User Interaction with Online Geospatial Systems

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Abstract

User interaction with online geospatial systems is an inter-disciplinary research field that combines the two disciplines Human Computer Interaction (HCI) and geographic information sciences. In recent years online geospatial systems have been created for different purposes such as way-finding systems, online atlases and collaborative systems. In order to accommodate the fact that an increasing number of people have access to geospatial data and technology, research has begun to focus on the impact and the utilization of such systems. However few studies regarding the usability of online geospatial systems have been conducted and most of these studies were set up in artificial lab-environments with few mostly poorly described test-users. Furthermore to the best of our knowledge no formal research framework currently exists that allows for analyzing the interaction of real-world users with such systems and that takes into account the spatial nature of these systems.

The goal of this thesis is to show that users, depending on their demographics, experience, skills and context show significant differences in their interaction strategies and performance. Another important factor that has been neglected in many recent laboratory-based usability studies is the user's computer. In this work, we want to show that users, depending on their computer's properties show significant differences regarding their interaction strategies, their performance and satisfaction.

The work in this thesis consists of three parts: 1. the establishment of an evaluation framework that categorizes and defines the interaction of real-world users with geospatial systems. The four main entities of this framework are the user (in terms of demographics, skills, knowledge and context), the system (defined by the interface design, spatial data, spatial functions, technologies and architectures), the user interaction (interaction strategies, performance and perception of spatial data), and the satisfaction of using the system. 2. the development of methods and software tools for gathering experimental data based on the four entities of the evaluation framework 3. the validation of the evaluation framework with case studies involving systems that have been developed for specific groups of end-users.

We have conducted three case studies where real-world users interact with three online geospatial systems. The important findings of those studies were that there are noticeable gender differences regarding spatial navigation, that user satisfaction appears to be biased by the user's previous experience with geographic information technologies and that the type of the input device used (e.g. mouse or touchpad) has a considerable influence on task-completion time and user satisfaction. The above results indicate that the user's demographic parameters and background have a significant effect on the user's spatial interaction strategies, performance and satisfaction. Furthermore we have found evidence that suggests that the user's perception of spatial data strongly depends on the scale.

We conclude that the design and development of spatial interaction functions (spatial navigation, digitization, selection of objects and locations) in online geospatial systems should highly depend on the type of users that the systems are developed for. To further fuel research on usability aspects of online geospatial systems, we provide the necessary tools and methods for conducting remote- and laboratory based testing of such systems.

Keywords: Human Computer Interaction (HCI), Geographical information systems (GIS), online geospatial systems (web mapping, web GIS), usability, user evaluation

Résumé

L'interaction de l'utilisateur avec les systèmes géospatiaux en ligne est un domaine de recherche qui combine deux disciplines: l'Interaction Homme-Machine (IHM) et les sciences de l'information géographique. Durant ces dernières années, leur mise en place a du répondre à différentes finalités, comme par exemple le calcul d'itinéraires, la mise en ligne d' atlas ou encore le soutien aux démarches collaboratives. Un nombre croissant de personnes ont accès à des données géospatiales et à la technologie y relative. L'utilisation de ces systèmes commence donc à intéresser la recherche. Cependant, peu d'études sur l'utilisabilité des systèmes géospatiaux en ligne ont été réalisées. La plupart de celles-ci ont été mises en place dans des laboratoires avec des utilisateurs mal décrits. En outre, à notre connaissance, aucun cadre formel de recherche n'existe actuellement. Ce dernier devrait faciliter l'analyse systémique de l'interaction des utilisateurs du monde réel avec de tels systèmes et prendre en compte leur caractère spatial.

L'objectif de cette thèse est de montrer que les utilisateurs, en fonction de paramètres démographiques, de leur expérience et de leurs compétences, ainsi que du contexte d'étude, révèlent des différences significatives dans leurs choix stratégiques et dans leur performance. Un autre facteur important, négligé dans de nombreuses études et se focalisant sur l'utilisabilité, est l'ordinateur de l'utilisateur. Dans ce travail, nous voulons montrer que les utilisateurs, en fonction des spécificités de leur ordinateur, font des choix de mode d'interaction qui influencent profondément leur performance et leur satisfaction.

Cette thèse se compose de trois parties distinctes : 1. L'établissement d'un cadre d'évaluation qui catégorise et définit l'interaction des utilisateurs du monde réel avec les systèmes géospatiaux. Les quatre principales entités de ce cadre sont l'utilisateur (en termes de démographie, compétences, connaissances et contexte), le système (défini par la conception de l'interface, par les données et fonctions spatiales, par la technologie et les architectures), l'interaction de l'utilisateur (modes d'interaction, de performance et de perception des données spatiales), et la satisfaction de l'utilisateur. 2. Le développement de méthodes et d'outils permettant de collecter des données expérimentales basées sur les quatre pôles du cadre d'évaluation. 3. La validation du cadre d'évaluation par des études de cas portant sur des systèmes qui ont été développés pour des groupes spécifiques d'utilisateurs finaux.

Nous avons mené trois études de cas dans lesquelles des utilisateurs du monde réel ont interagi avec trois systèmes géospatiaux en ligne. Les principaux résultats montrent qu'il existe des différences notables entre les hommes et les femmes en ce qui concerne la navigation spatiale, que la satisfaction des utilisateurs semble avoir été biaisée par leurs expériences précédentes se fondant sur les technologies et l'information spatiale, et que le type de périphérique d'entrée utilisé (par exemple la souris ou touchpad) a une influence considérable sur le temps nécessaire à l'achèvement de l'exercice et sur la satisfaction des utilisateurs. Les résultats ci-dessus indiquent que les paramètres démographiques de l'utilisateur, ainsi que le contexte d'étude, ont un effet significatif sur les modes d'interaction spatiale de l'utilisateur avec le système, sur les performances et sur la satisfaction. En outre nous avons découvert que la perception de l'information géospatiale dépend de l'échelle.

Nous concluons que la conception et le développement de fonctions d'interaction spatiale (navigation spatiale, numérisation, sélection d'objets et de lieux) dans les systèmes géospatiaux en ligne devraient fortement dépendre de l'utilisateur pour qui ceux-ci sont développés. Pour alimenter la recherche sur les aspects de l'utilisabilité des systèmes géospatiaux en ligne, nous fournissons des outils et les méthodes nécessaires à leur mise en place.

Mots-clés: Interaction homme machine (IHM), systèmes d'information géographique (SIG), systèmes géospatiaux en ligne, utilisabilité, évaluation avec des utilisateurs

Zusammenfassung

Die Interaktion von Benutzern mit Internet-basierten rumlichen System ist eine interdisziplinre Forschungsrichtung, welche Mensch-Maschine Interaktion (MMI) und raumbezogene Wissenschaften kombiniert. In den letzten Jahren sind Internet-basierte räumliche System für verschiedene Anwendungsbereiche entwickelt worden. Beispiele sind Systeme, die Routen berechnen können, Internetatlanten, und Systeme welche die Zusammenarbeit mehrerer Personen ermöglichen. Durch die Tatsache, dass eine wachsende Zahl Benutzer Zugang zu räumlichen Daten und Technologien hat, fokussiert sich auch die Forschung, die Nutzung solcher Daten und Technologien und deren Folgen zu ergründen. Hingegen existiert bis zum heutigen Tage kein formales Forschungskonzept, dass die Analyse der Interaktion von realen Benutzern mit dieser Art von Systemen ermöglicht und dass die räumliche Art dieser Systeme berücksichtigt. Darüberhinaus gibt es wenige Studien, die die Benutzerfreundlichkeit dieser System analysiert haben. Die meisten dieser Studien sind ausserdem in einer künstlichen Umgebung, mit wenigen schlecht beschriebenen Benutzern durchgeführt worden

Das Ziel dieser Doktorarbeit ist es zu belegen, dass Interaktionsstrategieen und die Interaktionsleistung (z.B. die Geschwindigkeit eine Aufgabe zu lösen) signifikant von demographischen Variablen, von der Erfahrung und dem Kontext der Benutzers abhängig sind. Desweiteren haben viele Studien, welche die Benutzerfreundlichkeit dieser Systeme in einer künstlichen Umgebung analysiert haben, den Einfluss des Benutzercomputers vernachlässigt. In dieser Arbeit soll bewiesen werden, dass der Computer des Benutzers sowohl einen statistisch signifikanten Einfluss auf Interaktionsstrategien und Interaktionsleistung hat, aber auch fr der Zufriedenheit des Benutzers solcher Systeme berücksichtigt werden muss.

Die vorliegende Dissertation besteht aus drei Teilen:

1. Die Erarbeitung eines Forschungskonzepts, dass die Interaktion mit wirklichen Benutzern und räumlichen Systemen definiert. Dieses Konzept besteht hauptsächlich aus vier Einheiten: Dem Benutzer (Demographische Parameter, Erfahrung, Fertigkeiten und Kontext), dem System (definiert durch Interface-design, räumliche Daten, räumliche Funktionen, Technologien und Architekturen), der Interaktion (Strategien, Leistung und die Wahrnehmung räumlicher Daten) und der Zufriedenheit des Benutzers.
2. Die Entwicklung von Methoden und Softwareprogrammen, die es ermöglichen, experimentelle Daten (die durch die vier Einheiten des Konzepts definiert sind) zu erfassen.
3. Die überprüfung des Forschungskonzepts mit Fallstudien, welche für spezifische Benutzergruppen entwickelte Systeme beinhalten.

In drei Fallstudien wird die Interaktion von Benutzern mit Internet-basierten räumlichen Systemen untersucht. Wichtige Resultate dieser Studien sind dass es geschlechtsspezifische Unterschiede bezüglich räumlicher Navigation gibt, dass die Zufriedenheit eines Benutzer von durch die Erfahrung mit räumlichen Systemen abhängig ist und dass das Eingabegerät (z.b. eine Maus oder ein Touchpad) einen signifikanten Einfluss auf die Geschwindigkeit mit der Benutzer Aufgaben löst hat, aber auch auf die Zufriedenheit des Benutzers.

