it is necessary to analyse it interactively from different viewpoints. Coordinated Multiple Views (CMV) are the perfect exploration environment for such tasks. Another aspect that needs to be considered about data is the data quality. The data used by cartographers is often erroneous, imprecse or incomplete and is therefore called uncertain data.

The goal of this thesis is to explore methods of uncertainty visualization in CMVs and to analyse them in context of effectiveness, efficiency and user satisfaction. Therefore, two different versions have been implemented that 1) integrate uncertainty into the data views, and 2) implement an extra uncertainty view. As a case study, the dataset of the Berezina river crossing during Napoleon's campaign in Russia was chosen. After implementing the two versions with the help of the JavaScript library D3.js, a usability study was conducted. A think-aloud protocol in combination with screen logging and video recording was done.

The results of the empirical study show that implementing an additional uncertainty view led to faster and more correct results. Both versions satisfied the test users while working with them. In addition, the frequency of user interaction with the single parts of the interface has been analysed based on the screen logging data. The resulting graphics show clearly that the test users of the second group (see 2)) only concentrated on the attribute and uncertainty views. Whereas the test users of the first group (see 1)) have been interacting with all views a lot. Combining all these results, leads to the conclusion that the users of the first group have been confused with the interface and worked therefore slower and less correct. Based on the results of the usability study, the second version can be recommended as working with it was faster, more correct and less confusing. But nevertheless, the empircial study showed that it may be disadvantageous for this version if the user does not understand the uncertainty view.

Kurzfassung

Daten werden überall und zu jeder Zeit produziert. Es ist nötig diese großen Datenmengen interaktiv von verschiedenen Gesichtspunkten zu betrachten, um sie zu untersuchen. Verknüpfte Mehrfensterdarstellungen sind eine perfekte Untersuchungsumgebung für solche Aufgaben. Des Ein anderer Aspekt der im Umgang mit Daten beachtet wird muss, ist die Datenqualität. Die Daten, die Kartographen benutzen, sind oftmals fehlerhaft, unpräzise oder unvollständig und werden deshalb als unsichere Daten bezeichnet.

Das Ziel dieser Arbeit ist es die Methoden der Unsicherheitenvisualisierung in verknüpften Mehrfensterdarstellungen zu untersuchen und diese hinsichtlich ihrer Effektivität, Effizienz und Nutzerzufriedenheit zu analysieren. Dafür wurden zwei verschiedene Versionen implementiert, welche 1) die unsicheren Daten in die Datenansichten integriert und 2) eine zusätzliche Unsicherheitenansicht einführt. Als Fallstudie wurde der Datensatz der Beresina-Überquerung während Napoleons Russlandfeldzug genutzt. Nach der Implementierung der zwei Versionen mithilfe der JavaScript Bibliothek D3.js wurde eine Nutzerstudie durchgeführt. Dafür wurde ein „Lautes-Denken“ Test in Kombination mit Screen logging und Videoaufnahmen genutzt.

Die Ergebnisse der empirischen Untersuchung zeigen, dass die Benutzung einer zusätzlichen Unsicherheitenansicht zu schnelleren und korrekteren Ergebnissen führte. Beide Versionen stellten den Nutzer während der Arbeit damit zufrieden. Außerdem wurde die Häufigkeit der Nutzerinteraktion im Interface mithilfe der Screen logging Daten analysiert. Die daraus resultierenden Graphiken zeigen, dass die Nutzer der zweiten Gruppe (s. 2)) sich während der Interaktion hauptsächlich auf die Attribut- und Unsicherheitenansicht konzentriert haben. Im Gegensatz dazu haben die Nutzer der ersten Gruppe (s. 1)) viel mehr mit allen Elementen interagiert. Die Kombination dieser Ergebnisse führt zu der Schlussfolgerung, dass die Nutzer der ersten Gruppe während der Arbeit mit dem Interface verwirrt waren und deswegen langsamer und weniger korrekt arbeiteten. Auf Grundlage dieser Ergebnisse kann die zweite Version empfohlen werden, da die Arbeit damit schneller, korrekter und weniger verwirrend war. Trotzdem zeigte die empirische Untersuchung, dass es nachteilig für diese Version sein kann, wenn der Nutzer die Unsicherheitenansicht nicht versteht.

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List of Figures

All non-credited figures are by the author.

List of Abbreviations

CHeval	Chur Evaluation Laboratory
CMV	Coordinated Multiple View(s)
CSS	Cascading Style Sheet(s)
CSV	Comma-Separated Values
D3.js	Data-Driven Documents (JavaScript library)
HTML	HyperText Markup Language
JSON	JavaScript Object Notation
STC	Space Time Cube
TUD	Technische Universität Dresden (Dresden University of Technology)

1 Introduction

Many different visualization techniques exist to display complex data. Each technique gives the user a different view of the data which is helpful to gain a deeper understanding of those data. As the data today are not only available in large amounts but rather also complex, the user needs to select, manipulate and compare the data in order to understand the underlying information. A good exploration environment for such tasks is the Coordinated Multiple View (CMV) environment (Roberts, J. C., 2007).

1.1 Motivation and problem statement

Geodata are used and produced constantly and everywhere around the world. There are 1627795 members contributing to the OpenStreetMap project (14.05.2014). About 3000 of them take part actively every day (OSMstats, 2014). According to the GlobalWebIndex, Google Maps is the most popular app. 54% of smartphone users access it regularly on their smartphone (GlobalWebIndex, 2013). Users are guided by the Google Maps Navigation function about 12 billion miles every year (Royal Pingdom, 2012). DigitalGlobe[1] is one of the leading companies that produces satellite images, aerial photographs and other geospatial content. The DigitalGlobe constellation collects about 3 million km² of imagery every day. In total they produce over 700 million km² of high-resolution images per year (European Space Imaging, 2012). When exploring these huge amounts of complex data, it is not sufficient only to analyse the data from one viewpoint. It is necessary to adopt different perspectives and angles. Otherwise, it will not be possible to explore and analyse the data correctly or to gain a deeper understanding of the information. Geographic visualizations allow the user to display large amounts of data and to explore and analyse them interactively. CMVs are the perfect exploration environment for these tasks as they provide the user not only with different perspectives of the data, but also with highly interactive techniques to examine and analyse the information. For example, CMV could be useful for analysing climate change or historical archives.

In the field of information visualization[2] many different visualization forms exist to display geographical information, e.g. Maps, cartograms, networks, charts, graphs, tables, symbols, diagrams and pictures. Each of these forms provides the users a different view of the

[1] https://www.digitalglobe.com/

[2] for more information relating information visualization see InfoVis.net (2002)

information which gives them a deeper understanding and may avoid misapprehension. CMVs combine those different forms in one screen in order to give the user the possibility to analyse diverse data of different qualities, scales, times or types through different perspectives. These views are linked together and automatically adopt the coordinated views when a manipulation is conducted. In fact, CMVs allow the user to communicate with the data: the user selects data to display, manipulates and compares them and then draws conclusions. This highly interactive system is based on the principle, that "insight is formed through interaction" (Roberts, J. C., 2008). Interaction techniques include filtering to reduce the quantity of the information, adaption of mapping parameters to highlight selected elements and navigation to focus on a specific part of the information.

Another aspect that needs to be considered about data is the data quality. The data, used by cartographers, is often erroneous, imprecise or incomplete. This may originate from inaccurate measurement or loss of information during the interpolation or rendering process (Pang, A. et al, 1996). Such inaccurate data are called uncertain data. Uncertainty describes "the difference between a real geographic phenomenon and the user's understanding of the geographic phenomenon" (Longley, P. A. et al. 2005). The main quality criteria that need to be considered concerning data quality are accuracy and precision (MacEachren, A.M., 1992). Whereas accuracy describes the closeness between a measured value and the true value, precision is defined as the closeness between independent measurements under the same conditions (International Standard, 1994). MacEachren (1992) further classifies uncertainty in locational, temporal and attribute accuracy and precision, as it may occur in each of the information spaces (location, time, attribute space). Cartographers have to consider uncertainty very wisely as it may lead to wrong decisions. Many research reports that deal with uncertainty visualization have been published in the last years. Reseach in the field of uncertainty visualization has led to a lot of different visualization techniques. But uncertainty may not only originate from the data quality. Data quantity may pose a problem as well, as it causes overlapping and unclarity. To avoid this, clustering techniques are needed in order to guarantee a better readability. But each data clustering process leads to uncertain knowledge about the individual phenomena.

The development of computer-based cartography and the invention of the Internet and webmapping technologies gave designers numerous possibilities to develop interactive visualizations. Many visualization techniques and interaction strategies have been introduced. When designing a CMV environment, the developer can choose from that wide variety of geovisualization forms and interaction methods. A lot of different datasets are available as well.

Much work has been done in the field of CMV, but, nevertheless, there are still open questions concerning temporal uncertainty visualization, the suitability of the existing techniques and the visualizaion of uncertainty in the CMV environment. This research will focus on the latter. There is a lot of literature available on all aspects of CMV. Many research projects cover the field of uncertainty visualization. But there is no appropriate work on how uncertainty can be expressed effectively in a CMV. Based on this, this research is motivated to evaluate the effectiveness of uncertainty visualization in CMVs. It aims at comparing two methods of uncertainty visualization: the first displays uncertainty in a special uncertainty view. In the second method, the uncertainty will be visualized in each of the data views. This goal of this research is to find out which method is more suitable to represent uncertainty in CMVs.

1.2 Research objective

The main objective of this research is to develop methods to effectively, efficiently and satisfying visualize uncertainty in the Coordinated Multiple View environment. The main objective can be split into three sub-objectives as follows:

A. To explore the methods of uncertainty visualization in the Coordinated Multiple View environment.
B. To analyse the suitability of the discussed methods to visualize uncertainty in the Coordinated Multiple View environment.
C. To verify the suggested methods to visualize uncertainty in the Coordinated Multiple View environment.

1.3 Research questions

- What kinds of graphic representations are currently used to visualize uncertainty?
- Which techniques will be used for evaluating the usability?
- What are the spatial and temporal characteristics of the case study dataset(s)?
- How can the visualization techniques be implemented in a CMV environment?
- How can these ideas be implemented in:
    - all data views?
    - a special uncertainty view?
- How can the effectiveness, efficiency and user satisfaction of the developed visualization methods be tested?

- How to setup the usability evaluation?
- How effective, efficient and satisfying are the methods used to visualize uncertainty in a CMV environment?
- Which representation technique can be recommended based on the usability tests?

1.4 Methodological approach

The methodological approach of the thesis can be structured into four phases. Each of these phases is descibed briefly below (Figure 1.1).

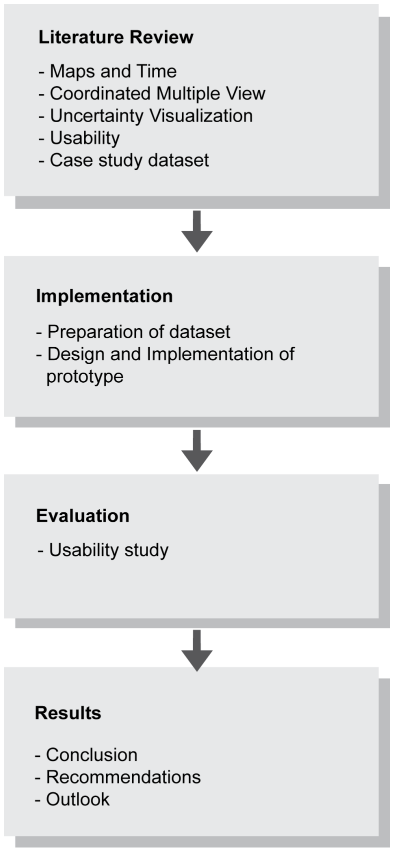

Figure 1.1: Research phases

1.4.1 Literature review

The main goals of this phase are to read relevant literature, identify the research objective and to define the research questions. This includes not only reading but also analysing appropriate literature in order to provide an overview and to explain the required background knowledge concerning the topics CMV, maps and time, uncertainty visualization and usability studies. Furthermore, the literature review is supposed to answer the first research question (*"What* *kinds of graphic representations are currently used to visualize uncertainty?"*) and discusses which technique would be suitable for this research. Another part of the literature review introduces several methods to evaluate the usability and aims at answering the second research question (*"Which techniques will be used for evaluating the usability?"*). The characteristics of the case study dataset are also analysed. In this context, the third research question (*"What are the spatial and temporal characteristics of the case study dataset(s)?"*) is answered.

1.4.2 Implementation

The dataset of the Napoleon's Campaign in Russia 1812 is used as a case study. Before the implementation phase starts, the dataset needs to be prepared. After analysing the possibilities of uncertainty visualization, this part deals with uncertainty visualization in a CMV. In this way, the fourth research question is answered (*"How can the visualization techniques be implemented in a CMV environment?"*). Two alternative representations are designed and implemented in order to answer the fifth research question (*"How can these ideas be implemented in (a) all data views, and (b) a special uncertainty view?"*). The first representation integrates the uncertainty in every data view. Tthe prototypes are implemented using the JavaScript library D3.js. The second method displays uncertainty in a special uncertainty view. An extra view is set up to visualize the uncertainty.

1.4.3 Evaluation

The created prototypes from the implementation phase are evaluated in this step of the workflow. In the literature review phase, different usability study methods to analyse the effectiveness, efficiency and user satisfaction of the developed prototype were examined. An appropriate method has been selected and the process of the usability study is here discussed to answer the sixth research question (*"How can the effectiveness, efficiency and user satisfaction of the developed visualization methods be tested?"*). Before the usability test is done, some preliminary considerations need to be made. In the course of this, the seventh research question (*"How to setup the usability evaluation?"*) is answered. Afterwards, a usability test is conducted in order to analyse which of the two visualization methods is more effective, efficient and satisfying.

1.4.4 Results

Results and conclusions are drawn from the data collected during the evaluation phase. The results show the usability of each of the two implemented methods and the eighth research question is answered (*"How effective, efficient and satisfying are the methods used to visualize uncertainty in a CMV environment?"*). Conclusions are drawn and recommendations are formulated in order to show which method is more effective, efficient and satisfying in visualizing uncertainty in a CMV. This also deals with the last research question (*"Which representation technique can be recommended based on the usability tests?"*). Finally, open questions are mentioned and further research suggestions are given.

1.5 Thesis structure

This thesis consists of six chapters. In the first chapter, an introduction to the background of the problem, the research objective and questions is given. It also discusses the conceptual framework of the thesis. The second chapter provides the background information and methods related to this research. The main approach to this chapter is the literature study, which discusses relevant literature on the topics of Maps and Time, CMV, Uncertainty and Usability. In the third chapter, the data for the case study are explained and relevant historical background knowledge is given. The fourth chapter describes the adopted methodology and implementation of the practical part. This part describes the implementation process in detail. The fifth chapter describes the process of the empirical study and evaluates the results of the usability research. The last chapter provides the conclusion and the final discussion. Furthermore, open questions are pointed out.

2 Literature review

This literature review discusses the basics that need to be considered when analysing the effectiveness, efficiency and user satisfaction of uncertainty visualization in a CMV. The following chapter provides background information on maps and time in general, explains the principles of CMVs, discusses uncertainty visualization and explores usability study techniques. It also examines which uncertainty visualization method and which usability evaluation technique are most suitable for this research.

2.1 Maps and time

When talking about spatial data, three components need to be considered: Location, attribute and time. Especially the latter, time, has been always an object of interest. People have been thinking about time for ages, and have been trying to understand temporal relations. They seek to understand the past, present and future. Even in today's everyday life, time is a really important aspect. People are interested in answering spatio-temporal questions such as "How long does it take me to go from A to B?", "What is the fastest way to go from A to B?" or "Where can I go from here within a specific given time?". Maps showing temporal content are not only interesting to look at, they are also important for prediction and planning. The following chapter discusses maps in relation to time and provides an overview concerning categorizations of existing visualization techniques for representing time.

2.1.1 Definition

Maps are an abstraction of reality. This statement, however, does not refer to the temporal component. When talking about maps and time, the temporal component needs to be considered as well. Kraak and MacEachren (1994) define temporal maps as follows: "A representation or abstraction of changes in geographical reality: a tool (that is visual, digital or tactile) for presenting geographical information whose locational and/or attribute components change over time". This definition addresses the specific criteria that also need to be considered for temporal maps.

When analysing visualizations of time and classifications of these, some basic preliminary considerations need to be done. They can be summarized into three topics: Time, data and representation (Aigner, W., et al., 2007) . An important aspect when talking about *time* is that of the temporal primitives. One needs to consider whether the time to be visualized is given as time points (instants in time) or time intervals (temporal primitive with an extent). Another important element is the structure of time (Figure 2.1). Time can be linear (ordered collection of temporal primitives), cyclic (finite set or recurring temporal primitives) or branching (time splits into two future time streams). There are facts to consider about the *data* as well. First, one needs to pay attention to the frame of reference, which can be abstract (non-spatial context) or spatial. Secondly, the number of variables is of interest, since the data can be univariate (temporal primitives with a single data value) or multivariate (temporal primitives with multiple data values). Thirdly, another point that needs to be considered is the level of abstraction of the data. For the *representation*, the visualizations can be distinguished based on their time dependency. The representation can be static (still images) or dynamic (the representation changes over time). In addition, the dimensionality is of interest, as the representation can be 2- or 3-dimensional.

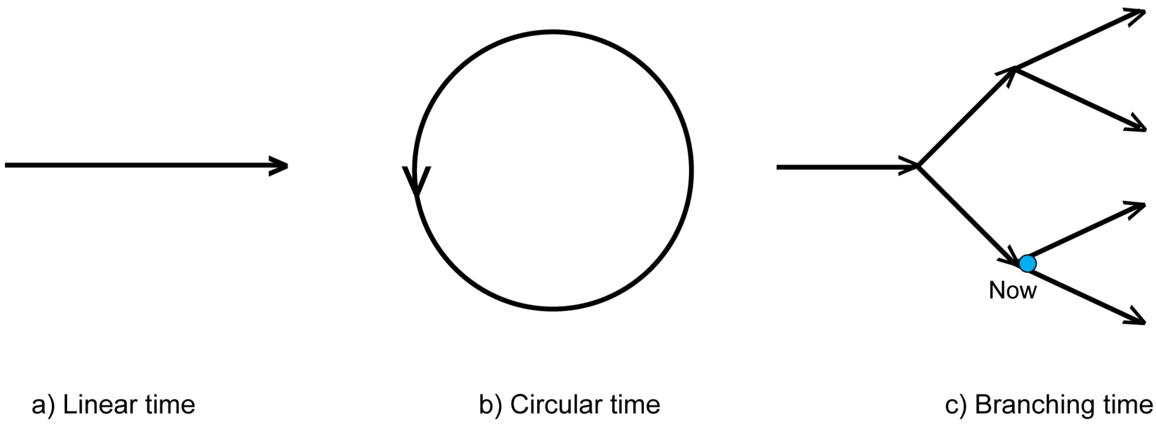

Figure 2.1: Structure of time (a) linear, b) circular, c) branching)

2.1.2 Visualization of time

There are several categorizations of temporal visualizations available. Most of these classifications are based on the distinction of static vs. dynamic representations and the application of single vs. multiple windows, such as the categorization of Monmonier (1990). There are several similar classifications of other researchers available, e.g. the categorization by Kraak and Ormeling (2010). The following part explains the categorization of Monmonier and points out the differences to that of Kraak and Ormeling.

The classification of Monmonier (1990) distinguishes between single static maps, multiple static maps, single dynamic maps and multiple dynamic maps. *Single static maps* use graphic variables and symbols to display events. Graphic variables have been introduced by Jacques Bertin (2010) and were originally size, value, texture, color (hue), orientation and shape, they have since been modified by several authors (e.g. Morrison 1974, MacEachren 1995) through the integration of the variables location, arrangement, color saturation, focus and clarity. The single static maps technique is a very simple solution and can only represent simple temporal and non-continous data. Therefore, it is not suitable for the representation of complex changes. *Multiple static maps* show a temporal sequence of a spatial phenomenom. These snapshots show the same spatial extent at different time points. This method makes it easy to compare two time points, but becomes difficult when more than two or three images need to be compared. The methods of single and multiple static maps are mainly based on the utilization of graphic variables. The following methods use graphic and dynamic visualization variables. The dynamic visualization variables introduced by DiBiase et al. (1992) and MacEachren (1994) are moment of display (display rate), order (structured sequence), duration (length of change/state), frequency (number of identical states/changes), rate of change (magnitude of change) and synchronization (several temporal animations running simultaneously). *Single dynamic maps* include the technique of animations. They show several frames that display a temporal sequence of views which represent change over time. This technique makes it easy for the user to discover changes. Another dynamic technique is *multiple dynamic maps*. This strategy shows "sequences of multiple views or allows the viewer to interact with maps and statistical diagrams representing different instants or periods of time" (Monmonier, 1990).

Kraak and Ormeling (2010) distinguish only between three cartographic depiction modes. *Single static maps* represent time by the use of graphic variables and symbols. *Series of static maps* (multiple maps) show a sequence of time points and *animations* display multiple frames one after the other. The technique of multiple dynamic maps is not considered in this classification (Figure 2.2).

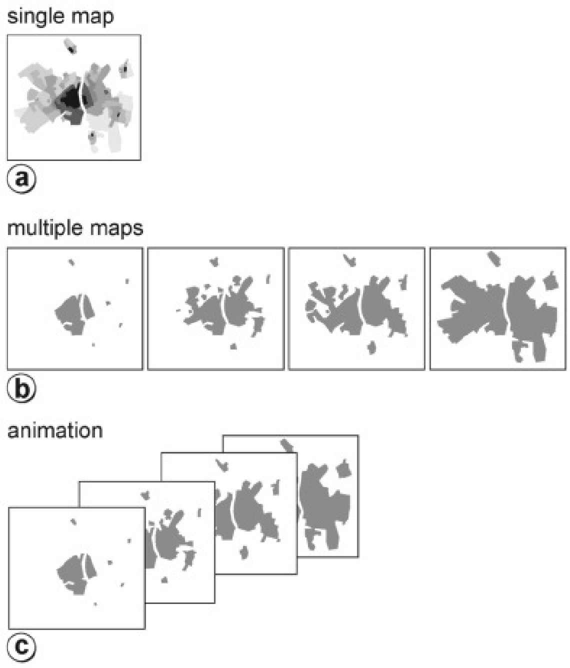

Figure 2.2: Cartographic depiction modes to visualize time by Kraak and Ormeling (a: single static maps, b: series of static maps (multiple maps), c: animation)

Another technique to visualize temporal data that does not fit into the classifications of Monmonier or Kraak and Ormeling is the Space-Time Cube (STC) and similar representations such as the Space-Time Prism introduced by T. Hägerstrand (1970). In addition to the X and Y axes which are used to display locations in a 2D space, the STC (Figure 2.3) uses a third axis to represent time (Z axis).

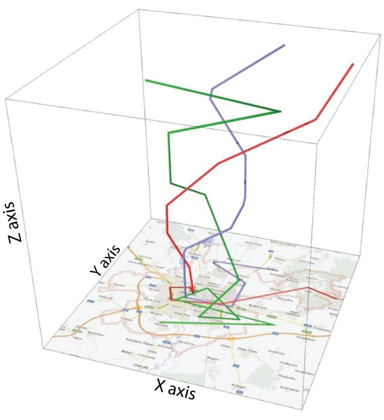

Figure 2.3: Space-Time Cube, modifyed (Popelka, S., et al., 2012)

2.2 Coordinated Multiple View

In today's world, enormous quantities of data are produced every day. In order to handle, process and analyse these huge amounts of data, special exploration environments are needed. An appropriate tool for this task is the CMV environment. CMVs provide the user with multiple windows that are coordinated with each other and represent different views of the data. The following chapter provides a definition for the term CMV and explains the most important aspects to be considered: Data, visualizations and interactivity.

2.2.1 Definition

A CMV is a "specific exploratory visualization technique that enables the user to explore their data" (Roberts, J. C., 2007) through multiple coordinated views. Looking at the data from different views and perspectives may help the user to understand the information better. The main goal of the concept is to permit the user to find information, to understand the complexity and the diversity of the dataset and to identify trends or patterns. This concept is based on the principle that "insight is formed through interaction" (Roberts, J. C., 2008), which allows the user to enter a dialogue with the data. Three main points need to be considered when talking about CMV: Data, visualizations and interaction. For the data, the researcher not only needs to decide how to (pre-)process the huge amount of available data, but furthermore how to handle missing and uncertain data. Different types of visualizations can be coordinated and used to display data in a graphic form. Afterwards, the user can interact with the information to explore it.

2.2.2 Data

When working with any kind of data, these data normally have to be preprocessed and prepared first. In today's world, many different datasets are available and additional data is being produced constantly and everywhere. Large datasets "contain more complex relationships, take longer to process and are thus slower and more confusing to explore" (Roberts, J. C., 2007). The existing algorithms to process the data need to be improved, as users do not want to wait for a view to render. There are two main sets of techniques that may be used for improving the data quality and for reducing the data quantity of the information: Data preprocessing and data mining techniques.

Data preprocessing methods are used to improve the quality of the data, to remove noise, missing values or inconsistencies, and to improve the efficiency of the following data mining process. The methods can be classified into four categories (Arora et al., 2011):

- Data Cleaning: Filling in missing values, smoothing noise, identifying outliers and correcting inconsistent data
- Data Integration: Integrating data from multiple sources to form coherent data
- Data Transformation: Bringing the data into appropriate forms for the data mining process by normalization, smoothing, aggregation and generalization
- Data Reduction: Obtaining a reduced presentation of the data

Data mining techniques can be used to categorize and summarize information and to reduce the quantity of the data (Roberts, J. C., 2007). The methods can be classified according to Fayyad (1996) into six commonly used categories:

- Classification: The task of classifying an item into one of several predefined classes
- Regression: Finding a function that models the data with the least error
- Clustering: The task of identifying a finite set of categories or clusters to describe the data
- Summarization: Describes methods for providing a more compact description for a subset of the data
- Dependency modeling: Characterizes the process of finding a model which describes significant relationships between variables
- Change and deviation detection: The task of identifying the most significant changes in the data from previously measured or normative values that might require further investigation

2.2.3 Visualization

Visualization forms are a powerful instrument to communicate information. Based on the adage “A picture is worth a thousand words”, many different visualization forms have been developed over the years. When designing a CMV, the developer can choose from a wide variety of visualization forms. Each of these forms can be integrated into a CMV and may show the user a different perspective of the data. In addition, it is a speciality of the CMV to display those different forms within one screen, separated in multiple windows (so-called views). In the following section, several visualization forms are presented in order to give a short overview (Roberts, J. C., 2008). Afterwards, some representations of multiple views are explained.

The visualization form that is the most important for cartographers is the *map*. A map is a flattened, abstracted and scaled-down representation of the earth's surface (mr-kartographie, 2010). There are many different forms of maps available, wherein the biggest distinction could be made between topographic maps showing topographic information and thematic maps that display statistical information. Another visualization form is the *network*. Networks describe relations and associations. Some examples of networks are trees, hierarchies and routing diagrams. To display mathematical or statistical information, *charts* are normally used. Commonly used charts are line graphs, bar charts, scatter plots or pie charts. *Tabulars and Matrices* display statistical quantities and numerical information. *Symbols* and *glyphs* are mostly used on maps to encode individual objects. *Pictures* can be also seen as a visualization form. They are normally associated with geographical content such as aerial photographs or satellite imagery.

As implied in the name, a CMV places different views in one screen. In addition, those views are coordinated. Multiple views allow "direct visual comparison of multiple windows" (Roberts, J. C., 2008). When two views are placed side-by-side, the system is termed a "dual view" (Roberts, J. C. 2007). There are several examples of dual views (Roberts, J. C., 2007, 2008): The first system is called *Overview and Detail* and displays the whole dataset in one view and a more detailed version in a second view. The system *Focus and Context* is a methodology to show the details in one view and a summary of the information in another. *Difference views* merge the views together in order to show the difference. The *Master and Slave Relationship* is a relation where one view controls another and exerts unidirectional control. It is also possible to put more than just two views next to each other. One example for that is the type small-multiple, which represents the data in many different visualization forms.

2.2.4 Interactivity

A CMV is not only about displaying many different visualization forms of the data in separate views. The most important thing is the coordination between each of the views. This means that, if the user changes one view, the other views will be adapted automatically. The user then can compare the results and adapt the views again according to requirements. This process can be repeated until the user finds the desired information. Although many interaction and exploration strategies are available, there is a lack of utilization. Many tools do not provide the full set of interaction functionalities. The following section explains some basics on the interaction and manipulation techniques, and afterwards discusses the concepts of the information placement.

There are not only a lot of different visualization forms available, a wide variety of interaction strategies exists as well. Examples for interaction techniques are filtering, pointing and picking interesting elements, selection, deletion, adaption, highlighting, dragging, changing of mapping parameters and navigation (zoom in and out, fly around the data). According to Roberts (2007), they can be categorized into indirect and direct manipulation techniques. *Indirect manipulation* describes strategies where the user changes the visualization by the way of sliders, menus or buttons, so-called dynamic queries. When it is the user who filters or selects elements, the technique is called *direct manipulation*. This allows the user to manipulate the visualization directly. Brushing is one popular example of this technique.

As explained before, the user can change the appearance of the visualization forms by interaction. One concept that need to be considered at this point is information placement. Based on the research of Roberts (2007, 2008), three different concepts are possible: Replace, replicate and overlay. *Replacement* indicates that, through interaction, the new view replaces the old one. The concept of *replication* means that a new window with the new information appears beside the old window. This may ease the comparison of different states of parameter change, but may also lead to a crowded screen when too many new windows are generated. The third concept is overlaying of the information. This means that the new information is merged with the old. This could be done, for example, by stacking it on top in another layer. The overlaying concept is especially useful for the user to compare the information and detect changes.

2.3 Uncertainty visualization

In recent years, the available amount of data has grown very fast. The reasons are to be seen in the technical developments in bandwidth, storage and computational power. Higher resolutions and the sophistication of datasets have led to huge amounts of complex data. Normally, such datasets include bigger proportions of uncertain data. For the visualization process, it is important to recognize and introduce this uncertainty into the graphic representation of the data. This helps users to understand hidden facts correctly, to decide on the extent to which they can trust the data and to determine whether or not it is risky to make decisions based on the data. Uncertainty visualization is of interest for many different application areas, such as climate studies, economic modelling or medicine. The following subchapter defines the term "uncertainty", discusses the state of the art and introduces several techniques for the visualization of uncertainty.

2.3.1 Definition

The perception of uncertainty in the literature today is not consentaneous. Uncertainty is often also denoted as "data quality" (Pang, A., 2001). There are also a lot of different definitions. One of them was introduced by Longley and describes uncertainty as "the difference between a real geographic phenomenon and the user's understanding of the geographic phenomenon" (Longley, P. A. et al. 2005). Other definitions describe uncertainty as a composition of different concepts. They summarize its elements as follows (Griethe, H., 2006):

- Error: Deviation from the real value
- Imprecision: Given resolution in comparison to the resolution needed
- Accuracy: Size of the interval in which the value is categorized
- Lineage: Source of the data
- Subjectivity: Degree of subjectivity in the data
- Non-specificity: Lack of distinctions for objects
- Noise: Undesired background information
- Missing data: Not measured or lost values

Data quality has always played a big role in cartography. Buttenfield and Beard (1991) note that quality "relates to accuracy, error, consistency and reliability." Moellering et. al. (1988) explain the data quality criteria as "locational accuracy, attribute accuracy, logical consistency, completeness and lineage." MacEachren (1992) provides a more basic categorization, as he distinguishes only between two quality criteria: Accuracy and precision. The term "accuracy" describes the closeness between a measured value and the true value. "Precision" is defined as the closeness between independent measurements under the same conditions (International Standard, 1994).

Peuquet's Triad framework (2005) describes the questions that need to be considered during the exploration process: What, when and where. Each of those questions addresses one information space. The what-question can be approached via the attribute space, the when-question applies the time space and the where-question adresses the location space. Based on this framework, MacEachren (1992) further classifies uncertainty into positional, temporal and attribute uncertainty, depending on the information spaces in which the uncertainty occurs. Positional uncertainty describes the absolute accuracy of the coordinates or the height of a point. Attribute uncertainty is the difference between an entity and its real world value. Temporal uncertainty adresses the accuracy and precision of time.

2.3.2 Sources of uncertainty

Uncertainty may occur for many reasons. It may originate from the data acquisition process, but could also appear at different steps of the visualization pipeline (Pang, A. T., 1996). The basis for each visualization is the data. Uncertainty may occur already at the data collection phase because of statistical variations. Irrespectively of whether the measurements were done by a human or a machine, the data will gain confidence with a growing number of measurements. But nevertheless, there are always statistical variations in the data. Uncertainty may also be introduced during the data acquisition process because of unsuitable data collection methods or erroneous data collection. Uncertainty may also arise in the data transformation process. Transforming the data may include conversion of the units of measure, fusion of different types of data in order to derive a new dataset, rescaling, resampling or quantification. Each of these transformations causes a modification of the original data and may introduce uncertainty. Last but not least, uncertainty may occur in the visualization process as well. Reasons for this may be rendering based on approximations, interpolation or the choice of different integration methods leading to varying visualizations.

2.3.3 Visualization of uncertainty

Uncertainty visualization is defined as the process to display data together with assisting uncertainty information in order to aid the user in data analysis and decision making (Pang, A. T., 1996). There are many different classifications of uncertainty visualization methods available. One can distinguish, for example, between positional, temporal and attribute uncertainty visualization, between qualitative and quantitative methods, between static and dynamic techniques, between intrinsic and extrinsic approaches, between explicit and implicit techniques and between coincident and adjacent methods. The following section describes and briefly explains such classifications according to several characteristics.

As described earlier in chapter 2.3.1, uncertainty can be classified into positional, temporal or attribute uncertainty depending on the information space in which the uncertainty occurs. While the visualization of temporal uncertainty is still an open research question, several techniques to display positional and attribute uncertainty exist. Possible visualization techniques include symbol focus methods (Figure 2.4) such as varying contour crisp- or fuzzyness, manipulated fill clarity, fog or adjusted resolution (MacEachren, A. M., 1992).

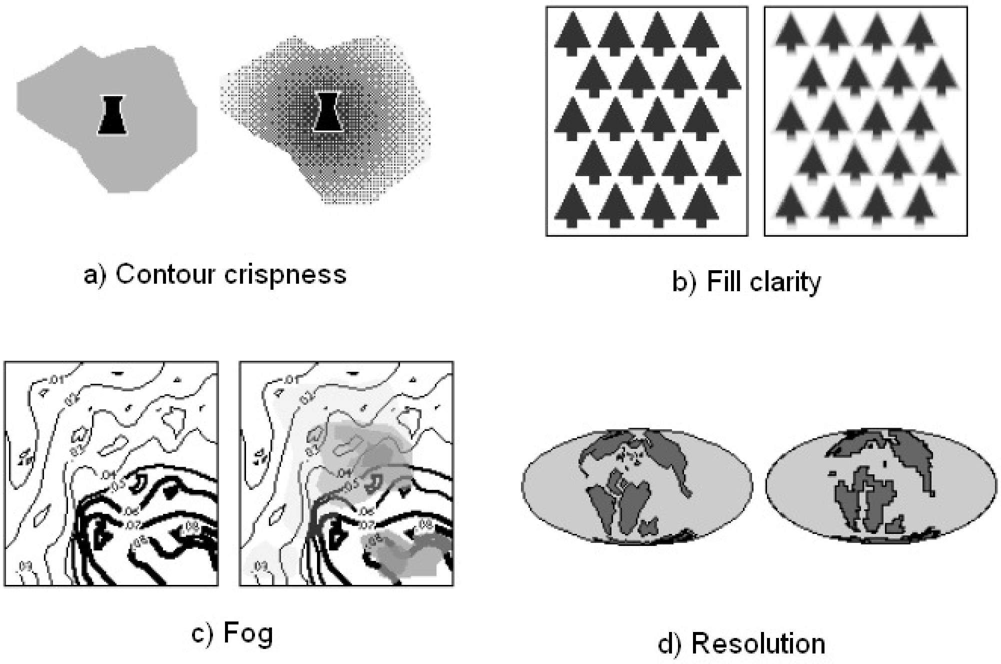

Figure 2.4: Uncertainty visualization techniques – a) Contour crispness, b) Fill clarity, c) Fog, d) Resolution (MacEachren, A. M., 1992).