Unsere Schlussfolgerung ist dass das Design und die Entwicklung von räumlichen Interaktionsfunktionen (z.B. räumliche Navigation, Digitalisierung, das Auswählen von Objekten und Orten) in Internet-basierten, räumlichen Systemen von den Benutzern abhängig sein sollten für welche sie entwickelt worden sind. Für zukünftige Forschungstudien, welche die Benutzerfrendlichkeit solcher Systeme analysieren, stellt diese Dissertation die notwendigen Werkzeuge und Methoden zu Verfügung; sowohl für Studien, welche in Laboratorien als auch in der Distanz durchgeführt werden

Schlüsselwörter: Mensch-Maschine Interaktion MMI, (Human-Computer Interaction, HCI), Geographische Informationssysteme (GIS), Internet-basierte räumliche Systeme (web mapping, web GIS), Benutzerfreundlichkeit, Benutzerstudien

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Abbreviations

AJAX	Asynchronous JavaScript and XML (see section 3.3.3)
CSUQ	Computer System Usability Questionnaire (see section 6.5)
EPFL	Ecole Polytechnique Fédérale de Lausanne
GIS	Geographical Information System
GPS	Global Positioning System
GUI	Graphical User Interface (see section 2.3)
GVIS	Geovisualization (see section 2.3.4)
HCI	Human-computer Interaction (see chapter two)
ISO	International Organization for Standardization
PHP	Hypertext pre-processor, see chapter three
QUIS	Questionnaire for User Interaction Satisfaction (see section 6.5)
RIV	Réseau Interactif en Viticulture, (Interactive Network for wine-cultivation, see section 7.2)
SUS	The System Usability Scale (see section 6.5)
UCD	User - centred system development (see section 2.4.3)
WMS	Web-Map Service (see section 3.3.3)
WFS	Web-Feature Service (see section 3.3.3)

1 Introduction

1.1 Motivation

The motivation for this thesis is rooted in the consideration of several recent trends in the development of information technology in general, and geospatial information technologies in particular.

One of the trends is the increasing connectedness of electronic devices, such as cellular phones and computers, to the Internet. This has shifted the usage of computer-powered devices from monolithic, stand-alone systems to interconnected networks of devices offering a variety of services and applications. In addition, the sinking prices of computer equipment and bandwidth make such devices more affordable for an increasing number of people.

The above processes have had several consequences. One is that the increasing number of potential users has made it urgent to put more stress on the development of user-friendly interfaces, as the wide mass of users does not necessarily have the time or the competence to try out and learn how complicated interfaces work. Second the increasing connectedness of electronic devices has driven the development of distributed system architectures. This distribution of computer resources has especially affected the handling of data. Today, in many cases data is no longer stored on the user's local device, but accessible through different services and applications distributed through the network

Geospatial information technologies have been highly affected by these trends as well. In the early phases of development, geospatial information system can be characterized as having been complicated stand-alone systems that only few experts were able to manage and to control. (e.g. the first operational GIS CGIS in Canada in the mid-1960'ies (Longley *et al.*, 2001)). Today we have cellular phones connecting to data-repositories through web-services, displaying geospatial information in three dimensions (e.g. the Google Earth[1] application on the iPhone[2]), we have collaborative platforms on the Internet, offering the possibility for its users to digitize and add their own data (e.g. the OpenStreetMap project[3]) and we can see on-line platforms, capable of running spatial

[1] http://earth.google.com
[2] http://www.apple.com/iphone
[3] http://www.openstreetmap.org

queries and displaying statistical data.

Despite the fact that the number and diversity of geospatial systems increases, there are no clear guidelines for the developers of such systems on how to design the user interface and interaction and how to represent geospatial data in a way that is adapted to the users' systems and the users themselves. Researchers in this domain (e.g. Traynor and Williams (1995), Goldin and Rudahl (1997), Haklay (2006), Nivala *et al.* (2008), Cöltekin *et al.* (2008) Wachowicz *et al.* (2008)) have identified a number of severe usability issues related to geospatial systems.

Moreover several researchers, e.g. (Mark and Frank, 1992; Unwin, 2005; Goodchild, 2007; Tsou and Curran, 2008), have stated that there is a lack of knowledge about how users (especially users who not necessarily are experts in geospatial information and geospatial information technologies) perceive and interact with such systems and how such systems could be developed in order to take user differences into account. We claim that this lack of knowledge is very important due to the fact that online geospatial system theoretically can be used by anyone having a computer connected to the Internet. Therefore the developers of such systems cannot take for granted that the final user in fact is capable of using a new product.

Human-Computer Interaction (HCI) is the field of research that studies the interaction of humans with computer technology. During the early 1990'ies HCI became a widely accepted discipline which took much of its ideas and theories from cognitive sciences, psychology, and design amongst others. Since then the field has developed a variety of different techniques to analyze and improve the interaction between humans and computer technology.

In geographic information (GI) sciences HCI has been a widely discussed research subject in the mid-1990'ies (e.g. Nyerges *et al.* (1995)). However at that time HCI was mostly discussed from cognitive points of view; there were few researchers who actually analyzed how real-world users interacted with interactive spatial systems.

Several authors (e.g. Preece *et al.* (2002); Kuniavsky (2007) in the domain of HCI have stressed the fact that it is essential to know and to understand the real-world user before starting to design and to develop a new product. However within the research field of geospatial information systems it has been stated that the developing community knows very little about the actual end-user (Unwin, 2005). Furthermore researchers such as Goodchild (2007) or Tsou and Curran (2008) argue that more attention should be paid to user-centric approaches.

1.2 Focus of research

With this thesis we want to address the gap between the theories that had been discussed by the GI-community in the mid-1990'ies and the recent demands that have been made to analyze who the users of geospatial technologies are and how they interact with this technology.

The focus of research in this thesis is the elaboration of techniques and methods to analyze the user and the interaction with geospatial information and geospatial information technology. By analyzing the user and user interaction we want to be able to explain why users interact the way they do. Based on these results we want to go a step further and establish guidelines on how geospatial technology and information shall be developed and designed in order to accommodate the users who are intended to use this technology and information.

In order to reach the above goal we have chosen to focus specifically on online geospatial system (also referred to as web-mapping systems, geoportals or web-GIS by the literature) for the following reasons:

Importance of online geospatial systems: As already mentioned, the growing connectedness of information technologies has been one of the incitements in the development of online geospatial systems. This trend still continues and the importance of such web-based systems thus increases.

Importance of the user: Given the versatile nature of online geospatial systems, there is a vast number of possible applications and utilizations for this category of systems. This versatility however stresses the importance of the nature of users that the system is designed for. Moreover, as we have previously stated, the user of an online geospatial system is in theory anyone with a computer connected to the Internet (contrary to an expert-user of desktop-GIS).

The ease of development: One reason for the choice of online geospatial systems is the fact that web-development, as opposed to desktop-software development, is more straightforward due to the fact that many components and technologies already exist. Especially the open-source movement has contributed with a considerable amount of components and technologies.

The feasibility of real-world evaluations: The fact that most people in todays industrialized society do have access to the Internet makes them possible end-users of online geospatial systems. Moreover the connectedness of the population facilitates the search for candidates to evaluate systems.

An additional incitement is that the major providers of online geospatial systems (such as Google, Yahoo, Microsoft and so forth) with certainty have evaluated their systems with real-world users in order to face competition; however the results of such evaluations are not publicly available and thus not reusable. However some software companies and open-source projects have tried to port ideas, features and functionalities from established Desktop GIS to online geospatial systems. Yet few researchers (e.g. Haklay and Zafiri (2008)) have explored whether modes of interaction that are taken from expert-GIS applications are usable within a web-context. Furthermore many web-based geospatial systems are assemblies of components with different concepts of use.

1.3 Research goals

Given the different incitements, the three principal goals of this thesis are:

- The establishment of a conceptual framework that formally describes how real-world users and their interaction with online geospatial systems can be categorized, analyzed and evaluated.
- The development of tools and methods for gathering information about the user and the interaction with online geospatial systems.
- The identification of parameters that influence users' interaction with online geospatial systems

Based on the results from the above work, we intend to:

- Formulate recommendations on how online geospatial systems should be developed by taking into account the specificity of the real-world user.

1.4 Outline

The remained of this thesis is structured as follows:

Chapter two: In this chapter we present various scientific theories found in the literature that underlie the work in this thesis, in particular theories on human-computer interaction with geospatial systems. We explain the different facets of the research field, ranging from the cognitive foundations to the hands-on usability research, and discuss the connections between them.

Chapter three: Here we describe previous work on the technological development of online geospatial systems. We give an introduction to the history of these systems and describe how online geospatial systems can be categorized, e.g. according to functionality, architectures, technologies and contexts of use, and which recent technologies and trends are the driving forces behind the development of such systems.

Chapter four: Chapter four provides the conceptual framework that was developed in this thesis to formally describe how real-world users and their interaction with online geospatial systems can be categorized, analyzed and evaluated. The framework consists of four fields of parameters that represent the interaction between a user and an online geospatial system. The four fields are: the user, the system, the interaction and the satisfaction. We will explain each of these fields and describe the parameters that characterize them.

Chapter five: Chapter five specifies the hypotheses and research questions that are tested in this work and that are used to validate the conceptual framework in the previous chapter. The hypotheses address specific connections between parameters that characterize the user, the system, the interaction and the satisfaction.

Chapter six: The sixth chapter describes the method that was used to validate the conceptual framework. Concretely, it specifies how to detect and analyze each of the parameters listed in the framework.