According to the characteristics of the uncertain data, the techniques can be further classified into qualitative and quantitative uncertainty visualization techniques. Qualitative uncertainty describes the uncertainty of the characteristics of the data, whereas quantitative uncertainty relates to the uncertainty of measured values. Furthermore, the techniques can be classified into static or dynamic techniques. Static techniques include the use of the graphic variables (see chapter 2.1.2). Other static techniques are additional geometric objects such as glyphs, labels, isosurface views, error bars or grid-based annotation lines. In addition, it is also possible to address other human senses (acoustic or haptic sense) by the use of sound or touch and vibration (Griethe, H., 2006). Fisher (1994) introduces the two sound variables tone and rhythm to indicate uncertainty. Both variables can be used in proportion to the error whereat the pitch or the length of the rhythm relates to the level of error. Dynamic techniques include the use of animations and involve the use of speed, blinking and motion blur. The application of dynamic variables (see chapter 2.1.2) is possible as well. In addition, one can distinguish between intrinsic and extrinsic uncertainty visualization (Figure 2.5). Intrinsic approaches use the visual variables of existing objects to visualize uncertainty. Extrinsic techniques integrate additional graphic objects for the representation of uncertainty (Kinkeldey, C., 2013).

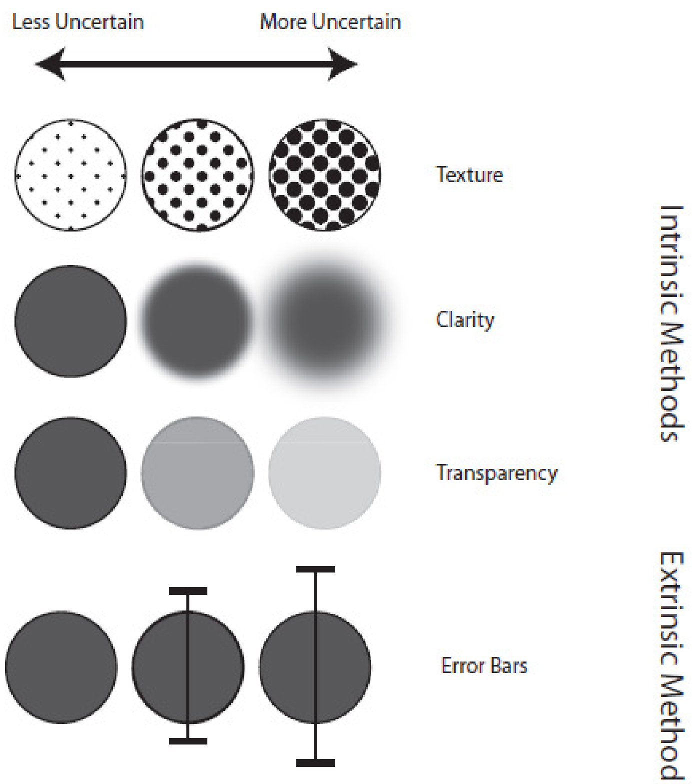

Figure 2.5: Intrinsic and extrinsic uncertainty visualization techniques (Deitrick, S., 2013)

Kinkeldey furthermore distinguishes between explicit and implicit uncertainty visualization. Explicit techniques express the uncertainty directly whereas implicit techniques visualize different possible outcomes (Kinkeldey, C., 2014). Especially interesting for the visualization of uncertainty in a CMV is the distinction between integration of the uncertainty in every data view (coincident) and the implementation of an additional uncertainty view (adjacent) (Kinkeldey, C., 2014). This thesis aims at comparing those two techniques and tries to find out which is more efficient for the visualization of uncertainty in a CMV. Therefore, both versions will be implemented.

2.4 Usability

At the moment, there are about 1.85 billion web pages accessible on the Internet (WorldWideWebSize, 2014). In addition, a countless number of systems, softwares and applications is available. There is no need for users to use systems that are confusing, erroneous or too complex. If users are not pleased with one system, they just choose another one. Therefore, it is important to study usability aspects and to improve the user-friendliness. In addition, it is significant to understand whether a system or an application is effective, efficient and user satisfying and helps the user to generate knowledge from it. The following subchapters provide information about the definition of the term "usability" and commonly used usability methods.

2.4.1 Definition

When designing products, usability is an important aspect to consider. Users normally do not want to get lost in the product, they expect an intuitive interaction and they do not want to be bothered by confusing error messages. Therefore more attention is directed to the development of user-friendly products and the study of usability aspects. ISO 9241 is a standard that covers the ergonomics of human-computer interaction. It describes usability as the "extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use." (International Standard, 1998).

There are multiple components to measure usability. In the definition of usability, ISO 9241 introduces the following three (International Standard, 1998):

- Effectiveness: The accuracy and completeness with which the user can achieve the desired (sub-)goals.
- Efficiency: A measurement of the resources expended in relation to the effectiveness of achievement of a specific (sub-)goal. This may include mental or physical effort, time, materials or financial costs.
- Satisfaction: The extent to which a user is free from discomfort and users' attitudes towards the use of the product.

Nielsen (1993) analyzes it more in detail and characterizes five criteria to measure usability. The attributes that he discusses in his studies are:

- Learnability: Infers that the system should be easy to understand so that the user can start work rapidly.
- Efficiency: Means that the system should be productively useable once the user has understood it.
- Memorability: The working principle of the system should be easy to remember, so that the user can return to it without any difficulties after a period of time without use.
- Errors: The error rate of the system should be low, so that the user faces only few errors during the working process. The errors must be easy to recover.
- Satisfaction: Working with the system should subjectively satisfy the user.

2.4.2 Preliminary considerations

Before conducting a usability test, it is necessary to discuss some basic considerations. First, some thoughts need to be spent on organization of the usability test. The test goals should be defined, a test plan should be drawn up, pilot tests should be run, and, last but not least, test users are needed.

Before a test is done, a test plan should be written to consider, among others, the following questions (Nielsen, J., 1993). The plan should also discuss the goals that should be achieved by this test:

- What is the goal of the test?
- Where and when will the test take place?
- How long will each test session take?
- What support is needed for the test (computer, software)?
- Who will be the test users?
- How many test users are needed?
- Which tasks will the users have to perform?
- Which criteria will be used to determine when the users have finished the test tasks correctly?
- What data are going to be collected, and how will they be analyzed?

Before starting the real usability test, it should be presented to some pilot test users. Normally about one or two pilot subjects are enough. These testers should identify incomprehensible task instructions, mismatches between the planned and actually needed time for a test session, and tasks which are too easy or too hard tasks, enabling the designer to clarify the definitions and to refine the experimental procedure (Nielsen, J., 1993).

Additional considerations need to be taken into account when choosing the test users. On the one hand, it should be decided whether novice or expert users are needed. Almost all tests are done with novice users, whereas experts can also be very helpful, as they normally already have experience with the product and are therefore faster in performing tasks. Nevertheless, the selected users should be as representative as possible (Nielsen, J., 1993). The test users for this research will be half people related to the geographic field and half people interested in history. People with these interests are especially interesting as test users as they fit the profile of users for who the interface is implemented. The number of test users is important as well. For this study, two equal control groups are formed. Each group tests one of the CMVs and consists of an equal number of people related to geo and people interested in history. Both groups will consist of 8 to 10 people.

2.4.3 Usability testing methods

There are several methods available, for testing of the usability of a product. According to the Chur Evaluation Laboratory (CHeval) of the Chur University of Applied Science (2013), these methods can be classified into analytical and empirical methods. Figure 2.4 shows a classification of the methods explained in the following section and, how they can be classified into the categorization of CHeval.

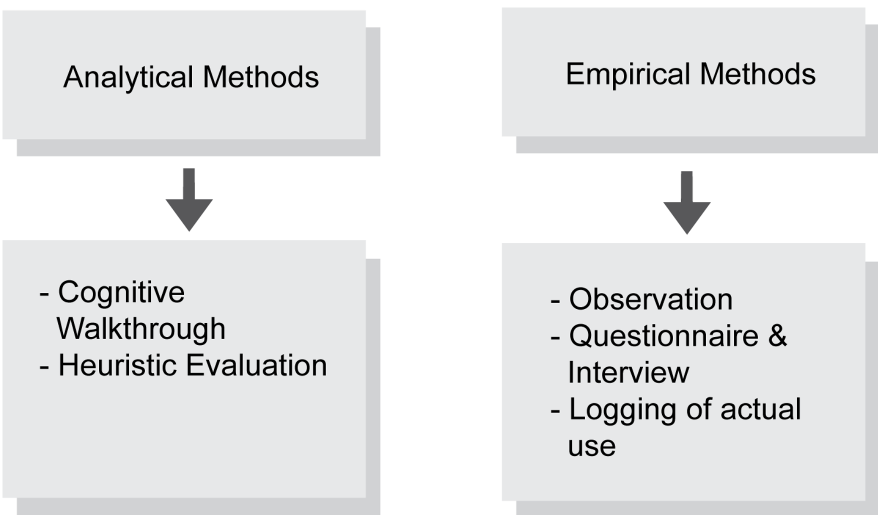

Figure 2.6: Usability testing methods

Analytical methods utilize the assessment of experts with the help of their expert knowledge and given guidlines (CHeval, 2013). One commonly used analytical method is the *cognitive walkthrough,* which consists of two main steps. In the first phase, detailed information on the user is collected and the analysis tasks are identified. Afterwards, the predefined working steps are performed by the experts, in order to analyse whether a normal user could use the system efficiently (CHeval, 2013). Another analytical method is *heuristic evaluation*. By way of this method, experts examine whether the user interface fits the predefined principles, the so-called heuristics. A violation of the principles would mean that a usability problem exists (CHeval, 2013).

Another group of usability methods is called empirical methods. These techniques gain their knowledge by consulting and observing real users of the product (CHeval, 2013). The first method is the *observation* method. This means simply watching the user during the working process. Observation of the user's behaviour can be either direct (the investigator is present) or indirect (audio or video recording). A special form of the observation method is the *think-aloud* method, where the test person continously thinks out loud during observation (Nielsen, J., 1993). *Eye-tracking* is also a special form of the observation method. This method tracks where the user looks first and which parts of the interface are perceived very intensely (CHeval, 2013). Another empirical method is the utilization of *questionnaires* and *interviews*. These methods study the user's opinion of the user interface. While interviews normally include at least one person asking the user questions, a questionnaire is often completed by the user alone with the questions on a sheet of paper or a computer screen. The main advantage of interviews is that the interviewer can explain items in more detail if the interviewee has questions (Nielsen, J., 1993). *Logging of actual use* is another empirical method to analyse usability. With the help of this method, the computer automatically collects statistical information about the use of the system. The statistics show which parts of the system are used regularly and which are not. From this, conclusions can be drawn to as to which parts need to be revised (Nielsen, J., 1993).

For this research, a combination of different techniques has been chosen for the empirical study. Thinking aloud in combination with screen logging and video recording will be used to analyse the effectiveness and efficiency of the product. A feedback questionnaire will give an impression about user satisfaction with the product.

3 Case study dataset

An historical dataset was chosen as a case study. The Napoleonic data were provided by the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente. It is clear that more and different datasets would make the study more universal. But the focus of this thesis is intended to be placed on the empirical study. Therefore, the decision was made to only use one case study dataset.

3.1 Napoleon's Campaign in Russia 1812

Napoleon's campaign in Russia was one of the greatest upsets in military history. The army was the biggest that the world had seen until then. Figure 3.1 shows an overview of the march. The following text passage explains the campaign briefly[3].

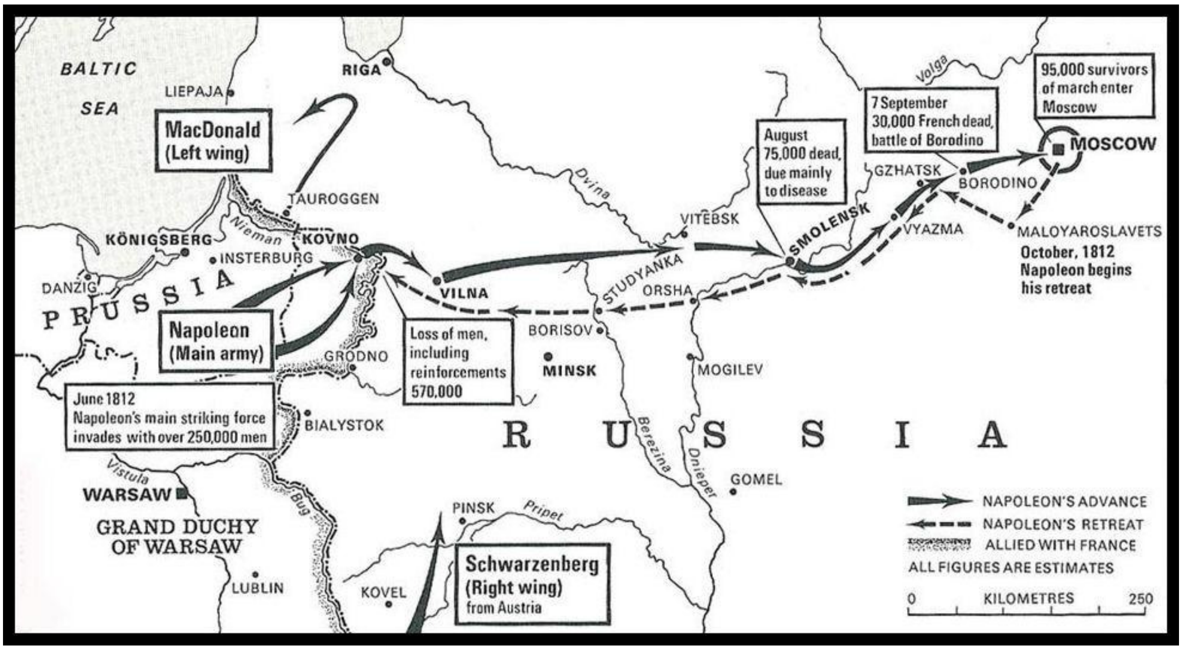

Figure 3.1: Napoleon's Campaign in Russia 1812

After the Treaty of Tilsit in 1807, France and Russia became partners in an alliance. But several reasons engendered Napoleon's mistrust of Russia's solidarity. During the French War versus Austria, Russia did not behave as Napoleon expected. An additional point of contention was Russia's withdrawal from the continental system. This led to threats and troop deployment, and

3 The following paragraph is based on two articles: 1) "Entsetzliche Verluste bei Napoleons Russlandfeldzug" (DIE WELT, 2012), 2) "24. Juni 1812 - Napoleon beginnt Russland-Feldzug" (WDR, 2012).

in June 1812, finally, Napoleon started his march with about 500000 soldiers. The “Grande Armée” consisted mainly of French, Italian, German, Dutch, Belgian and Croatian soldiers as Napoleon had annexed large parts of Europe. The Polish, Austrian and Prussian armies supported the Grande Armée as well. The military strategy that Napoleon used throughout the campaign was the so-called “Blitzkrieg” strategy. This meant that the soldiers mainly had to live from food and materials that they found in the surrounding area. Plans for logistics failed, as the fresh supplies got stuck in muddy lands. Hence, provisions were soon depleted, the surrounding area was plundered, and many soldiers died due to hunger already before they reached Russia. Heat, hunger, continous rainfalls, diseases and hygienic conditions claimed many victims. But no battle hab been fought so far as the Russians just moved backwards. When the Battle of Borodino was fought on 7 September 1812, Napoleon commanded nothing more than 130000 soldiers. 30000 of them died during this battle. On 14 September 1812, Napoleon moved into the empty city of Moscow, which had been evacuated before. In a normal capture, the officials of Moscow would have been forced to provide food and accommodation for the soldiers of the Grande Armée. But as the Russians had already evacuated Moscow, nobody was there to welcome Napoleon and to provide him with means of subsistence. This situation meant that every man was forced to find lodgings and sustenance for himself. Due to plunder and arson, many parts of the city started to burn. With an ruined city, no prospect of Russian capitulation and no supplies, Napoleons only choice was withdrawal. At temperatures of -30°C, the French troops shrank more and more as the army was only equipped with summer clothes and the winter was a harsh one. As much of the data got lost during the war, the total number of losses is uncertain. But several sources state that only about 30000 (Tarle, J. W., 1963) to 81000 (Helmert, H. et al., 1986) soldiers returned.

3.2 The Battle at the Berezina - 26.-29.11.1812

The battle at the Berezina from 26 to 28 November was the last during Napoleon’s campaign in Russia. It ended with a mixed outcome as the French army lost many soldiers during this battle but could finally cross the river. The following paragraph explains the history of the battle at the Berezina briefly[4].

On 19 October 1812, Napoleon decided to withdraw from Moscow. The bad weather conditions and Russian attacks hindered the French widthdrawal. Napoleon wanted to reach the Berezina before the Russian troops could block their way. The Russian armies of General Wittgenstein,

4 The following paragraph is based on the following article: “Beresina” (Napoleon Guide, 1999)

General Kutusov and Admiral Tshitsagov wanted to trap Napoleon at the Berezina and destroy his troops. Napoleon had originally planned to cross the frozen river, but the ice had thawed. Fortunately for the French, General Eble’s engineers ware able to build a bridge over the river. Marshal Oudinot’s task was to draw off Admiral Tshitsagov. Cavalry and infantry could quickly cross the river and a second bridge was built. It was opened just in time to bring cannons across when Tshitsagov started to attack the French troops. On the other side, the rearguard was fighting against Wittgenstein's arriving army. The corps of Marshal Victor held the enemy off at the Eastern side until they were able to follow their comrades. They pushed Tshitsagov out of their way and continued their retreat to France. 25000 French and 20000 Russian soldiers died in the battles, whereas about 20000 died while crossing the river.

3.3 Origin of the dataset

The routes of Napoleon’s Campaign are located in the area of today’s Lithuania, Belarus and Russia. The main path of the march started in the West at Kaunas, passed by Vilnius, Polotsk, Vitebsk, Smolensk, Dorogobuzh and Mozhaysk, until Napoleon’s troops were stopped in Moscow. On the way back, they took the route Maloyaroslavets, Vyazma, Smolensk, Orsha, Berezina River, Smorgon and Vilnius. Napoleon started his campaign on 24 June 1812. On 19 October 1812, he was forced to give the order for withdrawal. He returned to Paris in December; the rest of his army was abandoned to its fate.

One of the most famous maps showing the campaign is Minard’s Map (Figure 3.2). This map shows the route, the troop size and the temperature in one representation. The route is represented as a flow line, the size of the troop is indicated by a varying thickness of the flow line, and the temperature is displayed in an extra chart. In addition, advance and withdrawal are indicated by different colours (pink/orange and black). The information graphic of Charles Joseph Minard can be seen as a coarse basis for this dataset.