Chapter seven: In chapter seven we present three case-studies conducted in this thesis, where online geospatial systems have been evaluated with real-world users. The first of these case studies involves a system for the winegrowers in Swiss canton of Vaud, the second a system for ordering geospatial data and the third a system for pointing out spatial locations on an online map. Each of these case studies has a different setting regarding the real-world users that were at hand for testing the system, but also in terms of the functionality that the three systems offer.

Chapter eight: Chapter eight discusses the results of the three case studies and validates the conceptual framework. The importance of each of the different parameters from the conceptual framework is analyzed and the connections between the parameters and fields are discussed.

Chapter nine: In the final chapter we discuss the importance of our findings, provide recommendations for the design and development of user-friendly online geospatial systems, and give further ideas on how the results of our study can be used and developed in the future.

2 HCI for spatial systems

2.1 Introduction

Compared to the history of GIS, the research field of HCI is rather new. HCI as a discipline emerged in the late 1980ies and early 1990ies. Originally HCI was a combination of fields that studied the interaction of humans with machines from different angles. These fields include computer science, psychology, cognition, sociology, design, system development theories and evaluation techniques.

The emerging HCI generated a vast interest in applying its theories to the field of GI sciences in the early 1990'ies (e.g. Goodchild (1992)). Over the years however the inter-disciplinary research in these two fields shifted with respect to the aspect of HCI that was put in focus:

- In the mid 1990'ies several publications, conferences and workshops questioned the way data was represented and interaction was designed in geospatial systems (e.g. the NCGIA workshop on User Interfaces for GIS in 1991 (Mark and Frank, 1992) or the definition of geovisualization (GVIS) by DiBiase (1990) and MacEachren (1995)).
- In the late 1990'ies research was concentrated on cognitive issues of geospatial information and technologies (e.g. Nyerges *et al.* (1995))
- In recent years geospatial information systems have emerged that are no longer monolithic desktop applications, reserved for experts in the domain of geospatial sciences but which are based on web-based technology and aim at being used by a broad mass of very diverse users. This new trend has lead to new studies and investigations regarding the usability and design of web-based applications (e.g. You *et al.* (2007); Haklay and Zafiri (2008))

In this chapter we describe the research generated in geospatial sciences with respect to HCI. The chapter is structured according to the different areas of focus within HCI.

- **Cognitive science and the cognition of space:** In this section the main focus lies on the human and how the human perceives information and technology.

- **System design and the design of geospatial information and systems:** In this section we concentrate on the design of technology and how this design influences the interaction of humans with technology.
- **Usability and the usability of geospatial systems** In this section we investigate how the interaction of humans with technology can be analyzed and improved.

2.2 Cognitive science and the cognition of space

2.2.1 Definition

Similar to HCI, cognitive sciences draw ideas and concepts from several research fields such as psychology, philosophy, linguistics, anthropology, sociology and biology. Cognitive sciences are concerned with the study of the human mind and the processes that are associated with the mind.

Gärdenfors (1999) suggests that the history of cognitive sciences goes hand in hand with the development of computer technology in the 1940ies and 1950ies. At that period of time the field was driven by the idea that a brain functions in the same manner as a computer and that the act of thinking could be understood as the processing of information. This idea led to fundamental publications such as Turing's paper on computing machinery and intelligence (Turing (1950), cited in Gärdenfors (1999)), which later became famous as the Turing test (if a user who is communicating through a computer terminal with a computer program and cannot tell if there is a human or a computer behind the program, the program has passed the Turing test). Another important theory that was developed at that time, and that later many theories and concepts would be based on, is Miller's theory (Miller, 1956) that the human mind is capable of processing at most seven units of information at once.

In the following sub-sections we present theories and ideas that are fundamental for cognitive science. Thereafter we analyze how GI sciences have used cognitive theories to explain cognitive processes that are related to the space. First we focus on the cognition of artifacts and what role artifacts play in the cognition of a person and on the cognition of specific groups of persons. Thereafter we analyze the role of spatial cognition.

2.2.2 Cognitive Load Theory

An important concept within cognitive science is the cognitive load theory. It was established by Sweller (1988). The research on how the human memory functions is a central part of this theory. According to Cooper (1998) there are three kinds of memory:

- **Sensory memory:** It is used to perceive incoming information from all our senses. It extinguishes quickly.

- **Working memory:** The working memory provides our consciousness. It is used to attend to information. However, as Miller (1956) pointed out, this memory is limited to about seven chunks of information.
- **Long-term memory:** It stores all knowledge and skills in a hierarchical structure. Its capacity is unlimited.

The process of learning can thus be considered as the encoding of knowledge or skills into the knowledge base, stored in the long term memory so that knowledge and skills may be recalled and applied on demand. The input of new information always involves the knowledge base that helps us putting new information in the context of what has been learned.

Sweller (1988) uses the term "schema" to describe the combinations of elements that make up the cognitive structures of an individual's knowledge base. Schemes permit us to improve our memory by handling multiple elements as a single element and store them in the long-term memory. An example for this process is the chunking of information: humans remember information better if the information is chunked. A large set of elements (e.g. a telephone number) is easier remembered if its elements a structured. (e.g. graphical chunking: 80 - 06 16 instead of 8 0 0 6 1 6).

Learning thus involves a change in the schematic structures of the long-term memory. A novice becomes an expert by getting familiar with the material his cognitive structures associated with the material are changed so that it can be handled more efficiently by the working memory. As a result, learning a certain material is best done when the material is structured so that the learning process requires a minimal memory load.

According to Cooper (1998) the term "cognitive load" refers to the total amount of mental activity on working memory at an instance in time. This cognitive load is essentially influenced by the number of elements that have to be processed by the working memory. However the elements to be processes are defined by a so-called degree of interactivity which in turn also influences cognitive load.

The interactivity of elements is defined as the degree to which the elements of some to-be-learned information can, or cannot, be understood if considered in isolation. (Pollock *et al.*, 2002). A simple word such as "water" has thus a low interactivity as it is only a label for something (it can be considered in isolation) on the other hand a grammatical syntax, such as this sentence, has a high interactivity due to the fact that it only can be considered through several vocabulary structures it therefore has to be learned and understood through the consideration of connected elements.

The cognitive load theory has generated some principles that have become very important for the design of interfaces. for instance the notion of dividing cognitive load into intrinsic cognitive load and extraneous cognitive load (Cooper, 1998; Pollock *et al.*, 2002). Intrinsic cognitive load is the cognitive load that cannot be modified by changing its representation. The element interactivity remains high. Extraneous cognitive load is about the representation of the material to be learned. It can be reduced by changing its representation, for instance by using drawings instead of textual descriptions. The cognitive load theory thereby suggests that the goal of an interface design is to decrease extraneous cognitive load (e.g by omitting unnecessary features that distract users attention when completing a task). This principle is also one of the main goals of user-centered design(Oviatt, 2006) which will be explained later in section 2.3

2.2.3 Activity theory

The activity theory is another important theory that has been much discussed by the HCI community. It originated from Sovjet cultural-historical psychology of A. N. Leontjew (referenced in Fjeld *et al.* (2002) and Bødker (1991)) and L.S. Vygotsky (referenced in Bødker (1991)). It is based on the concept that tools mediate between subjects and objects and that an individual's creative interaction with his or her surroundings can result in the production of tools. An individual's mental processes are exteriorized in the form of tools and thus become accessible to other people and therefore useful for social interaction. (Fjeld *et al.*, 2002).

The unit of analysis in this theory is an activity that is directed at an object which encourages activity. (Kaptelinin *et al.*, 1999). An example of an activity are people who use or create tools out of their understanding for solving a task. These tools then become part of other peoples activities.

According to Kaptelinin *et al.* (1999) there are five basic principles that form the activity theory:

- **Internalization and externalization:** The internalization of activities is a process of transforming external activities into internal activities. Internalization also includes the idea of imagining potential interactions in the mind without actually doing the interactions in the physical world. Externalization involves thoughts that are externalized to e.g. objects in the physical environment. (Fjeld *et al.*, 2002; Kaptelinin *et al.*, 1999)
- **Hierarchical structure of activity:** According to Kaptelinin and Nardi (1997) activities are composed of different goal-directed actions that must be undertaken to fulfill the object. Actions themselves are composed of automatic operations which are not goal-directed, but rather provide an adjustment of actions.
- **Mediation:** By mediation, activity theory means that human activity is mediated by tools. Tools mediate or transmit the social knowledge and history that shaped them (Bødker, 1991). Moreover tools can influence the internal and external behavior of individuals (Kaptelinin and Nardi, 1997).
- **Development:** The activity theory suggests that humans interacting with the reality should be considered in the context of development. It is

thus important to understand how tools are used over time and not at a given point in time in a laboratory environment. Moreover development is not only an object of study but also a general research methodology that analyzes the use of an object over time. (Kaptelinin and Nardi, 1997; Kaptelinin *et al.*, 1999)

- **Object-orientedness:** According to the activity theory humans live in a reality that is composed of objects. These objects do not only have physical, but also social and cultural, properties and features. (Kaptelinin and Nardi, 1997)

Bødker (1991) argues that the activity theory can be a useful tool for the conception and design of systems, due to the fact that the theory helps understanding the work of future system users. Moreover the process of designing a system can be seen with the activity theory in mind. Bødker (1991) suggests for instance that the tools and materials that are used by software developers can be considered or the purpose of the developer's activity - what it is and how the developers fulfill this purpose.

2.2.4 Distributed cognition

Distributed cognition is an approach founded by the cognitive scientists Edwin Hutchins and Donald Norman in the late 1980ies - early 1990ies. (Norman, 1993; Hutchins, 1995b) As in the activity theory, this approach also incorporates social and cultural contexts of cognition. (Halverson, 2002). Hutchins (2001) writes that distributed cognition does not look for cognitive events *to be encompassed by the skin or skull of an individual*, but for a *broader class of cognitive events.*

Moreover Hutchins (2001) argues that the social context matters since cognitive processes involve the transmission and transformation of information. The social context is responsible for how information is transmitted and transformed and thus can be considered itself as a cognitive architecture. At larger scale culture is relevant as a history of material artifacts and social practices. Distributed cognition deals with cognitive processes across the boundaries of individual human beings. (Hutchins, 1995a)

According to Hutchins (2001) cognitive processes, necessary for human accomplishment, may be distributed in three ways:

- Across the members of a social group
- In the sense that the operation of the cognitive system involves coordination between internal (the individuals cognitive processes) and external structure (the material environment).
- Through time, in such a way that the products of earlier events can transform the nature of related events.

The distributed cognition approach raises important questions that are very relevant for HCI, such as:

- How representations can be designed to facilitate a flexible use
- How representations can be made more active so that they help users to see what is most relevant in order to decide what to do next
- How we can shift the frame of interpretation to achieve a better conceptualization of what is going on and what should be done

Hutchins gives several possibilities to address these questions using computer technology: digital objects can for instance be created with the ability to record their history of use and to produce graphical abstractions of their use. One example of such a digital object that has been developed at the University of New Mexico is a browser companion called PadPrints (Hightower *et al.*, 1998) It records and displays the browsing history of a user browsing the internet. The graphical representation of the browsing history can then be used by the user to visually navigate in the pages visited.

The distributed cognition approach has also been discussed in geospatial sciences, in the context of spatial representation. Spatial representation is an essential component of geo-visualization, and two distributed cognition principles that are important in this context are Donald Norman's naturalness and perceptual principles: *"Experimental cognition is aided when the properties of the representation match the properties of the thing being represented"* and *"Perceptual and spatial representations are more natural and therefore to be preferred over nonperceptual, nonspatial representations, but only if the mapping between the representation and what it stands for is natural - analogous to the real perceptual and spatial environment"*(Norman, 1993).

Furthermore the distributed cognition approach has been used to develop collaborative spatial systems. Golay (1995) for instance suggests that the approach is useful to support collaborative decision making due to the fact that it is based on *"rich representations made by individuals through a synergetic combination of action, dialogue and self-reflexion"*. Moreover Tomaszewski and MacEachren (2006) state that the approach helps understanding the role of maps as visual mediators for analytical reasoning.

2.2.5 Mental models

An important concept in cognitive sciences are mental models. The term of mental models has been coined by Craik (1943) (cited by Johnson-Laird (2004)). Craik stated that a mental model is "a small-scale model of external reality and its own possible actions within its head, it is able to try out various alternatives, conclude which is the best of them, react to future situations before they arise, utilize the knowledge of past events in dealing with the present and the future, an in every way to react in a much fuller, safer, and more competent manner to emergencies which face it.". Davidson *et al.* (1999)observe that mental models had a comeback in 1983 with the evolving cognitive sciences. Especially two different concepts of mental models were discussed at that time.

- Mental models as a way of describing the process which humans go through to solve deductive reasoning problems (as proposed by N.P. Johnson-Laird; referred by Davidson *et al.* (1999))

- Mental models providing humans with information on how physical systems work. Mental models were thus considered as generalizations of a number of situations that humans face; for instance the behavior of objects according to physical laws (as proposed by Gentner and Stevens; referenced by Davidson *et al.* (1999))

Mental models are also very important for studies in Human-Computer Interaction. In 1983 Donald Norman addressed the difference between conceptual models and mental models, stating that conceptual models are tools used for the understanding or teaching of physical systems; mental models on the other hand are what people really have in their heads. (Norman, 1983). This difference is very important for people who are designing and implementing physical systems since a conceptual model needs to reflect several person's mental models of a system (e.g. the end-user's, the designers' etc.).

Payne (2007) claims that mental models in the field of HCI label many different aspects of the user's knowledge about systems they use. The core in mental models is that the contents of people's knowledge (including their theories and beliefs) can be important for understanding user's behavior during the interaction with a system. Payne (2007) goes even a step further and states that users of machines are eager to form mental models in order to explain how a system behind the interface might work, and to build an understanding that is consistent with their previous experiences. Mental models are thus essential for humans as they enable users to operate devices or systems that they have never experienced before.

2.2.6 Spatial cognition

Montello (2001) defines spatial cognition as the study of knowledge and beliefs about spatial properties of objects and events in the world. It analyzes questions such as how spatial knowledge and beliefs are acquired and developed over time, how people navigate and stay oriented in space, how people use language to communicate with each other about space and how aspects of spatial knowledge and reasoning are similar or different among individuals or groups.

Montello (1993) and Montello and Golledge (1999) argue that the scale of the space to perceive or apprehend is very important for spatial cognition and propose to distinguish between five cognitive spaces:

- **The minuscule space:** The minuscule space is too small to apprehend without technological aid. Examples are molecules, atoms etc.

- **The figural space:** The figural space is small in scale relative to the human body and can be perceived from a single viewpoint. Examples are small, manipulable objects such as a pen or a cellular phone

- **The vista space:** The vista space is as large or larger than the body and can be perceived from a single viewpoint. Examples are houses or small valleys.
- **The environmental space:** The environmental space is large in scale relative to the body. It requires the human to move within it in order to perceive it. Examples are spaces of buildings or cities.
- **The gigantic space:** The gigantic space is too large to perceive without technological aid. An example is the universe.

Each of these cognitive spaces is thus apprehended differently and using different techniques. Montello (2001) writes that geospatial information is either acquired directly using sensorimotor systems that are activated when humans move, or indirectly through static and dynamic media such as maps and images, 3-D models, and language.

In the following sections and sub-sections we discuss different theories and ideas about how spatial information is acquired, stored and used by humans.

2.2.7 Cognitive maps

An important component of spatial cognition are cognitive maps. According to Kitchin and Blades (2002) a cognitive map refers to an individuals knowledge of spatial and environmental relations, and the cognitive processes associated with the encoding and retrieval of the information from which it is composed. Cognitive processes involved in the composition of a cognitive map are sensory inputs and the processes that are responsible for the encoding of this input information. (Hegarty *et al.*, 1999). All sensory inputs (vision, hearing, the vestibular sense, etc.) contribute to the construction of the cognitive map. However, vision is probably the most important sense for sensing the spatial layout of an environment. (See figure 2.1)

A cognitive map is furthermore influenced by inference and maintenance processes. For instance an individual is capable of deducing spatial information based on the information that is already encoded in the cognitive map by spatial reasoning (we will discuss spatial reasoning later in section 2.2.8).

Golledge (1978) states that cognitive maps are internally structured in an hierarchical manner. Landmarks are a very important component Gärling *et al.* (1982) argues that routes are even more important than landmarks and that people are encoding landmarks according to routes. Cognitive maps of a region can also be acquired by consulting maps. This acquisition has two results according to Kitchin and Blades (2002):

- training in map use provides guidance (it gets easier to read maps)
- studying a map can lead to a greater knowledge about a region by showing real world relationships

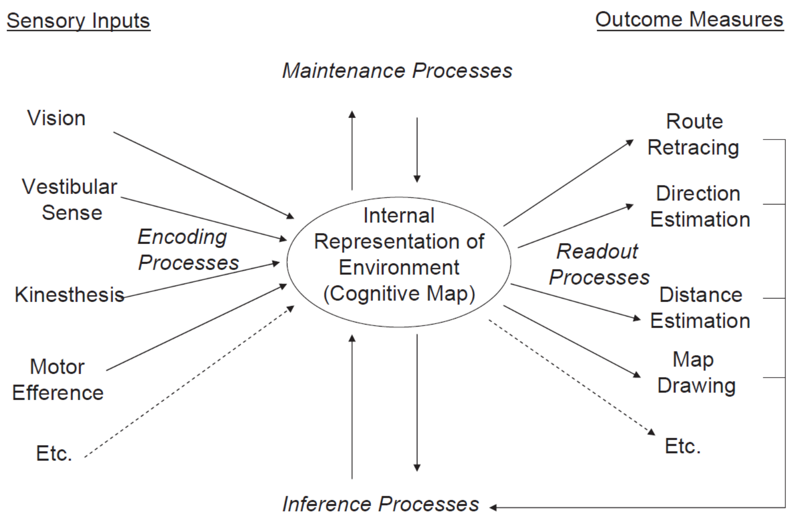


Figure 2.1: The perceptual and cognitive processes involved in constructing a cognitive map; adapted after Hegarty *et al.* (2006)

Tversky (2005) argues that the hierarchical structure of the individual's cognitive map is responsible for distortions, and cites a study by Stevens and Coupe (1978) where people do not remember the approximate locations of e.g states and cities, but their relative locations. The relative locations can then in turn infer distortions in terms of distances and directions. The benefit of a hierarchical structure however is that it facilitates inference.

According to Levine et al (1982) (referred in Kitchin and Blades (2002)) spatial information that has been learned from a map is stored in the cognitive map with the orientation (which is in most cases the north). Garling and Golledge (cited in Kitchin and Blades (2002)) share the opinion that it is very important to study cognitive maps in order to build environments that people can learn and navigate successfully. In this context Medyckyj-Scott and Blades (1992) (cited in Kitchin and Blades (2002)) think that cognitive map research is important for GIS developers. Systems that take into account how people process information will be easier to use.

2.2.8 Spatial reasoning

According to Tversky (2004) reasoning is to go beyond the information given, e.g. by transforming it according to rules as in deductive reasoning, or by making inferences or judgments from it. As mentioned above, cognitive maps can be used to infer information. Spatial reasoning can thus be described as the processes that interact with individuals' cognitive maps. The concept of spatial relationships plays an important role in the field of spatial reasoning.