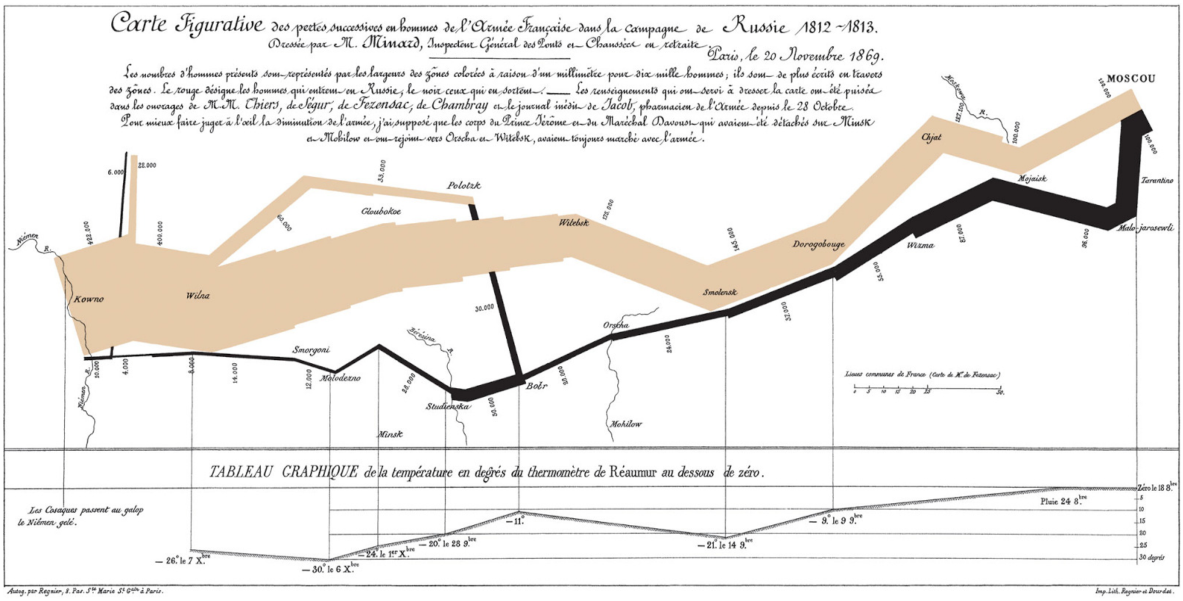

Figure 3.2: Minard's Map

One of the most disastrous battles during this campaign was the battle at the Berezina. The dataset contains several pieces of information about this battle, which are all combined in a graphic. This graphic was provided by the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente and can be seen in Appendix 1. It shows the crossing of the Berezina and contains separate information for each corps. It provides the user with information about the troop size of each corps and the exact time of their crossing. In addition, it highlights the uncertainty concerning the number of soldiers. A small table shows how many soldiers were involved according to different sources. The main goal was to visualize this graphic in a CMV and to develop two versions, one showing the uncertainty in a special uncertainty view, and another showing the uncertainty in each data view.

4 Implementation

In order to analyse the effectiveness of uncertainty visualization in CMVs, two different representations had to be implemented. The following chapter describes these two visualizations and explains the main steps of the workflow. First, a brief introduction is given to D3.js, the JavaScript library that was used for the implementation.

4.1 D3.js

D3.js (Data-Driven Documents JavaScript library) is a JavaScript library for the visualization of data for the web. To build interactive visualizations, designers often bring multiple tools together, such as HTML (Hypertext Markup Language), CSS (Cascading Style Sheets), JavaScript and SVG (Scalable Vector Graphic). D3.js combines these and enables the user to create dynamic and interactive graphics which run in web browsers. Pre-build functions can be used within D3.js to select elements, create SVG objects and to style them. Dynamic effects or transitions can be added to make the graphic interactive and/or dynamic. The JavaScript code is embedded within a HTML webpage and uses mainly CSS to style the objects. Most of the used data is stored in JavaScript Object Notation (JSON) or geoJSON files, or else as Comma-separated values (CSV) in data tables or lists (d3js.org, 2013). D3.js was introduced by Mike Bostock in 2011 and has become a powerful tool for the creation of data visualizations over the last years. The main advantages of D3.js are its flexibility to work seamlessly with existing technologies and the accessibility over the web without needing any specific plugins. Disadvantages of D3.js can be seen in the slowness when large numbers of elements need to be displayed, and the fact that it is only compatiple with new browsers such as Mozilla Firefox, Google Chrome, Safari and Opera. D3.js does not support Internet Explorer. During the implementation of this study, problems occured with Opera and Safari as well (visual.ly, 2013).

For the implementation phase, the examples of Mike Bostock were used as a main basis. Two webpages, especially, have been of interest. The webpage *bl.ocks.org*[5] shows various examples and the corresponding source code. The examples can be easily adopted and changed to the user's needs. Most of the source code used for this study has been adapted from examples on this page. The second page that was used often for the implementation of the two interfaces is the *Wiki*[6] of the D3.js, which is also hosted by Mike Bostock. This webpage provides detailed

[5] http://bl.ocks.org/mbostock
[6] https://github.com/mbostock/d3/wiki

tutorials and a gallery with examples for most of the existing charts, visualization forms as well as interaction and animation techniques. The page also contains the API Reference, which provides an extensive documentation and detailed explanations for all the available functions. This page was used mainly to look up detailed information about specific functions.

4.2 Implementation and description of the interface

Two different versions showing the same content have been implemented: The first version integrates uncertainty into the data views, while the second visualizes uncertainty in an extra uncertainty view. Before starting the implementation process, the data had to be preprocessed. In addition, a draft was designed in order to develop an conceptual framework. Afterwards, the two versions were implemented parallel, as most of the graphical elements were used in both interfaces.

4.2.1 Preliminary considerations and preparation of the dataset

Before the implementation process started, a first draft was developed. The idea was that both versions should have a view showing the geographical situation (location view), one view to represent the time (time view), and another showing the numbers of soldiers in detail (attribute view). The second version should contain an additional attribute view which represents the uncertainty. Furthermore, both versions should be kept as similar as possible, in order to have equal starting bases for the empirical study. In addition, the decision was made that both versions should be implemented in a non-dynamic environment, eventhough a temporal phenomenon was being visualized. The idea to include an animation was dismissed for the following reason: If one view were to contain an animation, the user's attention would be always attracted by this animation. Hence, it would be more difficult to pay the same amount of attention to the other views. Furthermore, the expected test users will not be experts. They are all specialized in a geographical field or have a deeper interest in histrory, but do not have any specific knowledge about the specific problem, i.e. the visualization of uncertainty in CMVs. Therefore, it is not so important to have detailed numbers or information included in the interfaces. It is not necessary to understand the situation in detail, as the user should rather gain an overview of the historical phenomenon. Primarily, the users should be able to extract approximate numbers and obtain an overview of the situation. These interfaces could be also used by students or other people interested in this historical phenomenon.

In the next step of the process, the dataset was prepared. The starting point was several different shapefiles. To visualize the geographical situation schematically, shapefiles containing places and rivers were downloaded from DIVA-GIS[7]. After extracting all the relevant objects and generating new shapefiles that contain all the information about the corps and their positions before and after the crossing, the files were converted into geoJSON files. In addition, a file containing lines which should represent the bridge was generated as well. Afterwards, the files could be used within D3.js. Furthermore, the numbers of soldiers for each state (before and after the crossing) had to be extracted from the provided graphic (Appendix 1) and the numbers for after the crossing and the box plots had to be calculated first. In addition, CSV files containing information about the number of the soldiers were generated. Some of the used numbers were directly integrated into the JavaScript files.

Uncertainty visualization methods that use fuzzyness, fog or unsharp edges or elements have not been used in the implementation process. Other solutions which use colour, size or thickness have been discussed and are explained in the following sections.

4.2.2 Uncertainty in all data views

The first version consists of three views: A location view, an attribute view and a time view. The uncertainty has been integrated into the data views (Figure 4.5). The view on the top left is a map-like depiction and shows the geographical situation schematically (Figure 4.1). A blue line represents the river and black squares show the cities in the surrounding area. The cities have been visualized as squares in order to achieve a visual differentiation between the corps and the cities. Black lines represent the bridge over the river. The corps are represented by circles. There are two circles for each corps, one for each of the states before or after the crossing. The circles are linked by grey lines which represent the path the corps took. In addition, grey arrows on the paths indicate the direction of movement. The size of the circles relates to the number of soldiers at each state. For representational reasons, the number of soldiers was scaled down by the factor 1500. Afterwards, the newly calculated number was applied as the strokewidth for the circle. Different colours were assigned to the corps. They were taken from the Colorbrewer[8]. A qualitative colour scheme with eight colours has been chosen, wherein yellow and orange (poor contrast to the background colour white) were dismissed and only the remaining six colours were used.

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[7] http://www.diva-gis.org/gdata
[8] http://colorbrewer2.org/

To integrate the uncertainty into the map view (Figure 4.1), three radio buttons were introduced. By clicking these buttons, the user can choose between the minimum (Figure 4.1-a) and maximum numbers (Figure 4.1-c) of soldiers indicated in the different sources. In addition, it is possible to select the average number of soldiers (Figure 4.1-b). The size of the circles varies according to the represented number. Several other techniques of integrating uncertainty in the map view have been discussed. The first idea was to use the colour of the circles and change their colour intensity according to the uncertainty. But indicating the uncertainty in this way was dismissed as it does not represent the different sources, but rather only an overall impression of the uncertainty in general. A second idea, namely to indicate the minimum, average and maximum numbers of soldiers by nested circles or rings could not be used because of readability problems. Especially in the cases of Corps I & IV and the Imperial Guard Young, the three circles or rings have quite similar sizes, so that it was not possible to visually distinguish them. Making them bigger and thereby readable was not possible either, as this would have made the circles or rings for the other corps too big. Another idea was to use the ring thickness instead of the radius to indicate the number of soldiers. This version was at least readable, but produced a too complex result which was no longer understandable. In the end, a version was chosen that is readable, not too complex and visualizes the minimum, average and maximum number of soldiers. Disadvantageous for this version is that these three possibilites cannot be seen and compared at the same time.

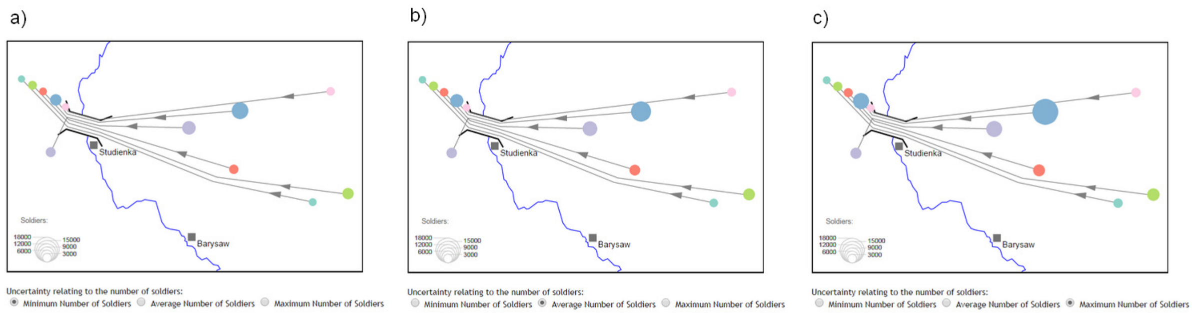

Figure 4.1: Map-like depiction with uncertainty (a) minimum number of soldiers, b) average number of soldiers, c) maximum number of soldiers)

All three versions use the same legend (Figure 4.2). Grey rings of different sizes indicate the numbers of soldiers. In order to provide good readability, only six categories with increments of 3000 soldiers were chosen. The legend is used universal for all three versions (minimum, average, maximum number of soldiers) as the values do not differ so much between the versions.

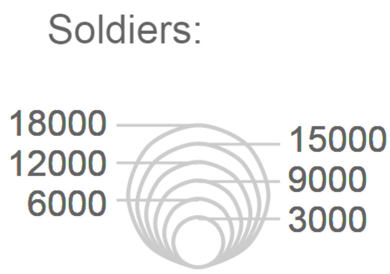

Figure 4.2: Legend for the map-like depiction

The graphic on the right of the interface in figure 4.3 shows a grouped bar chart. The bars represent the average numbers of the soldiers for each corps before and after the crossing, where the left bar represents before and the right bar after the crossing. The bars are coloured in the same way as the circles in the map-like depiction. This means that the colour again represents the different corps. Using the same colours for all views should help the user to connect faster between the different representations. In addition, black vertical lines on each bar, so-called error bars, indicate the uncertainty range. The line ranges from the lowest to the highest uncertainty value for each bar. Depending on the radio button the user chose to represent the minimum (Figure 4.3-a), average (Figure 4.3-b) or maximum (Figure 4.3-c) number of soldiers in the map-like depiction, an additional horizontal line indicates that number for each of the bars of this chart. Advantageous for this representation is the fact that the user can directly see the range of the uncertainty and can compare it to the average number of soldiers. In addition, it is possible to compare the uncertainty ranges of the different corps in relation to the number of soldiers of each corps.

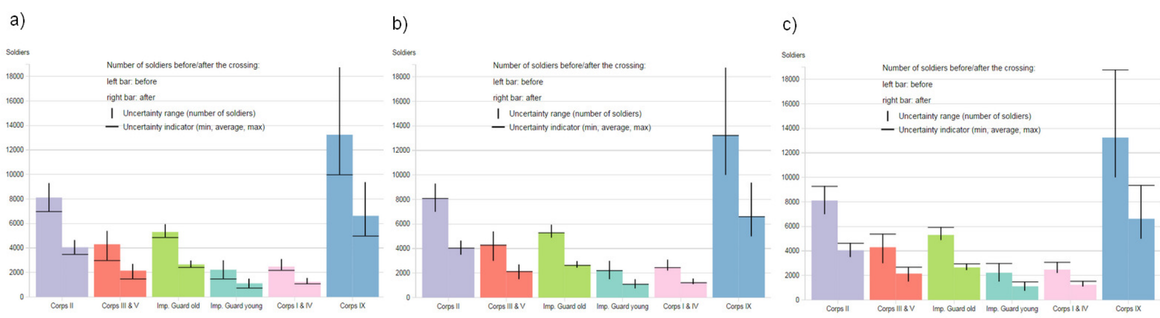

Figure 4.3: Bar chart with uncertainty ranges (a) minimum number of soldiers, b) average number of soldiers, c) maximum number of soldiers)

The graphic at the bottom of the interface shows six timelines (Figure 4.4). Each timeline belongs to one corps and represents three different time states: Before, during and after the crossing. The time states have been assigned the same colours as the circles in the map-like depiction. The time point “Crossing the river” has been kept in grey for two resons: First, as it is the only graphic that indicates the time point “Crossing the bridge”, the user can directly see that it does not relate to any other view. Second, it visually distinguishes the time point “Crossing” from the other two.

As the uncertainty only relates to the number of soldiers and does not vary over time, it has not been integrated into this graphic. In addition, not representing uncertainty in this view avoids too much complexity and confusion for the user.

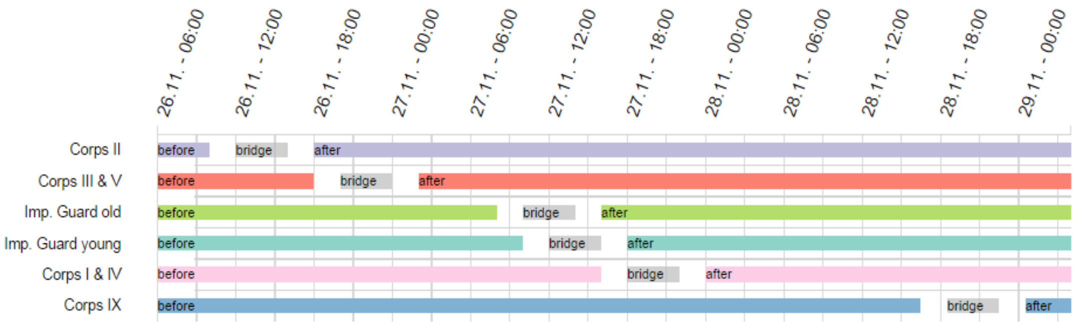

Figure 4.4: Timelines

It is possible to interact with the three graphics. The user can choose whether to have the minimum, average or maximum number of soldiers displayed by checking radio buttons. Depending on the active radio button, the representations of the map and the bar chart are adapted. In addition, the user can hover over the circles in the map-like depiction to get more information about the corps. The coordination between the views has been introduced by way of mouseover and highlight functions. When the user hovers over the points in the location view, the bars in the attribute view or the time ranges in the time view, the corresponding elements are highlighted in the other views (Figure 4.5). For highlighting of the corresponding elements of one corps, a more saturated colour than the original colour chosen for the corps is used. Moving the mouse away from the element deselects the highlighted objects again. Furthermore, the user can click a button to get more information about the historical phenomenon or click another button to get information about the functionality of the CMV.