There are several theories on how spatial reasoning functions. Notably several issues have been addressed:

- The manner in which individuals perceive and store spatial information in order to reason with it
- The scale, e.g. if there are differences between large-scale and small-scale reasoning
- The perspective, e.g. if spatial information is stored and used from a survey perspective where the viewpoint is overhead or from a route perspective (the individual's perspective)

Jahn *et al.* (2007) state that spatial reasoning follows certain principles. In a study Jahn *et al.* (2007) present evidence that suggests that individuals use chunking (also see the cognitive load theory section 2.2.2) in order to help the brain to store spatial information and to reason with this information. Furthermore culture seems to have a certain importance. E.g. in cultures where people write from left to right, people tend to name objects in a room clockwise direction. Moreover Simon (2001) states that several empirical studies suggest that there are gender differences related to spatial reasoning. For instance men are considered to be better in spatial orientation tasks, whereas females are better in verbal or linguistic tasks.

According to Frank (1996) the use of cardinal direction is typical for spatial reasoning in large-scale space, but other spatial relations are equally important. Hegarty *et al.* (2006) argue that scale is an important and distinguishing factor In a study conducted at the University of California, Santa Barbara, with almost 300 participants, there were very low correlations between the spatial abilities of individuals at small scale compared to the same persons' abilities at large scale.

In another study Lee and Tversky (2005) analyzed the notion of perspective in spatial reasoning and compared directions given in the cardinal system (the "survey perspective": go east, west, south, etc.) and route directions (the view point is that of the traveler and directions are given in left-right, etc.). Important conclusions of the study were that

- repeatedly retrieving information from different perspectives leads to perspective-free mental representations
- visual and spatial information are carried in different tracks of the brain

2.3 System design and the design of geospatial information and systems

2.3.1 Introduction

In HCI the design of a system is fundamental, since it defines the physical aspects of a system (the shape, the appearance, etc). These aspects are perceived by an individual's senses. In the context of technology-powered products the most important issue is the design of the user interface (UI) (Shneiderman and Plaisant, 2009), the interface between the technology behind a product and a human's senses and human actions (e.g. motor actions, speech or gestures). Narrowed to computer software (which geospatial systems are part of) the graphical user interface (GUI) is the most common type of interface between humans and the technology behind.

In this section we first discuss how HCI has addressed system design in a broad sense. Thereafter we discuss how different researchers have approached the design of geospatial systems. Since the aim of most geospatial systems is the visualization of geospatial data, we also discuss the design of maps and geovisualization (GVIS).

2.3.2 Design in HCI

In HCI the design of the user interface has one important goal: to make the interaction with the interface as efficient as possible. In order to reach this goal a series of ideas and guidelines have been established.

One important idea in this context is the concept of (perceived) affordance (Norman, 1999). Affordance is that the appearance of an object or a device gives hints about the proper way of using it. However, when designing GUI's the designer can only control perceived affordance due to the fact that the computer already has some physical built-in affordance, e.g. clicking on mouse-buttons. The computer display thus only virtually shows the affordance which is then perceived by the user.

Norman (1999) further illustrates how designers can guide the user of a GUI: through the introduction of constraints:

- **Cultural constraints** are conventions that are learned by the user - a user for instance knows that he can click on a button and that something is likely to happen, while a click on a text not necessarily has the same effect.
- **Logical constraints** The users can logically deduce what to do, e.g. if the user sees one location on an online map, but wants to visualize another one, he can logically deduce that he needs to move the map
- **Physical constraints** The users are physically hindered to do certain things, e.g. to move the cursor outside the screen

Graphical design is a major subject within HCI. The representation of graphical elements such as images, icons, diagrams, and text has an important influence on human perception and cognition. Watzman and Re (2007) give an overview of important guidelines regarding

- **Typographic design:** e.g. which font to use to increase readability
- **Layout:** for instance how to design a page
- **Design of diagrams, charts and icons:** e.g. to create a consistent visual language for an entire system
- **Colors :** for example which colors to combine to increase the contrast

Proper system design however does not only rely on the design of particular elements; the UI can also be viewed as a complex assembly of different graphical elements, actions and possibilities. This point of view falls under the notion of interaction design. According to Löwgren (2008) interaction design can be defined from a larger perspective (e.g. by Preece *et al.* (2002) : *"Interaction design is designing interactive products to support people in their everyday and working lives"*) or from a more restrained perspective which is the design of the behavior of systems and products with a specific focus on their use.

Based on accumulated experience, several researchers have developed guidelines ("heuristics") that are intended to help designers of user interfaces to increase the usability of their systems (usability will be discussed in section 2.4). The most known guidelines are Shneiderman's "Eight Golden Rules of interface design" (Shneiderman and Plaisant, 2009) and Nielsen's "Ten usability heuristics" (Nielsen, 1990). Shneiderman's golden rules are:

1. **Strive for consistency**
2. **Cater to universal usability**
3. **Offer informative feedback**
4. **Design dialogs to yield closure**
5. **Prevent errors**
6. **Permit easy reversal of actions**
7. **Support internal locus of control**
8. **Reduce short-term memory load**

Shneiderman and Plaisant (2009) emphasize that Shneiderman's rules need to be adapted to each environment that they are applied to and that they can be viewed as a good starting point for any user interface design. Nielsen's ten usability heuristics (Nielsen, 1990) are in some points very similar to Shneiderman's golden rules (e.g. regarding errors or the focus on consistency). They are:

1. **Visibility of system status**
2. **Match between system and the real world**
3. **User control and freedom**
4. **Consistency and standards**
5. **Error prevention**
6. **Recognition rather than recall**
7. **Aesthetic and minimalist design**
8. **Flexibility and efficiency of use**
9. **Help users recognize, diagnose, and recover from errors**
10. **Help and documentation**

2.3.3 Design of geospatial systems

The design of GIS was a thoroughly-discussed subject in the community of geospatial sciences in the early 1990'ies. In 1991 the National Center for Geographic Information and Analysis (NCGIA) organized a meeting on "User Interfaces for Geographic Information Systems" with the goal to discuss HCI-methods and to establish a research agenda.(Mark and Frank, 1992) Several participants of this meeting motivated why the user interface and HCI-methods are important issues.

Ferreira (1992) argued that the increasing number of features and functionality being integrated in GIS also makes the GUI very complex. Frank (1992) identified another issue that causes the GUI of GIS to be complex - it is the "mixing" of cartographic representation ("the map") and analytical operations. On the other hand Frank (1992) stated that the GUI of a GIS is the most important factor that contributes to its economic success or failure. Yet Gould (1992) argued that the reason why the GIS community was still far behind other software regarding their GUI was that the GIS community lacked the critical mass necessary to sustain its own optimized technology.

In order to address these issues Mark and Frank (1992) concluded that the following four subjects should have a priority for future research in user interface design for GIS:

1. The development of typologies regarding tasks and users of GIS. Mark and Frank (1992) state that the GIS-community knows very little about the actual users of GIS in terms of their training and how they conceptualize the use of GIS. Moreover it is not known which data they want to analyze and how they want to analyze it.

2. The fact that spatial concepts are critical to the design of UI for GIS. It has been observed that different users of GIS have different spatial concepts for geospatial features (e.g. a road can be considered as a link in a traffic network by user type A or a zone boundary in an electoral map by user type B). Mark and Frank (1992) therefore suggest that UI for GIS, based on a single spatial concept, are easier to learn. On the other hand such systems would be limited in functionality.

3. The trade-off between learnability and performance for experienced users. According to Mark and Frank (1992) there are several categories of GIS users: novice users who prefer an easy-to-learn interface; (intermediate) casual users and expert users who prefer shortcuts in performing tasks. The difficulty thus lies in designing a user interface that is a compromise between the requirements of each group.

4. Experimental testing of GIS in order to establish guidelines regarding user interfaces. At the NCGIA meeting Vora and Helander (1992) presented how usability measures could be used to conduct such tests. Furthermore Mark and Frank (1992) argue that real human subjects testing a GIS interface would be the most direct way to address the fact that the community knows very little about the users.

However, according to Haklay and Zafiri (2008), after the mid-1990ies the HCI-related research in geospatial sciences changed its focus from user interface design to spatial cognition (e.g. Nyerges *et al.* (1995), Frank (1998), Mark *et al.* (1999)) and the development of interfaces that require other forms of interaction (e.g. multimodal interaction Oviatt (1996), pen-based interaction using sketch-paradigms to query data Blaser and Egenhofer (2000), and virtual environments Cartwright (2006)). If we today (2009) look back at the research agenda from 1992, we can state that especially the second and third point have been addressed by the GIS industry and the developers of geospatial interfaces: In 1992 GIS were still very expensive stand-alone applications that were difficult to use. Today the development has led to products which are adapted to specific kinds of users (e.g. foresters, biologists, etc.) and there are products on the market which are adapted to ten-year old children such as virtual globes. (Goodchild, 2006)

It is only in recent years that user interface design for GIS and geospatial systems has gained new attention. Haklay and Zafiri (2008) for instance have evaluated the user interfaces of a variety of GIS using screenshots that real-world users made of their work environments. The conclusions of this study were:

- users are sacrificing the map area in order to accommodate other parts of the interface
- users have inactive toolbars on their interfaces, which take away map area

In another study (which will be discussed later in section 2.4) Skarlatidou and Haklay (2006) found out that a larger map area reduced the time of performing basic tasks using an online geospatial system.

Within the domain of cartography the discussion about usable geospatial interfaces has been related to the development of interactive multimedia atlas information systems (MAIS). Compared to GIS the functionality of MAIS in terms of analysis and visualization capabilities is intentionally limited in order to provide a set of data that is adapted to the user. Another important difference is that authors of MAIS control the functions and the data that is available in the system (in GIS it is the user who chooses the data and the functions)(Hurni, 2008). As opposed to GIS users of which the community has very poor knowledge (Mark and Frank, 1992; Unwin, 2005), the user of interactive multimedia atlases is very well known (e.g. (Haeberling, 1999)). This fact has made the development of user-adapted MAIS interfaces feasible. Furthermore many multimedia atlases are developed by states and governments (e.g. the Atlas of Canada[1] or the Atlas of Switzerland[2], see figure 2.2) who do have the resources to conduct a user-centered system development process (Kramers, 2007).