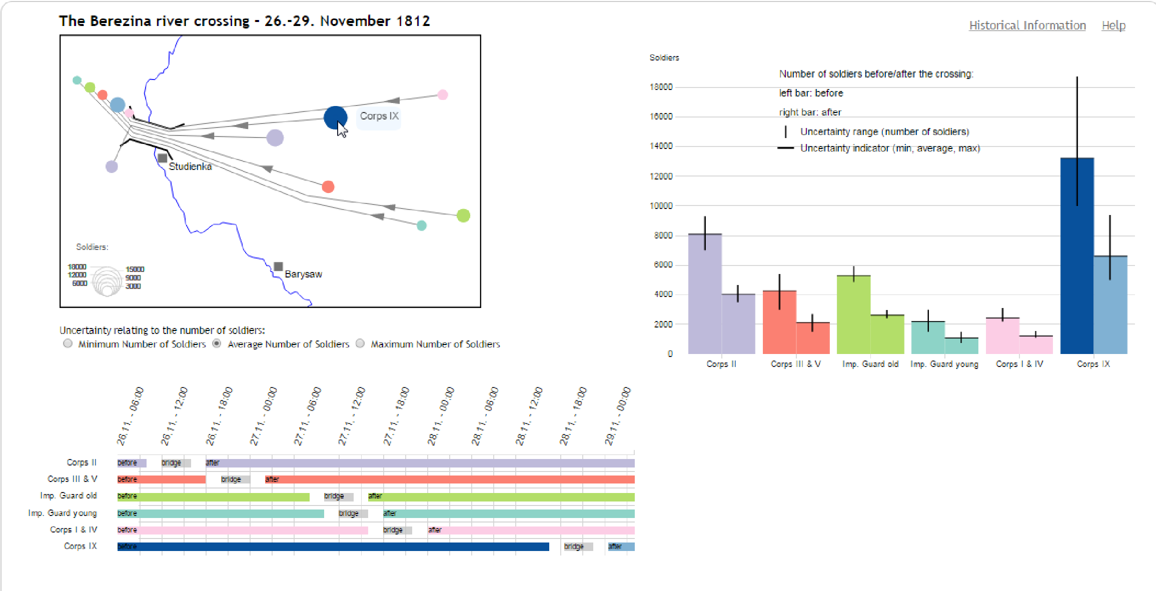

Figure 4.5: CMV with uncertainty integrated into the data views

4.2.3 Uncertainty in an extra view

The second version consists of four views: A location view, an attribute view, a time view and an uncertainty view (Figure 4.9). The uncertainty is only integrated in the additional uncertainty view. The view on the top left in the CMV shows a map-like depiction which summarizes the geographical situation schematically (Figure 4.6). A blue line, black squares and black lines again represent the river, the cities in the surrounding area and the bridge over the river. Their representation is identical to that in the other CMV version. The corps are again represented by circles. There are two circles for each corps, one for each of the states before or after the crossing. The circles are linked by grey lines which represent the path the corps took. As in the first version, grey arrows indicate the direction of movement. In contrast to the first version, the size of the circles only relates to the average number of soldiers for each state. For representational reasons, the average number of soldiers was scaled down by the factor 1500 in this version. Afterwards, the newly calculated number was applied as the strokewidth for the corresponding circle. The colours in this version have been kept identical to those in the first version. Each colour represents one corps and visually links to the other views which use the same colours. This graphic gives the user an overall impression of the situation and allows visual comparison of the corps and their numbers of soldiers before and after the crossing and between each other.

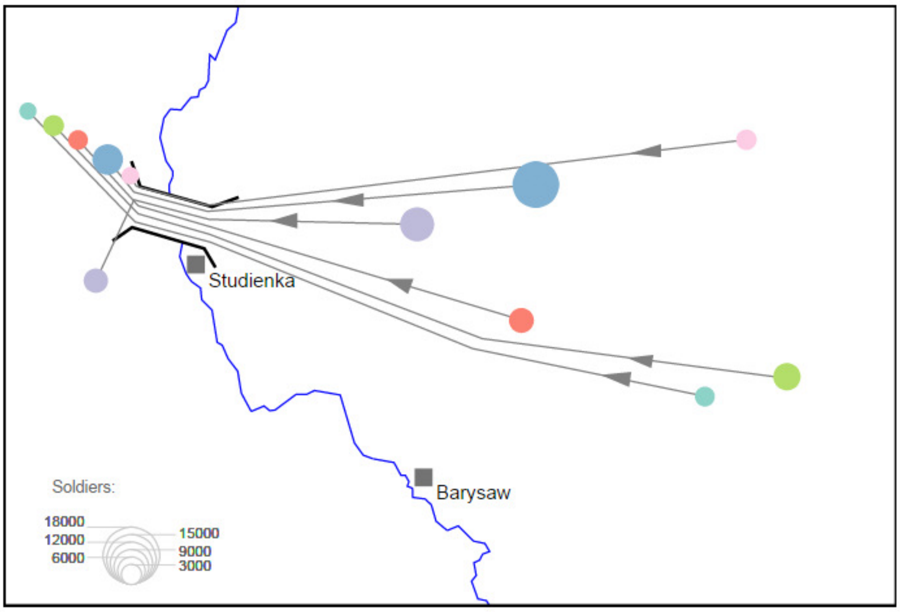

Figure 4.6: Map-like depiction without uncertainty

The graphic on the top right in the CMV shows a grouped bar chart (Figure 4.7). The bars again represent the average number of soldiers for each corps before and after the crossing. The left bar relates to the number of soldiers before and the right bar to after the crossing. This simple bar chart allows the user to easily compare the average number of soldiers.

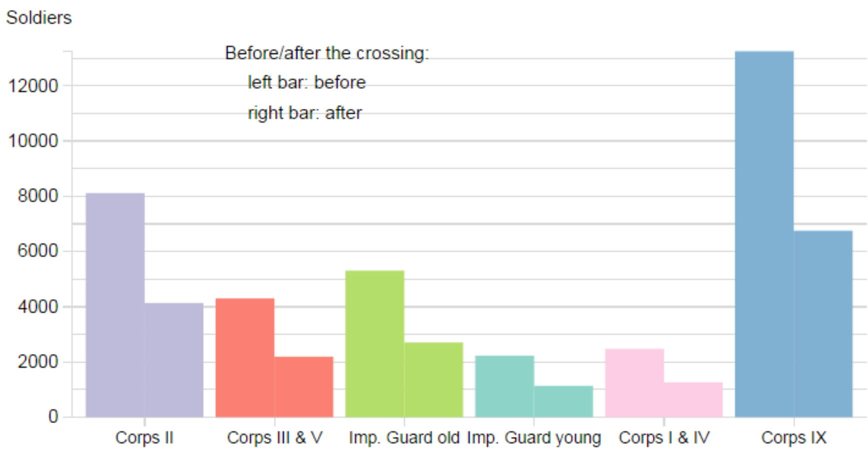

Figure 4.7: Bar chart without uncertainty

In the graphic at the bottom left of the interface, six timelines have been visualized again (Figure 4.4). The same graphic as in the first CMV version (uncertainty integrated into the data views) has been used. Again, each timeline belongs to one corps and represents three different time states: Before the crossing, crossing the river and after the crossing. The time states have been assigned the same colours as the circles in the map-like depiction, in order to follow the idea of a visual connection between the different views.

The graphic at the bottom right shows a box plot (Figure 4.8). It shows the number of soldiers for each corps according to the four different sources used for the implementation (Chambray, Wilson, Fain and Gourgaud). The bars of the box plot display a range of the middle 50% of the values. The black vertical lines (whiskers) indicate all the values that do not lie in the range of the box. The horizontal black lines represent the minimum, mean and maximum values. Depending on the time point the user selected, the bar chart automatically adapts to the corresponding diagram (before or after the crossing).

The possibility of using a simple grouped bar chart was also discussed for this view. But in contrast to a box plot, having a bar for each source for each corps gives the user the possibility to extract really detailed values for each of the four sources. In order to avoid this, and to give the user the same possibilities in both CMV versions, a grouped bar chart was dismissed and a box plot was chosen. Furthermore, the used box plot is quite similar to the bar chart with error bars which was used in the other CMV version.

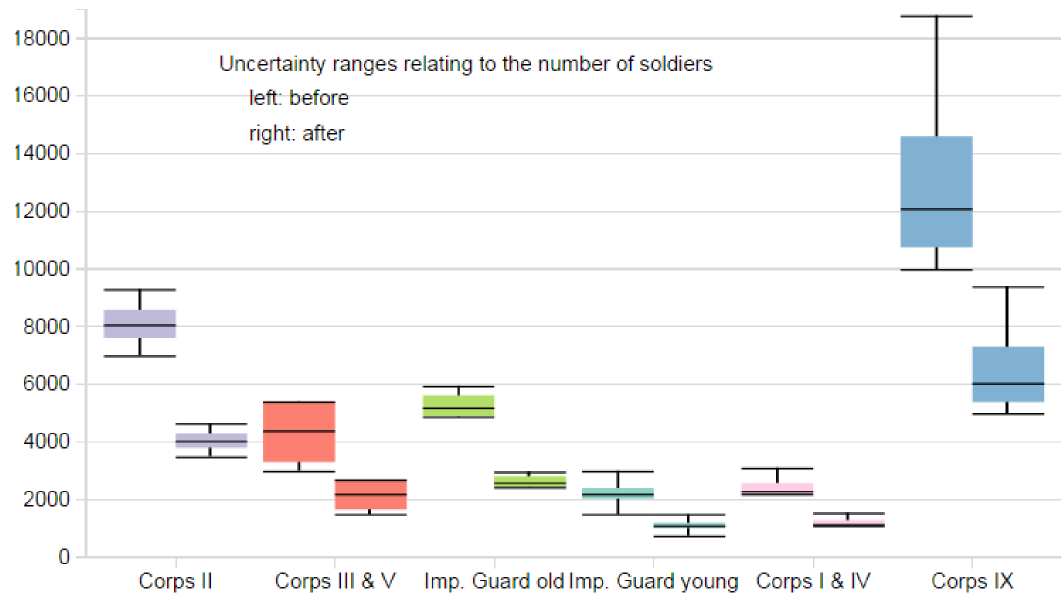

Figure 4.8: Uncertainty box plot

It is again possible to perform a coordinated interaction with the four graphics. The user can hover over the circles in the map-like depiction to get more information about the corps.

Furthermore, it is again possible to hover over the points in the location view, the bars in the attribute view, the time ranges in the time view or the bars in the uncertainty view to highlight the corresponding elements in the other views (Figure 4.9). For highlighting of the corresponding elements of one corps, a more saturated colour than the original colour chosen for the corps is used again. Moving the mouse away from the element deselects the highlighted objects again. In addition, the user can again click the buttons at the top to get more information about the historical phenomenon or the functionality of the CMV.

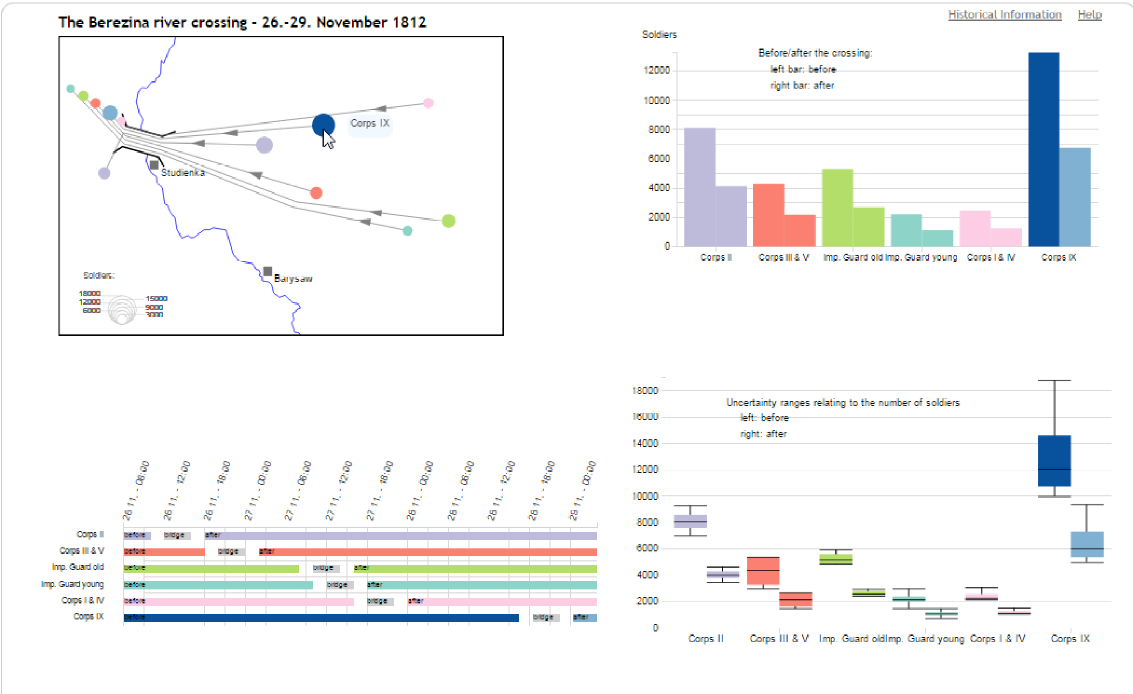

Figure 4.9: CMV with extra uncertainty view

5 Evaluation

The two different versions implemented in the previous phase of the thesis are now analysed with regard to their effectiveness, efficiency and user satisfaction. Therefore, a usability test is performed. Afterwards, the collected usability data will be analysed in order to give a recommendation as to which of the two versions is more effective, efficient and satisfying for the user.

5.1 Usability test

A combination of a think-aloud protocol, video recording and screen logging was used for the empirical study. To analyse the two different versions, two control groups were formed. Each control group analysed one CMV. The following sections explain the hypothesis, the test plan and the test procedure.

5.1.1 Hypothesis

The goal of the usability test was to analyse which of the two versions (untertainty integrated in the data views, extra uncertainty view) is more effective, efficient and user satisfying. Before the user test was conducted, a hypothesis was developed. To this end, the supposed advantages and disadvantages of the two versions were analysed. While the first version with the integrated uncertainty allows the user to visually connect the attribute and uncertainty information faster and provides two different visualizations of the uncertainty, the second version with the extra view is considered to be easier and faster to understand. On the other hand, the first version is more complex and harder to understand, as the user needs to first recognise which information belongs to the uncertainty and which does not. Disadvantageous for the second version may be the fact that the user needs to connect not only three, but rather four views, which demands for a higher cognitive load. In addition, having only one visualisation of the uncertainty may be a problem if the user does not understand the visualisation. In this case, the user cannot extract the uncertainty information, whereas this could have been facilitated by another visualization of the information in the first version.

Based on these sub-hypotheses, the following main hypothesis was established. The first version is considered to entail less cognitive load and connects the attribute and uncertainty information faster. In addition, different visualizations of the uncertainty information give the user a better understanding of the uncertainty information. This version is supposed to need more time to understand all the information in the beginning, but will then lead to a deeper understanding.

5.1.2 Test users

First, suitable test users had to be found. The interface should mainly be used by people interested in the historical situation. Therefore, people interested in history and people with a relationship to geography or cartography were chosen as test users. An online questionnaire (Appendix 2 and 3) was sent to people that could fit the required profile. The questionnaire included questions that asked for the people's knowledge about cartographic interfaces, their general interest in history, Napoleon's Campaign and the crossing of the Berezina. After analysing all the submitted answers from the online questionnaire, the test users were classified into two different control groups, each consisting of eight people. Both control groups should be as equal as possible with regard to gender, age and knowledge of cartographic interfaces or history. In total 16 test users were selected. They were divided into two groups so that each group consisted of 2 male persons with geo background, 2 female persons with geo background, 2 male persons with history background and 2 female persons with history background. In addition, the test users were classified by age and history knowledge. In the online questionnaire the test users were asked to indicate their interest in history on a scale from 1 (not interested) to 5 (very interested). On this basis, the test users were divided into the two control groups CMV 1 and CMV 2 (Figure 5.1). CMV 1 has an average age of 28.3 years and an average history knowledge of 3.625. In CMV 2, the average age is 26.7 years and the average history knowledge is 3.875.

CMV 1 (uncertainty integrated)	CMV 2 (extra view)
Geo1	Geo2
Geo3	Geo4
Geo5	Geo7
Geo6	Geo8
History2	History1
History4	History3
History7	History5
History8	History6

Figure 5.1: Overview of the two control groups

5.1.3 Test preparation

Before the real test sessions could start, a pilot test was started. The pilot test was conducted with a person who could fit the “interested in history” profile. The only problem that occured during the test was that he did not recognize the buttons in CMV 1 (uncertainty integrated into the data views). In order to avoid this problem during the test, a kind of layout plan was created and given to the test users before the actual test started. In addition, the camera was replaced as the original one was not working properly.

The actual user tests were conducted between 14 October and 2 November 2014. Most of the tests were held in a quiet room in the Cartography Institute at the Dresden University of Technology (TUD). Three tests were held at the test user’s home, as they could provide a second computer screen. All the other equipment needed, including a laptop, a camera, a tripod and a mouse, could be provided by me or the Cartography Institute. One test had to be conducted without a second computer screen. Because of a power failure at the TUD, the user test had to be moved spontaneously to another place. The actual test procedure consisted of three parts: In the introduction part, the users had to read an introduction script, sign a consent form and answer three test questions to practise the think-aloud method. The second part was the question part. In this part, the people were asked seven questions. In the last part, the users had to fill in a feedback questionnaire. The whole test procedure took about 30 min. Only three of the tests were held in English, as all the other test users were German-speaking. Therefore, two similar versions (German and English) were made of all the documents (consent form, introduction script, test plan, feedback questions). All the documents can be found in the appendices (Appendix 4 and 5).

The technical details of the software and hardware used are as follows:

Hardware:

- Acer Extensa 5235 Notebook
- LG Electronics W2343T computer screen (for the tests done at the Cartography Insitute)
- ISY IMC 1000 mouse
- Panasonic Lumix DMC-FZ38

Software:

- Operating system: Win7
- Browser: Google Chrome, Version 38.0.2125.104
- Screen logging software: Camtasia Studio 8, Version 8.4.3.1792

5.1.4 Testing phase

Before the actual test started, the test users were given an layout plan to make them aware of all elements included in the CMV. Afterwards, the real test started. The test consisted of seven main questions, which were followed by two sub-questions. After giving an answer to the main question, the users were each time asked to indicate their (un-)certainty about their answer on the Likert scale. The Likert scale is a fixed response format and is used to measure attitudes or opinions (SimplyPsychology, 2008). The scale used for this study ranges from 1 to 5, where 1 indicates uncertain and 5 means certain. The second sub-question that was asked after each main question referred to other answers that could be given to the previous asked main question.

The following sections present the seven main questions and indicate the correct answers. As it is not possible to extract the exact numbers that were asked for from the diagrams, all answers that pointed in the correct direction were considered correct. Thus, if people showed that they understood the principle of the visualization but could not manage to extract the exact number, that was considered a correct answer.

Test questions

The main goal of the three test questions was to familiarise the user with the interface, to practise the think-aloud method and to direct attention to all the data views. The three test questions were A: “Which corps moved southwards after crossing the bridge?” (map view), B: “Which corps crossed the Berezina last?” (time view) and C: “Which corps had the highest variability in the number of soldiers?” (attribute view or rather attribute and uncertainty view). The correct answers to these questions were A: Corps II, B: Corps IX and C: Corps IX. All test persons were able to answer these questions correctly.

Question 1

The first main question was “How many soldiers have been invoved in Corps II before the crossing?”. The correct answer to this question should have been 8113. Nevertheless, because of the readability of the attribute view most users answered this question with “8000”, which was accepted as a correct answer. Afterwards, people were asked for other possible answers. This question could be answered within a range from 7000 to 9300. The user's accepted answers were spread mainly over a range from 7000 to 9000.

Question 2

The second question was "How many soldiers have been involved in the Imperial Guard Old before the crossing?". The test users' answers covered a range from 5000 to 5500, whereas the correct answer would have been 5306. All answers to this question were considered correct. The correct answer to the subsequent sub-question should have been a range from 4880 to 5945. The test users mainly answered with 5000 to 6000. Some of the answers already started at 4500 or 4800. Two users could not answer this question correctly.

Question 3

"Which Corps was the biggest before the crossing?" was the third question. The only possible answer to this question was Corps IX, as all users gave. One person indicated that another answer was possible to this answer, which is actually incorrect.

Question 4

The fourth question was "Which one was bigger before the crossing: Corps III&V or Imperial Guard Old?". All test users answered with Imperial Guard Old, as this is the more obvious answer. But as the two uncertainty ranges overlap, it was also possible to answer with Corps III&V. 81.25% were able to indicate this when they where asked for another possible answer.

Question 5

"How many soldiers of Corps I&IV could cross the Berezina?" was question five. The test users' correct answers covered mainly a range from 1000 to 1300, whereas the exact answer should have been 1237. Only one person failed to answer this main question. 31.25% could not give correct other answers to the second sub-question. Based on the uncertainty range, other answers would have been possible in a range from 1100 to 1550. The accepted answers of the test users ranged from 800 to 1700.

Question 6

The sixth question was "How many soldiers of Corps IX could cross the Berezina?". All people were able answer this main question correctly and gave answers in a range from 6000 to 7000. The exact answer should have been 6625. Other possible answers range from 5000 to 9400.

Only two test users were not able to answer this sub-question, while the other users' answers ranged from 4500 to 9800.

Question 7

The last question was "Which Corps was the smallest after crossing the bridge?". The most obvious correct answer to this question is Imperial Guard Young. Only one test user answered Corps I&IV, which is actually a second possible answer. 18.75% could not answer this question correctly. Another 18.75 % gave another answer: Corps III&V. In fact, this answer was to be considered correct as well, as in the case of the minimum number of soldiers of Corps III&V and the maximum number of soldiers of Imperial Guard Young, these two would be of equal size.

After the question part, the test users were asked to complete a simple feedback questionnaire. It consisted of two questions, namely "What did you like about this CMV?" and "What didn't you like about this CMV?".

5.2 Analysis of the outcome

The two versions are analysed with reference to the questions "Which version visualizes uncertainty in a way that the user can answer the questions more correctly?", "Which version visualizes uncertainty in a way that the user can answer the questions faster?" and "Which version do the users like more/most?". The following section analyses the two versions in detail in terms of their effectiveness, efficiency and user satisfaction.

5.2.1 Uncertainty in all data views

In order to analyse the effectiveness of this version (CMV 1), a closer look at the given answers is needed (Figure 5.6). Only 50% of the users of this group were able answer all the questions correctly. The other 50% gave a total of 12 incorrect answers, which means that 21% of all given answers were considered as incorrect answers. One interesting aspect here is the distribution of the wrong answers. The incorrect answers do not follow any pattern but rather seem to be randomly spread.

Time measurements in think-aloud tests have to be handled carefully as people have different rates of speaking or thinking. Some people's answers are more detailed, some's are less.

Nevertheless, it is worth taking a look at the time the users needed to answer the questions, in order to analyse the efficiency of this version. On average, the test users needed about 322.5 s in total to answer all the questions. Figure 5.2 shows the average time needed to answer the single questions. It is noticeable that, especially in the beginning, it took quite a lot of time to find an answer. In the course of the question part, less time was needed to answer the questions.

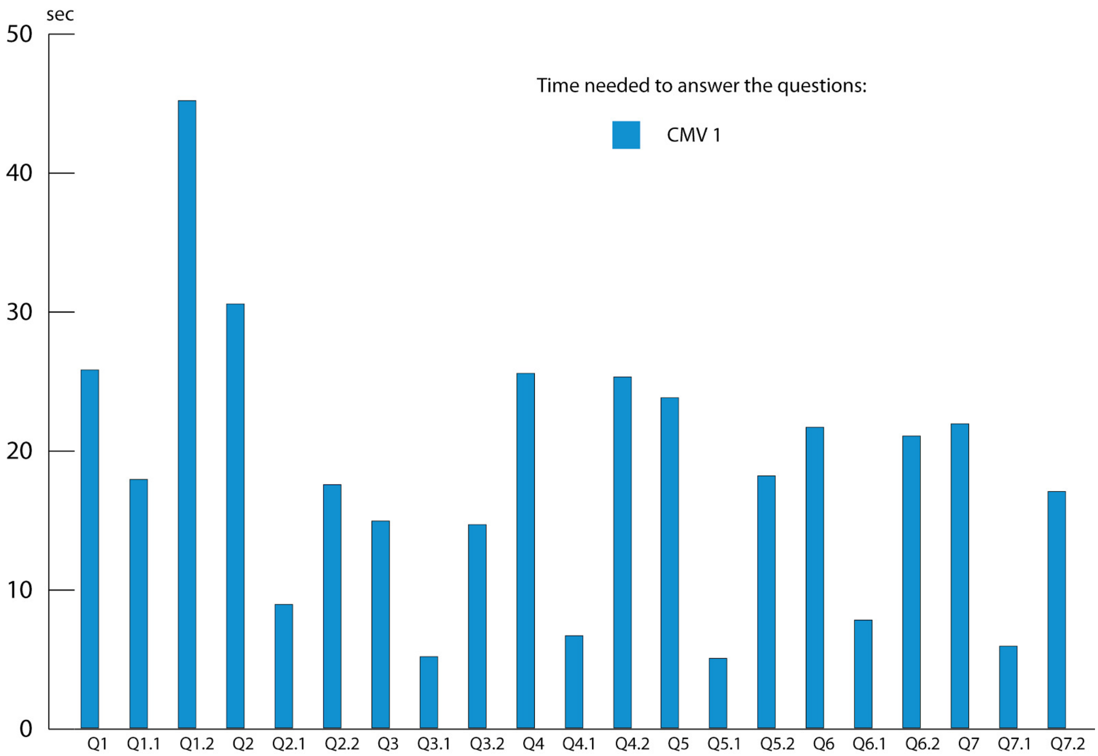

Figure 5.2: Average time needed to answer the questions in group CMV 1

The feedback (Figure 5.3) given by the users is not so meaningful. Most of the positive feedback is not specific to one of the visualization techniques, such as “colours”, “clarity of the interface” and “coordination of the views with mouseover”. The same applies for the negative feedback. “scale of the map and attribute view”, “map is too simple” and “only in English” are valid for both visualization techniques. Nevertheless, there are a few criteria that are only valid for one of the two visualizations. Some of the test users liked the uncertainty ranges in the attribute view and mentioned that this version is self-explanatory. The users did not like the complexity of the CMV. Contradictory to the positive feedback, some of the users were not satisfied with the uncertainty ranges in the attribute view. One user suggested integrating the uncertainty information in the time view. Only one of the users who answered one or more questions incorrect was not satisfied with the complexity of the interface.

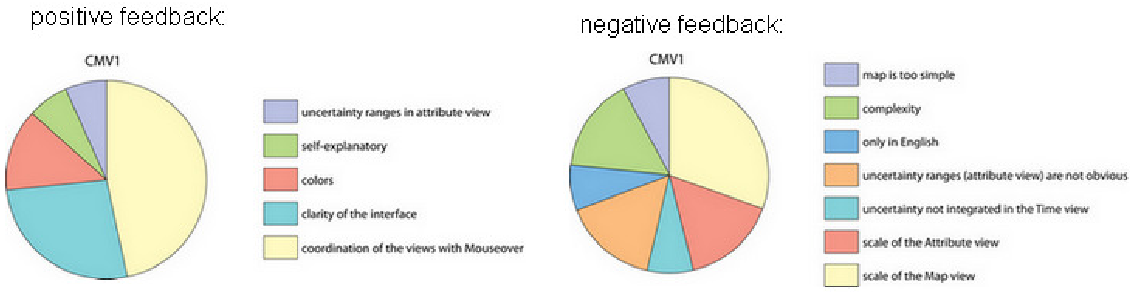

Figure 5.3: User feedback group CMV 1

5.2.2 Uncertainty in an extra view

At first, the effectiveness of this version (CMV 2) was also analysed. 62.5% of the users answered all questions correctly (Figure 5.6). In total, ten incorrect answers (17,8%) were given. What is noticeable about this version is the fact that one of the test users (Geo7) did not understand the visualization of the box plot. Therefore, this user answered every sub-question incorrectly which means that seven of the ten worng answers were given by this one user.

In order to analyse the efficiency of this version, it is again necessary to look at the time needed to answer the questions. The average time needed to answer all questions was 281.5 sec. Especially interesting is the average time needed to answer each question. Figure 5.4 shows that there are no big time differences between the first and last questions. The test users answered the questions quickly from the beginning, without any major improvements towards the end.

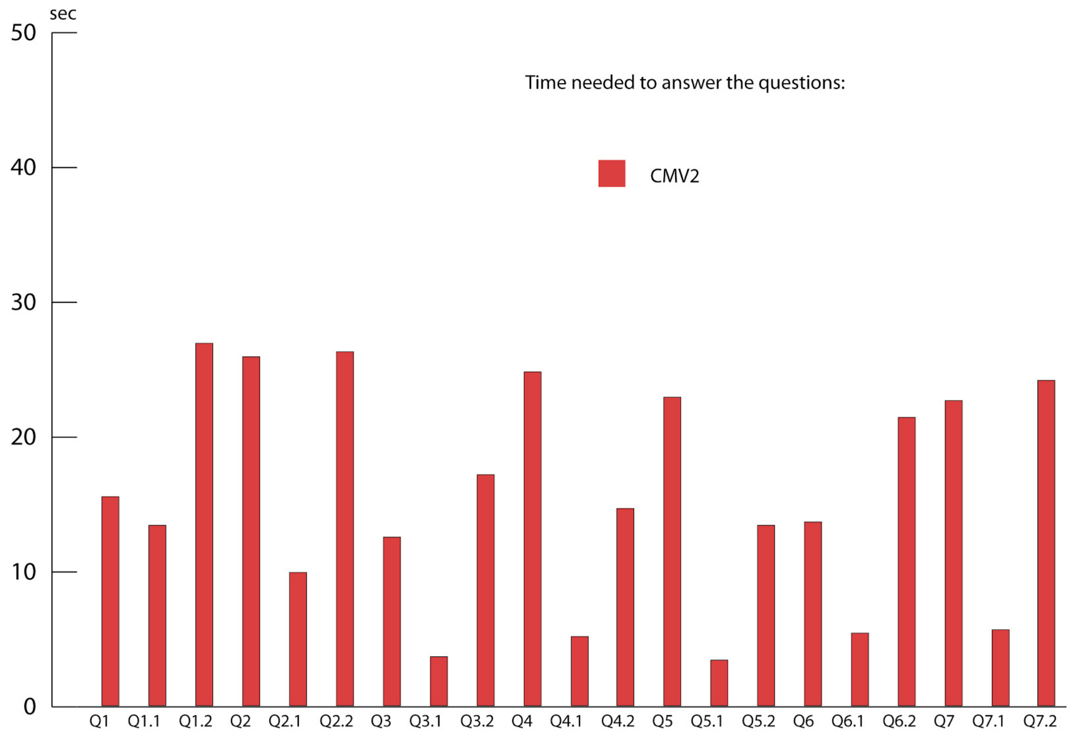

Figure 5.4: Average time needed to answer the questions in group CMV 2

As already explained in section 5.2.2, most of the user feedback given is not very meaningful as it is valid for both versions. Looking at the criteria that are only valid for this version, it can be seen that the users liked the uncertainty view. Especially the test users who gave incorrect answers were not satisfied with the complexity of the CMV. In addition, one user suggested combining the attribute and uncertainty views. This would in fact produce the visualization used in the attribute view of the other version (CMV 1, uncertainty integrated into the data views).

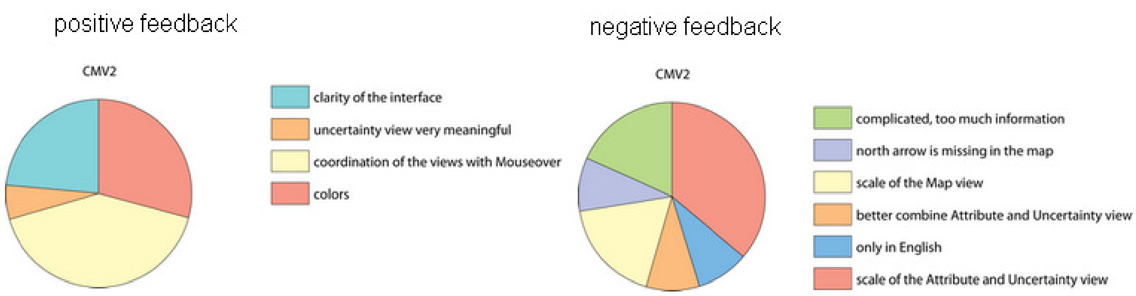

Figure 5.5: User feedback group CMV 2

5.3 Conclusion

As explained in sections 5.2.2 and 5.2.3, there were 12 incorrect answers in the CMV 1 group and ten in the CMV 2 group (Figure 5.6). The ratio of wrong answers between the two versions stands out even more clearly if the user who did not understand the visualization of the boxplot (Geo7) is excluded. In that case, there are only three incorrect answers for version CMV 2. Referring to chapter 2.4.1, where effectiveness is defined as "the accuracy and completeness with which the user can achieve the desired (sub-)goals", this results indicates that version CMV 2 can be considered more effective.

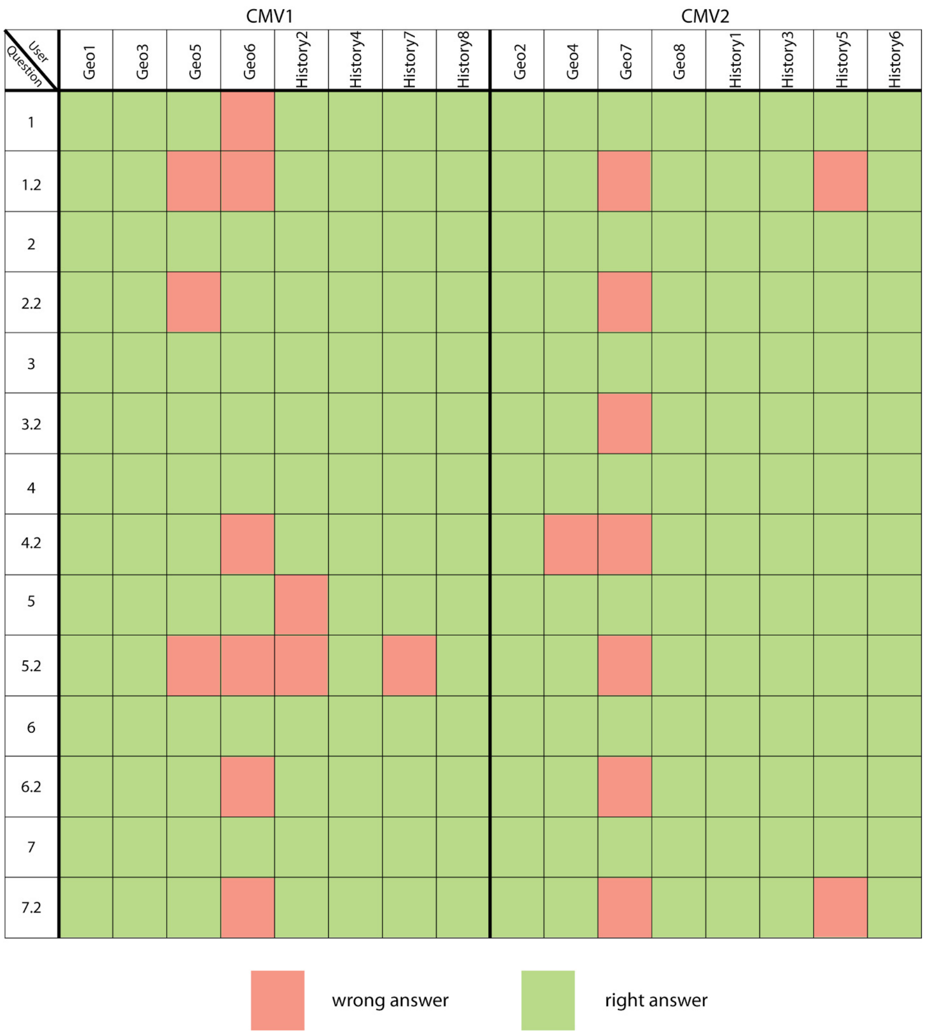

Figure 5.6: Overview of the given answers

In order to analyse the efficiency of the two versions, it is necessary to look at the time measurements. As explained earlier, time measurements in think-aloud tests may be erroneous and therefore have to be considered carefully; they are nevertheless worth looking at (figure

5.7). What stands out at first sight is question Q1.2. It shows that group CMV 1 needed quite a lot of time to answer this question. A possible explanation for this could be that, especially in the beginning, the users of group CMV 1 needed more time to understand the CMV. Looking more closely, it can be seen that there are only 6 of 21 questions where group CMV 2 needed more time to answer (Q2.1, Q2.2, Q3.2, Q6.2, Q7, Q7.2). Only two of those six needed considerably more time (Q2.2 and Q7.2). This indicates that the users of group CMV 1 generally needed more time to find the answers. This statement is also supported by the average total times needed to complete all the questions. The test users of group CMV 2 were on average 50 s faster than the users of group CMV 1. A closer look at all the questions Q*.1 points out another interesting fact. The Q*.1 questions always asked for the user's (un-)certainty about the previously given answer to the main question. The test users of group CMV 1 needed on average 10 s more in total to answer these questions. This shows that the users needed more time to decide about their (un-)certainty. Based on all these facts and the definition of efficiency from chapter 2.4.1, the conclusion can be drawn that the users worked more efficiently with version CMV 2.