The design of the user interface in MAIS has been the concern of several studies. Cron (2006) for instance has developed a concept for the design of such

[1] http://atlas.nrcan.gc.ca
[2] http://www.atlasderschweiz.ch

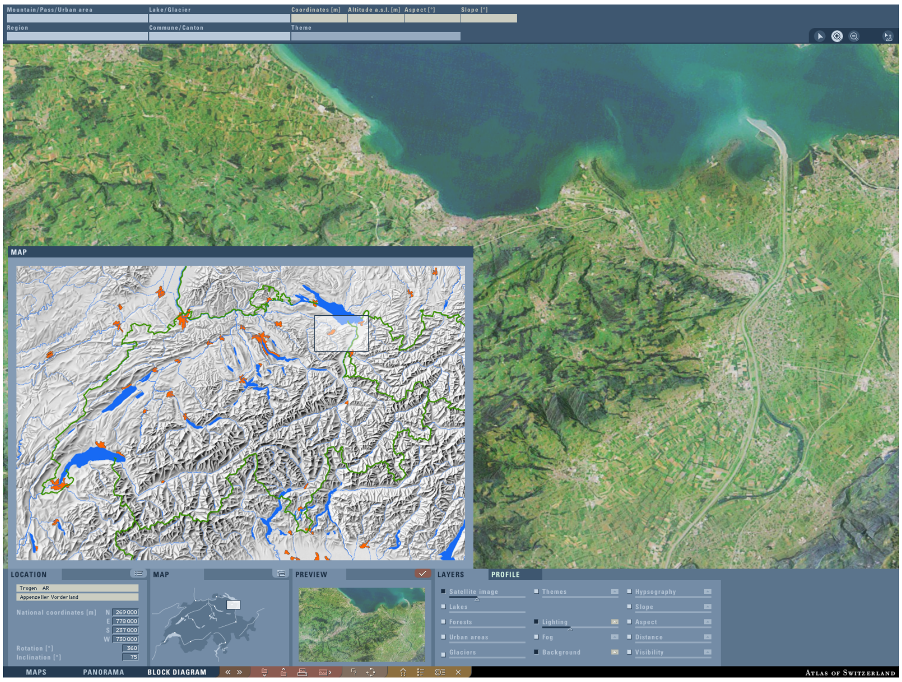


Figure 2.2: The Atlas of Switzerland

systems in terms of graphical layout, functionality and cartographic representation based on guidelines such as (ISO, 1994).

2.3.4 Digital map design and geovisualization

The design of maps has been the concern of cartography since the establishment of cartography as a scientific discipline. According to MacEachren (1995) cartography can be considered as the process where information from the geographic environment is interpreted by a cartographer who in turn produces a map for different recipients (see figure 2.3). A map is thus a cartographer's interpretation of the real world. The cartographer thereby has the responsibility to ensure that this interpretation is understood by the recipients. Monmonier (1991) gives an impressive overview of the consequences of this responsibility in his book "How to lie with Maps". However it must be noted that the responsibility for the interpretation of a map (or of any sort of media transmitting a message) is not solely with the person who is producing the map - the recipient of a map has the liability to critically consider its contents and message.

In order to help the cartographer to ensure that the recipients understand the map Slocum *et al.* (2005) suggest nine questions that a cartographer should ask himself before designing a map:

- *How will the map be used? Will it be used to portray general or specific information?*
- *What is the spatial dimension of the data? For instance, are the data available at points, lines or areal?*

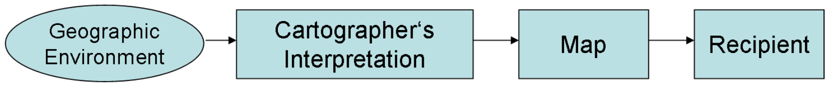


Figure 2.3: Cartography as a process of information communication (after MacEachren (1995))

- *At what level are the data measured (e.g. nominal, ordinal, interval or ration)?*
- *Is data standardization necessary? If the data are raw totals, do they need to be adjusted?*
- *How many attributes are to be mapped?*
- *Is there a temporal component to the data?*
- *Are there any technical limitations? (e.g. colors vs black and white)*
- *What are the characteristics of the intended audience? (e.g. general public)*
- *What are the time and monetary constraints?*

Slocum *et al.* (2005) argue that these issues have a considerable effect on the design of the final map and decide upon parameters such as colors or fonts. Bertin (1973) defined seven basic visual variables that decide the graphical design of a classical thematic map:

- **Position:** Bertin (1973) writes that the position of an object on a map may vary in the two dimensions of the map.
- **Size:** Areal objects may vary in their size; linear objects in their length. Poidevin (1995) mentions that an equilibrium should be found in order to facilitate map reading.
- **Shape:** According to Poidevin (1995) the variable shape defines the external shape of point and line-objects and the internal shape of areal objects. Too many different shapes on a map are not helpful for the interpretation of maps. Moreover care should be taken to the optical effect of shapes - shapes could suggest hierarchical structures, even if the original intension was to display differences.
- **Value:** The value of an object can change from light to dark. The variable value should not be used to express quantities (Poidevin, 1995).
- **Texture:** The variable texture is according to Poidevin (1995) scarcely used in cartography. Depending on the pattern, cartographers should pay attention to a flickering-effect when using patterns for areal forms.
- **Orientation:** Changing the orientation of graphical objects can, according to Poidevin (1995) be used to limit the number of different objects on the map.
- **Color:** Poidevin (1995) states that this variable is used very frequently in cartography. Color is also a variable that needs to be used with care since it can invoke associations (e.g. blue for water, gain, cold; red for

loss, warm, etc.) and can have different meanings in different cultures. Moreover Jenny and Kelso (2007) mention that about 8% of the male population are color-blind and thus perceive colors differently.

In order to determine whether or not the cartographer has succeeded to use graphical elements in the best way, Robinson (1952) (cited by MacEachren (1995)) postulated that *effectiveness* should be measured. However Edward Tufte's concept of *graphical excellence* Tufte (1998) contests the sole focus on effectiveness. According to his concept, clarity, precision and efficiency should be the most important factors of graphical representation. A representation should let the spectator focus on the data and not on the methodology or the technology that is used to produce it. One method that triggers the human eye to focus on the data is to encourage the spectator to compare different pieces of data or different levels of detail (Tufte, 1998).

The way traditional cartography was conceived and the way maps were used again changed during the 1980'ies with the increasing capabilities of computer technology and visualization software (such as CAD systems). This development led to the establishment of geovisualization (abbreviated GVIS). (MacEachren, 1995). MacEachren demonstrates the impact that the GVIS-perspective has on map-making and map use with his well-known cube diagram (figure 2.4), which is based on DiBiase's distinction between public and private realm. (DiBiase, 1990)

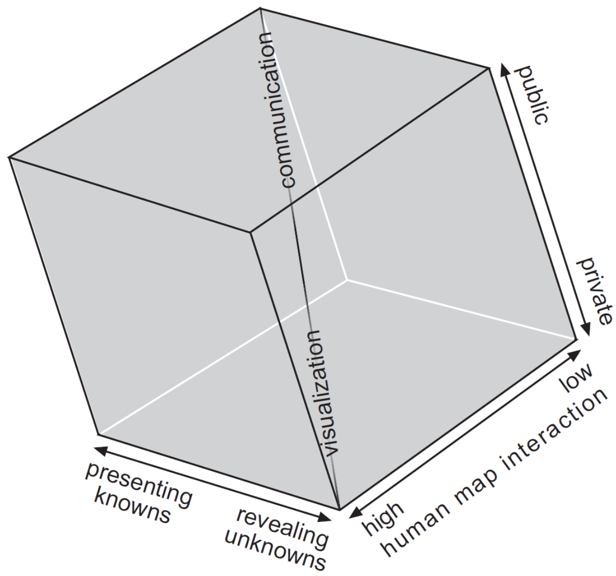


Figure 2.4: The map use cube (after MacEachren (1995))

According to MacEachren (1995) map use can be considered along three axes:

- Human-map interaction: low (the user has limited ability to change map representation) to high (the user can manipulate maps substantially)
- Private-public realm: private (an individual generates a map for his own use) to public (maps are made available to a group of users)
- Presentation-exploration: presenting knowns to revealing unknowns

An example for map use with low human-map interaction which is presenting knowns for the public is a so-called You-are-here map (YAH map); for instance in a public park. Geovisualization on the other hand can be mentioned as an example for a private high human-map interaction to reveal unknowns.

A central concept of GVIS is exploration. DiBiase (1990) states that exploration will be the only effective way to explore enormous data sets. The map use cube (figure 2.4) can thus be interpreted with the perspective of how research is conducted: An individual's exploratory research first becomes confirmed, then synthesized and finally presented for the public.

If we reconsider the model of traditional cartography (presented in figure 2.3) we can state that GVIS blurs the definitions of "cartographer" as the actor who interprets the real world and produces a map and the "recipient" of the map due to the fact that the "recipient" also becomes an actor. Figure 2.5 illustrates the handling of information (information that only humans understand) and data (information that only computer technology understands) in the context of GVIS. Within this process there are several steps where either information or data gets interpreted by humans or computer software.

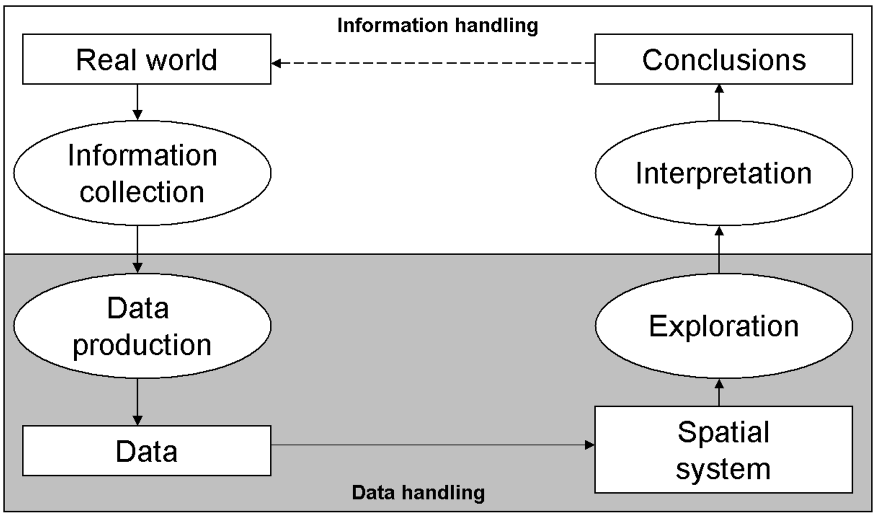


Figure 2.5: The process of information and data handling in the context of GVIS); after Ingensand (2001), based on Eklundh (1999) and Bartelme (1994)

From a design point of view GVIS also changes the view of traditional map-making (e.g. Bertin (1973), Slocum *et al.* (2005)). At three points in the process (see figure 2.5) design questions arise:

- **Data production:** If the data for instance is stored as raster-data (such as aerial images) design issues arise regarding the colors used, the resolution at which the data is stored, the projection and the format.
- **Geospatial system:** The programmers and designers of geospatial software need to think of the possibilities they want to offer a user to visualize and explore the data.
- **Data visualization and exploration:** At the point where a user of a geospatial system visualizes and explores the data in order to present the results of his research for further people.

Two design issues regarding data production and geospatial systems are the following:

- Geospatial data is stored digitally in files and databases. This aspect implies that the data can be passed on from computer to computer. Computers however are heterogeneous artifacts which are composed of different hard- and software configurations. The display of exactly the same digital file on a computer with for instance a monochrome yellow and black tube display will show the data differently than a computer with a more modern LCD-monitor at 16,7 millions of colors.
- Geospatial data are, as opposed to paper-maps, often not readily-rendered raster data files. This fact stresses the importance of map-rendering in the map-rendering software. Especially vector-based formats leave much of the map-rendering to the software and thus influence the design of the map substantially.

Jenny *et al.* (2008) state that some of these issues can be addressed with software that adapts the rendering of geospatial data as much as possible to the hardware that is given. Nevertheless the designers of digital maps should think of the users with the poorest hardware configurations (such as small low-resolution displays) and use:

- The anti-aliasing technique, a technology that blurs the image when viewed from a close distance. If the image does not contain too many details, the overall readability is increased.
- Symbols and labels that are still readable at low resolutions
- Map-generalization through shape simplification

Another issue, described by Cartwright (1997), is the increased demand for more advanced and sophisticated presentation, stimulated by for instance multimedia and virtual reality. Räber and Jenny (2001) state that the individual, interacting with digital maps, keeps the information longer in mind if the maps, on one hand, are well-designed and, on the other hand, different media (pictures, text, sound, animation) are used to transmit this information. In order to respond to this demand in design DiBiase (1992) (citet by Slocum *et al.* (2005)) extended the visual variables established by Bertin (1973) with variables and categories of animation. DiBiase's variables are "duration' (the length of time that a frame of an animation is displayed), "the rate of change"(defined by the magnitude of change and the duration of each frame) and "order" (the sequence of frames). MacEachren (1995) later added the variables "display date" (when the change was initiated), "frequency" (the number of identifiable states per time unit) and "synchronization" (the temporal correspondence of two or more time series).

2.4 Usability

2.4.1 Definition

Usability is widely considered as one of the main components and driving powers behind HCI. Dumas and Redish (1999) argue that within usability, research-focus is put on the people who will use a system or an application. Dumas and Redish (1999) remind that users in many cases are busy people trying to accomplish important tasks and that the product is thus used in order to be productive. It is therefore the user who decides if a product is easy to use.

Usability however consists of a variety of different aspects that need to be considered. Today there are three widely accepted definitions for usability and the usability aspects that should be taken into account: ISO (1994) defines that usability aims at increasing aspects of a system such as a system's **effectiveness**, **efficiency** and user **satisfaction**. Shneiderman (1998) includes the parameters **speed of performance**, **time to learn**, **retention over time**, **rate of errors by users** and **subjective satisfaction**. The usability expert Jakob Nielsen proposes **efficiency**, **learnability**, **memorability**, **errors/safety** and **user satisfaction** (Nielsen, 1993) as the main components.

A simple distinction between effectiveness and efficiency has been coined by Drucker (2007). Efficiency is the ability to do things right, while effectiveness is to do the right things. Novick (1997) however points out that in HCI studies it is difficult to address and to measure effectiveness since effectiveness also includes the quality of the interaction. Moreover Novick (1997) critizises that in HCI effectiveness often is measured with the time to complete a task and task outcome (whether or not a goal has been reached).

According to the ISO 9241 standard (ISO, 1994), efficiency is defined as the resources expended by the user in relation to the accuracy and completeness of goals achieved. A high efficiency is thus achieved when the user reaches a goal with little resources (e.g. cognitive resources). In the context of efficiency Fitts' Law (Fitts, 1954) has become a widely respected and used principle: the time required to rapidly move to a target is a function of the distance to the target, but also the size of the target.

Both Jakob Nielsen (Nielsen, 1993) and Ben Shneiderman (Shneiderman, 1998) have included into their definitions of efficiency that the utilization of one system or application in fact can vary over time and that a user learns how to utilize a product. The different aspects of these thoughts are thus the time and effort to learn how to use a product and the effort to memorize its utilization.

User satisfaction is an aspect that is included in all three definitions. Doll and Torkzadeh (1988) defines it as the *affective attitude* of a user towards a specific computer application. A user's affection however can be positive or negative. (Cheung and Lee, 2005) for instance state that negative attitude towards something has a greater power than a positive attitude and give the example of an experiment where the participants of an experiment either gain or lose money - the participants losing money were more upset about losing than the participants happy about gaining the same amount.

Hassenzahl (2001) points out that many approaches to satisfaction focus on the user's perception of effectiveness and efficiency and argues that aspects such as fun and pleasure should be taken into account as well for the measurement of satisfaction.

2.4.2 Addressing and improving usability

It is widely accepted that a products' success highly depends on its usability, e.g. Gould (1992). This insight has led to the establishment of a series of different techniques and methods for addressing and improving usability. These techniques can be defined under three categories:

- Usability inspection techniques - techniques that are based on guidelines and other established usability principles
- Usability testing methods - methods involving the testing of a product using individuals
- User-centered system design - a framework that supports the development of a product involving the end-users of a product

Usability inspection techniques: Nielsen (1994) has listed seven different methods that are all based on guidelines for how the usability of a system can be analyzed:

- The heuristic evaluation : A technique where usability specialist analyze a system's usability using established usability principles (Nielsen, 1994). This technique however has been criticized that not as many usability problems can be detected as with real-world user, yet the cost of conducting a heuristic evaluation is much lower than the involvement of real-world users (Hollingsed and Novick, 2007).
- Cognitive walkthrough: a method to simulate a user's problem solving process, e.g. by checking if a user's goals and memory content can be assumed to lead to the next correct action (Nielsen, 1994). This method

is today a popular usability testing method and can also easily be learned by novice evaluators (Hollingsed and Novick, 2007).

- Formal usability inspections: This methods uses a procedure with strictly defined roles to combine heuristic evaluation and cognitive walkthroughs. It is a review of the interface by its designer and his of her peers of user's potential task performance (Nielsen, 1994; Hollingsed and Novick, 2007). Since its establishment it has been rarely used and little research has been conducted on formal usability inspections.

- Pluralistic usability walkthrough: An adaptation of cognitive walkthrough where users, developers and people dealing with human factors meet to discuss dialogue elements of an interface. (Nielsen, 1994). Hollingsed and Novick (2007) state that this approach is often used in industry.

- Feature inspection: The goal of this method is to describe the technical features of a piece of software as detailed as possible. It includes lists of sequences of features (used to accomplish typical tasks) and checks for long sequences (such as steps that would not be natural for users to try and steps that require extensive knowledge or experience) (Nielsen, 1994). According to Xenos *et al.* (2004) this method has the advantage that it does not require a large number of evaluators and that it leaves the user free to take any actions considered appropriate for achieving a goal.

- Consistency inspection: A method where designers of different projects inspect an interface in order to verify if it is consistent with the other designer's interfaces. (Nielsen, 1994). According to Wilson and Rosenbaum (2005) this method can be useful in companies where different products are used.

- Standards inspection: According to Nielsen (1994) in this method an expert inspects an interface according to interface standards (such as for instance industrial standards)

Usability testing methods: Besides usability inspection methods there are also techniques for testing the usability of interfaces. Dumas and Redish (1999) states that the primary goal of such usability testing techniques is to improve the usability of a product. The participants of a usability test represent real users performing real tasks during the test. The role of the evaluator (the person who conducts the test) is thus to observe and record what participants say and afterwards to analyze the data and to diagnose the real problems. Based on these results the evaluator gives recommendations on how to address these problems and how to improve a product's usability.