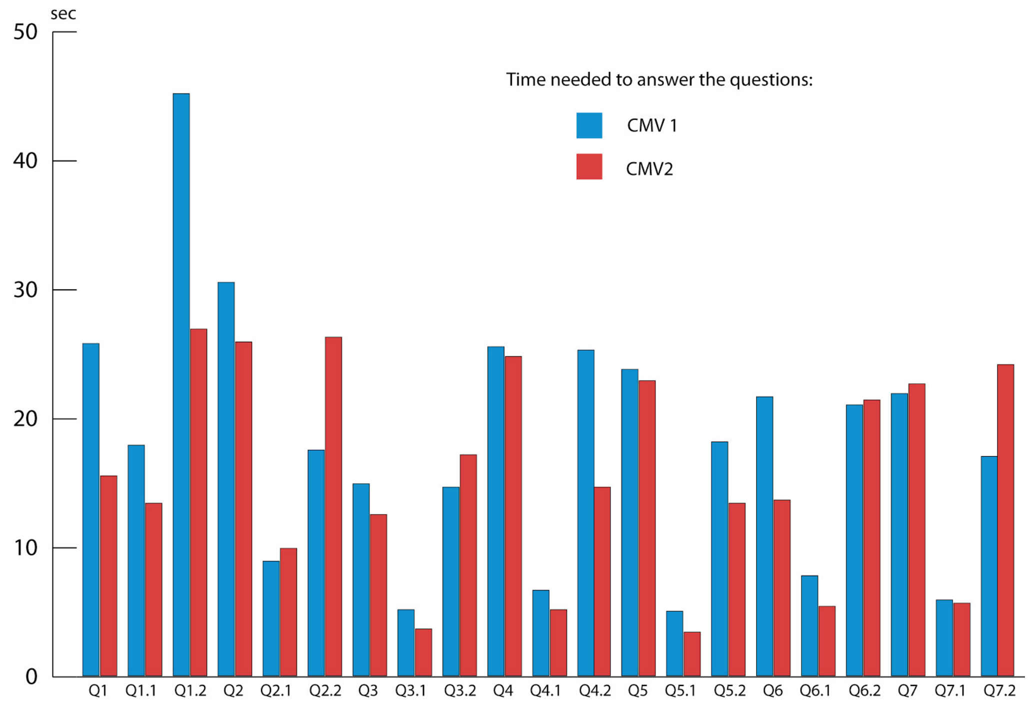

Figure 5.7: Comparison of the time needed to answer the questions in both versions

In comparison to the results of the effectiveness and efficiency analysis, the results of the user feedback are not so clear. As described earlier in sections 5.2.2 and 5.2.3, most of the feedback given is valid for both versions. Only a few criteria gave an impression of what the test users liked or did not like especially about their particular versions. In general, however, those criteria are not so significant that a decision can be made as to which of the two versions is more satisfying. On the contrary, the test users gave the impression that they were generally satisfied with their versions during the usability test.

Besides these results relating to the effectiveness, efficiency and user satisfaction of the two versions, another intersting fact can be seen. Independently from the two versions, the test users with geo background gave 77 % of the incorrect answers and needed on average 50 s more in total to answer the questions. This shows that the test user’s background influences the results. The test users with history background have been working more effective and efficient with the interfaces.

In addition to the effectiveness, efficiency and satisfaction, user interaction was analysed based on the screen logging data. With the help of a pixel raster, the frequency of actions per pixel was counted. Figure 5.8 shows the frequency of user actions per pixel. No attention was paid to the duration of user actions per pixel in this analysis. The figure illustrates that the users were working mainly with the map and the attribute view, but nevertheless paid considerable attention to all three views. There are two possible explanations for that: 1) the test users were animated to use all three views, or 2) the test users were confused by the single views and tried to work with all three views in order to find the answers. Referring to the results from the effectiveness and efficiency analysis, it is more likely to be the latter explanation, as this explains why the test users of group CMV 1 worked less correctly and more slowly.

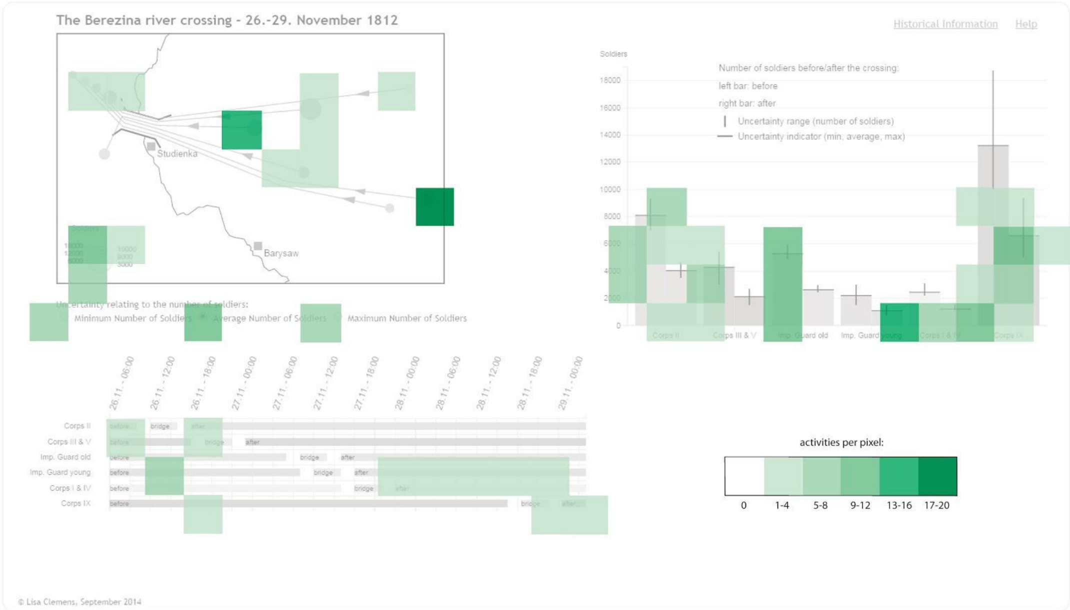

Figure 5.8: Frequency of user actions in CMV 1

Another picture can be seen when the frequency of actions per pixel is analysed in CMV 2 (Figure 5.9). The user interaction in this version concentrates mainly on the uncertainty and on the attribute view. Referring to the effectiveness and efficiency analysis, this indicates that the test users in this group quickly understood which parts of the interface are important and useful to find the answers. The figure shows that the test users concentrated mainly on these parts. Although this version did not animate the users to interact with all views, this figure shows clearly why the users of this group worked more correctly and faster.

Figure 5.9: Frequency of user actions in CMV 2

Comparing these results to the hypothesis (section 5.2.1) reveals that the empirical study confuted the hypothesis. The results illustrate that the first version (CMV 1) needs too much time to understand and is too complicated. In contrast to the hypothesis, the second version (CMV 2) was easier and faster to understand. The analysis showed that the first version is disadvantageous because of its complexity. On the other side, the second version was advantageous in matters of clarity and time needed to understand. In addition, it was not a problem for the user to connect four views. Nevertheless, it is disadvantageous for version CMV 2 if the user does not understand the uncertainty view.

Based on the prediscussed results of this study, the second version (CMV 2, uncertainty in an extra view) can be recommended. This version is more effective and efficient and is satisfying for the user, although it is not more satisfying than the other version. Nevertheless, other results may be possible if other visualization techniques or datasets are used. At this point, further research needs to be done in order to develop more universal valid results. In addition, this result can be only seen as a trend because of the small number of test users. More tests need to be done in order to gain more universal valid results.

6 Summary and outlook

The last chapter summarizes the findings of the thesis by answering the research questions. The introduction of the thesis (chapter 1.3), framed a number of research questions in order to explore, analyse and evaluate the methods of uncertainty visualization in CMVs. This chapter gives answers to these research questions. Afterwards, open research questions are pointed out.

6.1 Answers to the research questions

The nine research questions given in the introduction chapter have been answered within this thesis. Summaries of the findings to each research question are given below.

- What kinds of graphic representations are currently used to visualize uncertainty?

According to the characteristics of the uncertain data, the techniques can be classified into qualitative or quantitative, static or dynamic, intrinsic or extrinsic, and explicit or implicit uncertainty visualization techniques. Especially interesting for this thesis is the distinction of techniques integrating the uncertainty in every data view (coincident) and the implementation of an additional uncertainty view (adjacent). Possible visualization methods include the use of symbol focus methods such as varying contour crisp- or fuzzyness, manipulated fill clarity, fog or adjusted resolution. Another method is the use of the graphic variables to visualize uncertainty. Other static techniques include the use of additional geometric objects, such as glyphs, labels, isosurface views, error bars or grid-based annotation lines. Dynamic visualization techniques use dynamic variables, such as speed, blinking or motion blur. It is also possible to indicate uncertainty by addressing the acoustic or haptic senses with sound, touch or vibration.

- Which techniques will be used for evaluating the usability?

Several techniques such as online questionnaires, eyetracking and think-aloud tests have been discussed for the usability test. In the end a combination of a think-aloud test, video recording and screen logging was used, with additional questionnaires before and after the actual user test. An online questionnaire was used to select appropriate test users, and the think-aloud test, video recording and screen logging were used to analyse the effectiveness and efficiency of the tested

CMV. Afterwards, a feedback questionnaire gave an impression of the test users' satisfaction with the interface.

- What are the spatial and temporal characteristics of the case study dataset(s)?

Napoleon's Campaign in Russia 1812 was one of the greatest upsets in the military history. The army was the biggest the world had seen until then. The routes of Napoleon's Campaign are located in the area of todays Lithuania, Belarus and Russia. The Battle of Berezina took place from 26 to 29 November 1812, between the French army of Napoleon, who was retreating after his invasion of Russia and wanted to cross the Berezina, and the Russian armies. The battle was the last one during Napoleon's campaign in Russia. It ended with a mixed outcome, as the French troops lost many soldiers during this battle, but finally could cross the river. The data used provided individual information about the numbers of soldiers for each corps. The uncertainty relates to the number of soldiers, as four different sources indicate different numbers. In addition, the dataset provides information about the exact date and time of the crossing of the Berezina by each corps.

- How can the visualization techniques be implemented in a CMV environment?

There are two possible techniques to implement uncertainty visualization in a CMV environment. The first technique integrates uncertainty into all data views, whereas the second technique provides an extra uncertainty view. As the goal of this study is to analyse which of these two techniques is more effective, efficient and satisfying, it is important to implement both versions as similarly as possible. Both versions should provide the same possibilities to extract the uncertainty information.

- How can these ideas be implemented in (a) all data views, and (b) a special uncertainty view?

As discussed in chapter 4, there are several possible visualization techniques. For the integration of the uncertainty into all data views (a)) several techniques have been discussed, especially for the map view, such as nested rings or circles or colour intensity. Due to readability or complexity problems, an implicit technique was chosen in the end. The user can switch between the minimum, average and maximum numbers of soldiers with the help of radio buttons. For the attribute view, an extrinsic approach was used. An error bar indicates the uncertainty range on the basis of a bar chart showing the average number of soldiers for each corps. The uncertainty has not been integrated into the time view, as it only relates to the number of soldiers and does not vary over time. In addition, not representing uncertainty in this view avoids too much complexity and confusion for the user. For the second version (b)), the visualization of a box plot was chosen as this is quite similar to the chosen visualization of the attribute view in the first version. The visualization technique of a grouped bar chart was dismissed due to the constraint that the users should be able to extract the same information from both versions.

- How can the effectiveness, efficiency and user satisfaction of the developed visualization methods be tested?

For the empirical study, a combination of different usability methods has been chosen. A combination of a think-aloud test, video recording and screen logging was used during the question part. A questionnaire was used to select appropriate test users. A feedback questionnaire gave an impression of the users' satisfaction with the tested CMV. To analyse the two different versions, two control groups were formed. Each control group analysed one CMV. The control groups consisted of equal proportions of people related to geo and people interested in history.

- How to setup the usability evaluation?

First, appropriate test users were selected with the help of an online questionnaire, which was sent to users that could fit the profile. Afterwards, the users were split into groups that were equal in terms of gender, age, and history or geographic knowledge. The second part of the empirical study was the actual usability test. After reading an introduction script and signing a consent form, the users were asked seven main questions, each followed by the same two sub-questions. The first sub-question asked for the user's (un-)certainty about the given answer to the previous main question, while the second sub-question asked for other possible answers to the main question. After the question part, the users were asked to fill in a feedback questionnaire that asked what the liked and what they did not like about the tested CMV. For all the documents (online questionnaire, introduction script, consent form, test plan, feedback questionnaire), see the appendix. Most of the tests were conducted in a quiet room at the Cartography Institute of the TUD. Three tests were held at the test user's home. Another three tests were conducted in English, whereas the rest of the tests were conducted in German.

- How effective, efficient and satisfying are the methods used to visualize uncertainty in a CMV environment?

Working with the first version (uncertainty integrated into the data views) needed more time to answer the questions and resulted in fewer correct answers (21% wrong answers). In contrast, the test users of the second version (uncertainty in an extra view) were able to answer the questions faster and more correctly. This becomes all the more evident when the user (Geo7) who did not understand the visualization of the boxplot is excluded (5% wrong answers). The users of group CMV 2 were on average 50 s faster in total than those of group CMV 1 while answering all questions. Hence, the conclusion can be drawn that working with the first version is less effective and less efficient than working with the second version.

- Which representation technique can be recommended based on the usability tests?

Based on the results of the study, the second version (uncertainty in an extra view) can be recommended. This version is more effective and more efficient than the first version (uncertainty integrated into the data views). Both versions satisfied their users, but working with the second version led to faster and more correct results. Nevertheless, the second version may be disadvantageous if the user does not understand the visualization of the uncertainty view.

6.2 Further research

Performing just one usability test with only one dataset does not give a universal result. What has been analysed in this study gives only results for the visualization of uncertainty in CMVs in connection with this specific dataset and these specific visualization techniques. Tests with similar datasets and similar visualization techniques may prove this result. On the other hand, performing the test with other visualization techniques or datasets may already lead to different results. Therefore, the findings need to be handled carefully and further research needs to be done.

On the visualization side, it is necessary to perform the same research with different visualization techniques, in order to analyse the effect of different visualization techniques on the results of this study. Changing the visualization may effect the user's understanding of the data and therefore also change the results of the study. It needs to be analysed whether other visualization techniques would derive the same or different results. In addition, a different dataset may change the results as well. From the point of view of usability testing, it is necessary to analyse whether a different group of test users or a different usability testing method gives another result. Furthermore, the results have to be considered carefully because of the small number of test users. The results of the empirical study would become more reliable if other usability testing methods were to confirm them. In addition, this thesis has not yet discussed the question of the effect of testing a CMV with three views versus a CMV with four views. It is possible that performing the same study with two CMVs each with three views may lead to different results.

This master thesis is only a small piece of the work that can be to analyse uncertainty visualization in CMVs. As pointed out above, it does not provide a universal result. Additional studies should analyse the effects of different visualization techniques, datasets or usability tests on these results. Further research needs to be done in oder to achieve universal results.

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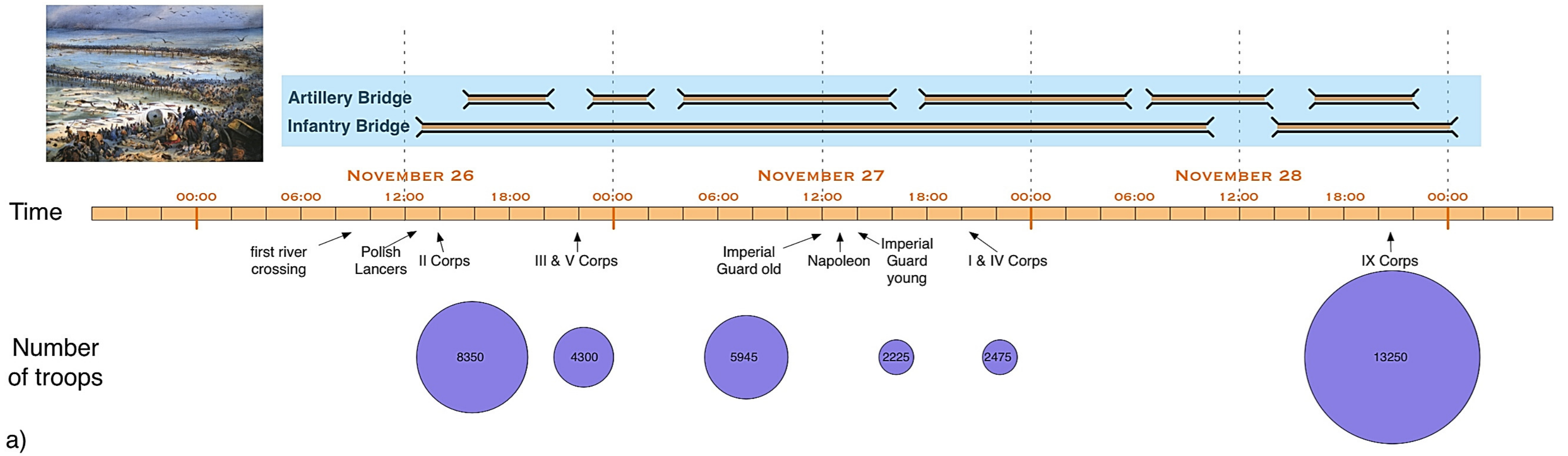
Appendices

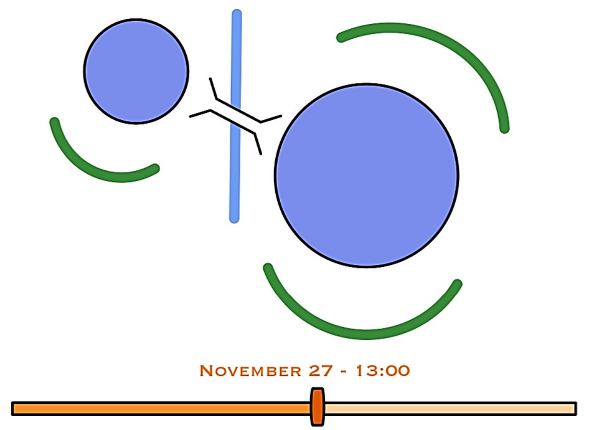
Appendix 1

Graphic with the data used for the implementation (provided by the Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente)

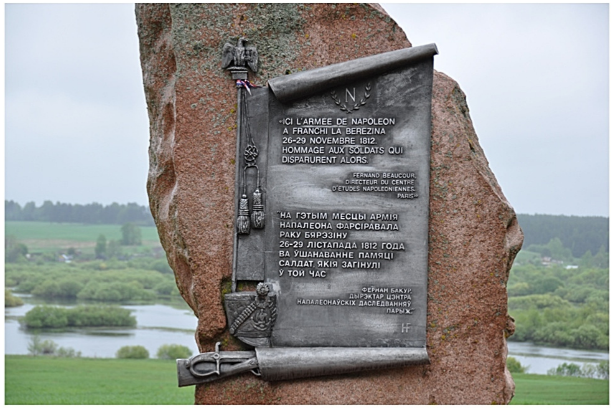


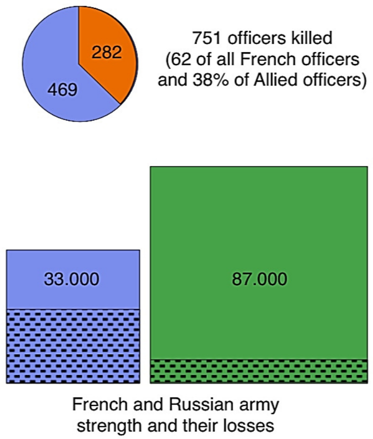
a)

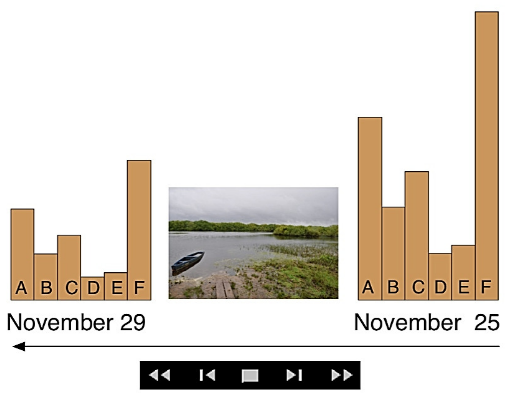
b)

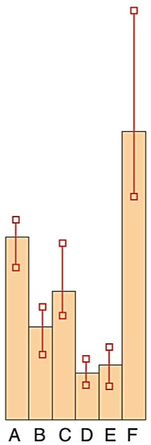


c)









Size of the French army
estimates by:

	Chambray	Wilson	Fain	Gourgaud
A. II Corps	7000	7800	9300	8350
B. III & V Corps	3000	3400	5400	5400
C. Imperial Guard (old)	4900	5500	4880	5945
D. Imperial Guard (young)	1500	3000	2200	2200
E. I & IV Corps	2400	3100	2200	2200
F. IX Corps	18800	13200	10000	11000

d)

MJ 6-7

Appendix 2

Online questionnaire used to select and classify the test users (English)

Empirical Study - Uncertainty visualization in CMVs

(english)

* Required

1. **Name** *

2. **Gender** *
   Mark only one oval.
   - male
   - female

3. **Age** *

4. **What is your profession?** *
   Mark only one oval.
   - researcher
   - student
   - teacher
   - Other:

5. **Are you colorblind?** *
   Mark only one oval.
   - yes
   - no

Education

6. **What is your highest level of education?** *
   Mark only one oval.
   - secondary school
   - vocational training
   - university of applied science
   - university
   - Other:

7. **What was/is the field of study?** *
   Mark only one oval.
   - cartography, geoinformatics, geography
   - history
   - computer science
   - social studies
   - natural science
   - Other:

Computer Skills

8. **How often do you use a computer?** *
   Mark only one oval.

   every day
   a couple of times per week
   once a week
   a couple of times per month
   once a month
   never

9. **How often do you use the internet?** *
   Mark only one oval.

   every day
   a couple of times per week
   once a week
   a couple of times per month
   once a month
   never

10. **How often do you use use interactive (carto-)graphic interfaces (e.g. Google Maps, Bing Maps, ...)?** *
   Mark only one oval.

   every day
   a couple of times per week
   once a week
   a couple of times per month
   once a month
   never

History knowledge

11. **How much are you interested in history?** *
   Mark only one oval.

	1	2	3	4	5	
not interested						very interested

12. **What do you know about these historic phenomena?** *
   Mark only one oval per row.

	nothing	a little bit	basic knowledge	a lot
Napoleon's Campaign in Russia 1812				
Crossing of the Berezina River 26-29.11.1812				

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Appendix 3

Online questionnaire used to select and classify the test users (German)

Empirische Untersuchung - Unsicherheitenvisualisierung in CMVs

(deutsch)

* Required

1. **Name** *

2. **Geschlecht** *
   Mark only one oval.
   - männlich
   - weiblich

3. **Alter** *

4. **Was ist ihr Beruf?** *
   Mark only one oval.
   - Forscher
   - Student
   - Lehrer
   - Other:

5. **Sind sie farbenblind?** *
   Mark only one oval.
   - Ja
   - Nein

Ausbildung

6. **Was ist ihr höchster Bildungsabschluss?** *
   Mark only one oval.
   - Gymnasium
   - Ausbildung
   - Fachhochschule
   - Universität
   - Other:

7. **Was war/ist das Studienfach?** *
   Mark only one oval.
   - Kartographie, Geoinformatik, Geographie
   - Geschichte
   - Informatik
   - Sozialwissenschaften
   - Naturwissenschaften
   - Other:

Computerfähigkeiten

8. **Wie oft benutzen sie den Computer?** *
Mark only one oval.

- jeden Tag
- mehrmals die Woche
- einmal in der Woche
- mehrmals im Monat
- einmal im Monat
- niemals

9. **Wie oft benutzen sie das Internet?**
Mark only one oval.

- jeden Tag
- mehrmals die Woche
- einmal die Woche
- mehrmals im Monat
- einmal im Monat
- niemals

10. **Wie oft benutzen sie interaktive (karto-)graphische Interfaces? (z.B. Goolge Maps, Bing Maps, ...)** *
Mark only one oval.

- jeden Tag
- mehrmals die Woche
- einmal in der Woche
- mehrmals im Monat
- einmal im Monat
- niemals

Geschichtswissen

11. **Wie sehr sind sie an Geschichte interessiert?** *
Mark only one oval.

	1	2	3	4	5	
nicht interessiert						sehr interessiert

12. **Was wissen sie über diese historischen Szenarien?** *
Mark only one oval per row.

	nichts	ein wenig	Grundwissen	viel
Napoleon's Russlandfeldzug 1812				
Überquerung des Berezina Flusses 26-29.11.1812				

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Appendix 4

Documents used for the empirical study (English)

- Consent form
- Introduction script
- Test plan
- Feedback questionnaire

Consent form

I declare that I received the information about the study

„The effectiveness of uncertainty visualization in a 'Coordinated Multiple View' environment using a temporal dataset (casestudy)"

and this consent form for the participation in this study.

I have been informed about this empirical study sufficiently oral or in a written form.

I agree that data about me will be collected and recorded within this study. It is guaranteed that individual-related data will not be handed to a third party.

I know that picture and sound recordings will be made at my session.

I agree with the as aforesaid explained procedure and confirm this with my signature. I grant the permit to use these recordings within scientific research.

Subject

Place: ____

Date: ____

Name: ____

Signature: ____

Introduction skript

We are here to test the visualization of uncertain data in so-called “Coordinated Multiple View” environments. Coordinated Multiple Views show different views of a data set in different windows in one screen. These views are coordinated with each other which means that interaction in one view leads to the automatic adoption of the other views. During this study, uncertain data has been visualized in these Coordinated Multiple View environments and two different versions have been developed. The goal of this study is to analyze which one of these two versions visualizes the uncertain data more effective and efficient and pleases the user more while working with it. You are going to test one of the two versions during this session.

I will ask you to answer some questions during the interaction with the interface. Try to do your best but do not worry about your success. The interface will be tested, not you! My role today is to record the advantages and disadvantages of this version seen from your point of view. It is important for me to get your real, honest opinion.

In order to follow your thoughts during the test, I ask you to “think aloud”. This means that you should comment all your actions and impressions. Please ask questions at any time, however I probably won’t answer them before the end of the test.

I will make some notes while you are working. In addition, picture and sound recordings of you will be made which will be used for the analysis of the study later.

If you feel unwell, you can quit the test at any time.

Before we start, I’ll give you some historical background information: Napoleon's Campaign in Russia 1812 was one of the greatest upsets in the military history. The troop was the biggest the world had seen until then. The Battle of Berezina took place from 26 to 29 November 1812, between the French army of Napoleon, who was retreating after his invasion of Russia and wanted to cross the Berezina, and the Russian armies. The battle was the last one during Napoleon's campaign in Russia. It ended with a mixed outcome as the French troops lost many soldiers during this battle but finally could cross the river.

As mentioned earlier, uncertain data has been visualized in these Coordinated Multiple View environments. In this case, the uncertainty relates to the number of soldiers which have been involved in the crossing of the Berezina. Four different sources state the number of soldiers differently. Therefore, the in the interface visualized numbers have to be considered with this knowledge in mind. This uncertain data has been integrated in the different data views in one of the versions and has been visualized in an extra view in the other version.

Do you have any questions?

If not, then let’s start.

task nr.	description	max. time (only for me)	requirements, comments (only for me)
0	*test task (a-c)* Before we start, we'll do some little test task to practise the "thinking aloud". I'll ask you some questions. While you are searching for the answer, please think aloud!		
-	Here is an overview of the interface I will show you. Please have a look at it and make sure you had a look at all elements!	2min	picture
-	Please turn on the screen		screen off
a	Which Corps moved southwards after cossing the bridge?	2min	only one answer possible
b	Which Corps crossed the Berezina last?	2min	only one answer possible
c	Which Corps has the highest variability in the number of soldiers?	2min	only one answer possible
-	Ok, let's start! As we just practised, I'll ask you questions which you answer by thinking aloud.		
1	How many soldiers have been involved in Corps II before the crossing? Think about the different numbers of soldiers stated in the different sources: how certain are you about your answer? On a scale fom 1 to 5 where 1 is uncertain and 5 is certain: how certain are you? Would other answers be possible? Which?	3min	
2	How many soldiers have been involved in the Imperial Guard Old before the crossing? Referring to the different numbers of soldiers in the different sources: how certain are you about your answer on the scale from 1 to 5? Would other answers be possible? Which?	3min	

3	Let’s have a look at all Corps before the crossing: which was the biggest? In relation to the scale: How certain are you abou your answer? Would another answer be possible? Which?	3min	only one answer possible
4	Let’s have a look at Corps III&V and the Imperial Guard Old before the crossing: which one was bigger? Let’s move to the scale again: How certain are you about your answer? Would another answer be possible? Which?	3min	
5	How many soldiers of Corps I&IV could cross the berezina? Back to the scale: How certain are you about your answer? Would other answers be possible? Which?	3min	
6	How many soldiers of Corps IX could cross the berezina? On the scale: How certain are you about your answer? Would other answers be possible? Which?	3min	
7	Which Corps was the smallest after crossing the river? On the scale again: How certain are you about your answer? Would another answer be possible? Which?	3min	
-	That was the last question! But before you are finished, you have to fill in this feedback questionnaire!		

Feedback-Questions

What did you like about this interface?

What didn’t you like about this interface?

Appendix 5

Documents used for the empirical study (German)

- Consent form (Einverständniserklärung)
- Introduction script (Einleitungsskript)
- Test plan (Ablaufplan)
- Feedback questionnaire (Feedback Fragebogen)

Einverständniserklärung

Ich erkläre, dass ich die Information zur Studie

„Zur Effektivität der Visualisierung von Unsicherheiten in 'Verknüpften Mehrfensterdarstellungen' unter Verwendung eines temporalen Datensatzes (Fallstudie)"

und diese Einverständniserklärung zur Studienteilnahme erhalten habe.

Ich wurde für mich ausreichend mündlich und/oder schriftlich über die wissenschaftliche Untersuchung informiert.

Ich erkläre mich bereit, dass im Rahmen der Studie Daten über mich gesammelt und aufgezeichnet werden. Es wird gewährleistet, dass meine personenbezogenen Daten nicht an Dritte weitergegeben werden.

Ich weiß, dass Bild- und Tonaufnahmen von einer Sitzung gemacht werden.

Mit der vorstehend geschilderten Vorgehensweise bin ich einverstanden und bestätige dies mit meiner Unterschrift. Ich gebe die Erlaubnis, diese Aufnahmen im Rahmen wissenschaftlicher Forschung zu verwenden.

Testperson

Ort: ____

Datum: ____

Name: ____

Unterschrift: ____

Einleitungsskript

Wir sind hier um die Visualisierung von unsicheren Daten in sogenannten “verknüpften Mehrfensterdarstellungen” zu testen. Verknüpfte Mehrfensterdarstellungen zeigen mehrere Ansichten eines Datensatzes in verschiedenen Fenstern in einem Bildschirm. Diese Ansichten sind miteinander verknüpft, was bedeutet, dass Interaktion in einer Ansicht zur automatischen Anpassung der anderen Ansichten führt. Im Rahmen dieser Studie wurden unsichere Daten in diesen Mehrfensterdarstellungen visualisiert und zwei verschiedene Versionen entwickelt. Ziel dieser Studie ist es zu untersuchen, welche der beiden Versionen die unsicheren Daten effektiver und effizienter darstellt und den Nutzer während der Arbeit damit mehr zufriedenstellt. Während dieser Sitzung werden sie eine der beiden Versionen testen.

Ich werde sie auffordern, einige Fragen während der Interaktion mit dem Interface zu beantworten. Versuchen sie ihr Bestes, aber machen sie sich keine Gedanken über ihren Erfolg. Das Interface wird getestet, nicht sie! Meine Rolle heute ist es, die Vor- und Nachteile dieser Version von ihnen aus gesehen aufzunehmen. Für mich ist es wichtig, ihre echte, ehrliche Meinung zu bekommen.

Um auch während des Test ihren Gedanken folgen zu können, bitte ich sie “Laut Mitzudenken”. Das heißt, alle ihre Handlungen und Eindrücke mitzukommentieren. Stellen sie auftretende Fragen bitte zu jeder Zeit, allerdings darf ich diese wahrscheinlich erst am Ende des Test beantworten.

Während sie arbeiten, werde ich einige Notizen machen. Außerdem werden Bild- und Tonaufnahmen von ihnen gemacht, welche zur späteren Auswertung der Studie genutzt werden.

Wenn sie sich unwohl fühlen, können sie den Test jederzeit abbrechen.

Bevor wir starten, bekommen sie hier ein paar historische Hintergrundinformationen: Napoleons Russlandfeldzug 1812 war eine der größten Niederlagen in der militärischen Geschichte. Die Truppe war eine der Größten, die die Welt bis dahin gesehen hatte. Die Schlacht an der Berezina fand vom 26. bis 29. November 1812 zwischen der französischen Armee, welche sich nach der Russlandinvasion zurückzog und die Berezina überqueren wollte, und der russischen Armee, statt. Die Schlacht war die Letzte während Napoleons Russlandfeldzug. Sie endete mit einem gemischten Ende bei dem die Franzosen viele Soldaten während der Schlacht verloren, aber letztendlich den Fluss überqueren konnten.

Wie bereits erwähnt, wurden in diesen koordinierten Mehrfensterdarstellungen unsichere Daten visualisiert. In diesem Fall bezieht sich die Unsicherheit auf die Anzahl der Soldaten, die an der Querung der Berezina beteiligt waren. Vier verschiedene Quellen geben die Soldatenanzahl unterschiedlich an. Die in dem Interface angegebenen Zahlen müssen also mit diesem Wissen im Hinterkopf betrachtet werden. Diese unsicheren Daten wurden in einer Version in die verschiedenen Datenansichten integriert und in der anden Version in einer extra Ansicht visualisiert.

Haben sie noch Fragen?

Wenn nicht, dann lassen sie uns beginnen.

Aufgabe Nr.	Beschreibung	Max. Zeit (nur für mich)	Voraussetzungen, Kommentare (nur für mich)
0	*Testaufgaben (a-c)* Bevor wir anfangen, machen wir nun noch einige kleine Testaufgabe um das “laute Mitdenken” zu üben. Dafür stelle ich dir einige Fragen, die du beantwortest. Während du nach der Lösung suchst, denkst du bitte laut mit.	5min	
-	Hier ist eine Übersicht über das Interface das ich dir zeigen werde. Bitte schau es an aber stell sicher, dass du alle Elemente angeschaut hast	2min	
-	Bildschirm anmachen		Bildschirm aus
a	Welche Truppe marschierte nach der Überbrückung südwärts?	2min	nur eine Antwort möglich
b	Welche Truppe überquerte die Berezina als Letztes?	2min	nur eine Antwort möglich
c	Welche Truppe hat die größten Schwankungen bezüglich der Anzahl der Soldaten?	2min	nur eine Antwort möglich
-	Ok, lass uns nun beginnen. So wie wir das gerade geübt haben, stelle ich dir einige Fragen, die du beantwortest, indem du laut mitdenkst.		
1	Wie viele Soldaten waren in Corps II beteiligt vor der Überquerung? Wenn du an die verschiedenen Zahlenangaben in den unterschiedlichen Quellen denkst aus denen die Daten kommen, wie sicher bist du? Auf einer Skala von 1 bis 5 wo 1 unsicher und 5 sicher bedeutet, wie sicher bist du dir? Könnte eine andere Antwort(en) auch möglich sein? Welche?	3min	

2	Wieviele Soldaten waren in der Imperial Guard Old beteiligt vor der Überquerung? Im Bezug auf die verschiedenen Zahlenangaben in den Quellen: Wie sicher bist du dir auf der Skala von 1 bis 5? Wären andere Antworten ebenfalls möglich? Welche?	3min	
3	Betrachten wir alle Truppen vor der Überquerung: welche war die Größte? Bezogen auf die Skala: Wie sicher bist du dir? Wäre eine andere Antwort denkbar? Welche?	3min	nur eine Antwort möglich
4	Betrachten wir Corps III&V und die Imperial Guard Old vor der Überquerung: welche Truppe war größer? Die Skala wieder: Wie sicher bist du dir? Wäre eine andere Antwort denkbar? Welche?	3min	
5	Wieviele Soldaten von Corps I&IV konnten die Berezina überqueren? Gehen wir wieder zur Skala: Wie sicher bist du dir? Welche Antworten wären noch denkbar?	3min	
6	Wieviele Soldaten von Corps IX konnten die Berezina überqueren? Auf der Skala: Wie sicher bist du dir? Welche Antworten wären noch denkbar?	3min	
7	Welche Truppe war nach der Überquerung die Kleinste? Auf der Skala: Wie sicher bist du dir? Wäre eine andere Antwort denkbar? Welche?	3min	
-	Das war die letzte Frage! Aber bevor du fertig bist, musst du noch diesen Feedback-Fragebogen ausfüllen!		

Feedback Fragen

Was mochten sie an diesem Interface?

Was mochten sie nicht an diesem Interface?