HCI sciences have established a series of different approaches for how a usability test can be conducted:

- The think-aloud protocol: According to Dumas and Redish (1999) a verbal or think-aloud protocol is to have users think out loud while performing any task (from reading a text to working with a product). In cognitive science it is an often-used technique to observe the cognitive processes during the utilization of a system. Ericsson and Simon (1993) propose quite well-defined rules for conducting such a test. For instance if the user keeps silent for a period of time, the evaluator has the right to remind the user to continue thinking aloud.

- The co-discovery method: This method involves two users working simultaneously on one system (Brinck *et al.*, 2002). It is a useful usability testing method if it is expected that users are likely to work together on the same system.
- The question-asking protocol: This protocol can be considered as an extension of the think-aloud protocol. The difference is that users make questions during their reaction with the system, addressed to an evaluator. The method aims at finding information that users need. (Mandel, 1997; Giannakos, 2009)
- Performance measurement: This method is about the quantitative measurements of aspects such as the "number and percentage of tasks completed correctly with and without prompts or assistance", "the number and percentage of tasks completed incorrectly" (Rubin and Chisnell, 2008). User performance addresses the aspects efficiency, effectiveness and learnability of usability

It has been broadly discussed how many users are necessary to detect usability problems. For instance Virzi (1992) claimed that five users is the magic number to reveal 80% of the problems, Nielsen and Landauer (1993) showed that five users will uncover about 70% of the major usability problems and the next few users will find nearly all the remaining problems resulting in 85%. Perfetti and Landesman (2001) argue that eight users are not enough due to the fact that a system can be very complex and the possible combinations of interactions too high to be tested by only eight users. Lindgaard and Chattratichart (2007) put up the theory that there is no support for the fact that the number of users determines the number of problems found. Instead they claim that the number of problems found depends on the number and quality of tasks and elements. As a result usability researchers should focus more on the selection and preparation of the tasks than on the significance of the number of users.

User-centered system-development: A very important approach in the context of usability is the user-centered system-development (UCD) process. It is based on the fundamental idea that a person who will use a future system also should be part of the development process. Preece *et al.* (2002) give two main reasons for the user-involvement in the development process:

- Expectation management: at an early stage of the development process the user can see what the possibilities of a future product are (e.g. by looking at an early prototype) It becomes less likely that the user gets disappointed by the final product.
- Ownership: users who are involved in the development process are likely to feel that they are contributing to the product and also that the product becomes their own.

Another advantage is that the developers of a product get a better understanding of the end user's needs and goals.

The UCD is thus an iterative process that, according to different authors (Preece *et al.*, 2002; ISO, 1999), has four different steps (see Fig 2.6):

1. Understand the user and the context of use
2. Specify requirements
3. Elaborate solutions (e.g. prototypes)
4. Test and evaluate solutions

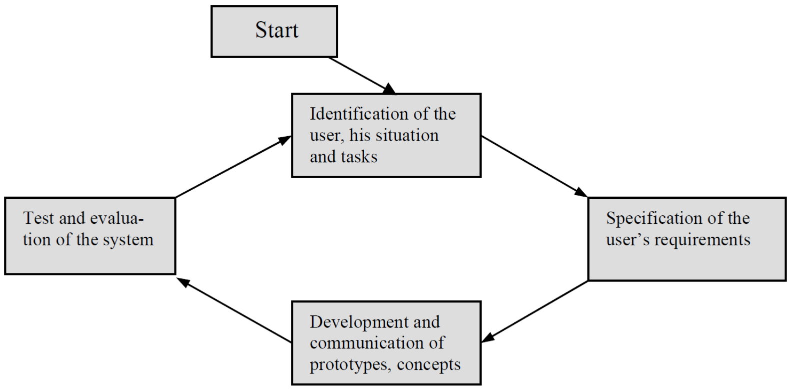


Figure 2.6: The user-centred system development process(adapted after Preece *et al.* (2002)

Step 1 - Understand the user and the context of use: Gould and Lewis (1983) were among the first to stress that a development process should start with the identification of the user and the task. Preece *et al.* (2002) clarify this statement by defining:

- The user's tasks and goals are the driving force behind the development of the future product.
- The user's behavior and context of use need to be studied before the development starts.
- The system needs to be designed to support the users in their behavior and context
- The user's characteristics (e.g. in terms of physical and cognitive abilities) are very important for the development and design of the future product.

Interviews and inquiries are examples for strategies that can be used to identify the user and to find out in which situation the user would use the future product.

Step 2 - Specify requirements: The contact with the user must result in a specification of requirements. The specification is thus a list of the desired functionalities, but should also contain reflections about the design and the technologies that can be used during the development.

Garrett (2002) has identified five stages for the elaboration of such design-guidelines for a specific web-based system. These five stages are intended to help designers to identify goals that need to be considered when designing for specific users:

1. Strategy: What do we want to get out of the system? What do the users want? What objectives do we have by developing the system? (e.g. business goals)

2. Scope: What features do we need to include in the system? What content needs to be available?

3. Structure: How will the features of the system fit together (considering interaction design and content architecture)?

4. Skeleton: How can we arrange the different structures that we have identified in the interface? (e.g. by grouping functionalities, by specifying navigation through content)

5. Surface: What will the system look like visually (considering graphical design)?

Step 3 - Develop prototypes: The third step in the UCD process is the development of prototypes according to the specifications and requirements. Preece *et al.* (2002) state that it can be difficult for the designers of a prototype if users are actively involved in the design process (since users usually do not have the same experience in design as designers), but that it is important that the designers are aware of the users.

Step 4 - Evaluate the prototypes: During the fourth step of the development process, prototypes are evaluated and validated (in this section we have listed a variety of different techniques and methods to evaluate a product's usability). If the users are not satisfied with the prototype the development process starts over with a new analysis of the users needs (Preece *et al.*, 2002)

According to Gould *et al.* (1997) a user-centered approach to system development and design should be preferred in all situations. There are two main reasons for this preference:

- End users are experts on their work and therefore the only ones that can describe it

- End users are the ones that are most suitable for testing and evaluating prototypes and systems that are developed for them

Further, system developers often believe that they can find the perfect design for a system from the first try, but in reality, a good design involves continuous iterations of the design-model described.

2.4.3 The usability of geospatial systems

In 1991 at the NCGIA workshop it was already recognized that the increased functionality of GIS as well as growing number of users added to the importance of usability. (Mark and Frank, 1992) Furthermore the question was raised if it could be possible to produce guidelines for GIS user interfaces that could be applied across different applications, platforms and products. Medyckyj-Scott (1992) argued that the user interface of GIS is often produced when the product is nearly complete and that it later becomes difficult to change it. Medyckyj-Scott (1992) continued his criticism by stating that there had been no systematic empirical evaluation of what the GIS user interface issues are and that up to then only some comments made by GIS users had been noted.

In order to address the lack of usability in GIS' Medyckyj-Scott (1992) proposed to first find out who the users of GIS are in terms of their skills and knowledge and which tasks they need to do with GIS. Then usability evaluations should be carried out.

Usability testing and inspection of GIS

In 1995 at the CHI conference Traynor and Williams (1995) presented a paper titled "Why are Geographic Information Systems Hard to Use?". In this paper the authors point out two basic GIS usability issues that had been detected in a user study where computer science graduate students tested seven GIS software packages:

"GIS' interfaces reflect the system architecture view, rather than the view of the user's work."

"GIS require a sufficient level of knowledge in geography, cartography, database management and computer skills"

According to Knapp (1994) (referenced by Traynor and Williams (1995)) GIS tasks can be reduced to four basic operators. Knapp (1995) defines these operators as "identify, categorize, compare and associate".

- **Identify:** Knapp (1995) states that there are three types of identification that are relevant for spatial data: spatial identification (e.g. to identify an object's length, volume, shape, slope, etc), temporal identification (for instance temporal change) and associative identification (to distinguish or categorize objects).

- **Categorize:** According to Knapp (1995) this visual operator is used to arrange or organize objects according to a nominal, ordinal or interval/ratio based class, e.g. according to a spatial attribute (nominal), to a temporal sequence (ordinal) or the number of objects in a class (interval/ratio)

- **Locate:** Knapp (1995) states that this operator is used to determine an object's absolute or relative location in space or time, for example an object's specific coordinates
- **Associate:** This operator is defined as the joining of spatial and/or temporal relationships (Knapp, 1995). An example for a spatial association is the containment of objects, e.g. "within" or "between"

Traynor and Williams (1995) argue that GIS interfaces do not explicitly support these operators, but their menus are rather structured according to the architecture of the software.

Regarding the skills and knowledge necessary to manipulate a GIS, Traynor and Williams (1995) argue that the GIS-terminology uses both a cartographer's vocabulary (for instance the notions of view, overlay or thematic layer) and a computer scientist's knowledge (e.g. table, attribute and query). This GIS-specific mixture of different domain's vocabulary incites two problems: 1. It becomes more difficult to learn to use a GIS. 2. Once learned how to use a GIS, a GIS-expert has difficulty in communicating with other people (for instance at a workplace) due to the fact that they use another vocabulary. Regarding the vocabulary used in GIS, Gould (1995) even goes a step further by arguing that GIS do not support the natural expression of many basic spatial relations. Gould (1995) argues that this problem must be rooted in the fact that the GIS designer and the cartographer do not share the same objective reality.

Two studies involving real-world users were conducted by Davies and Medyckyj-Scott; (Davies and Medyckyj-Scott (1994) and Davies and Medyckyj-Scott (1996)). The first study involved sending out 430 questionnaires to organizations (including research establishments, consultancies, local and national governments, map publishing companies, and national parks) in twelve different countries regarding the usability of different GIS. The base for the questions was the ISO 9241 standard (ISO, 1994).

The authors finally received 159 usable questionnaires regarding thirty different products. The conclusions of the study were that

- GIS software is poor at providing useful error messages
- Non-technical end-users are often unable to adapt the interfaces to their preferences
- The documentation should be more accurate, consistent and task-related
- GIS user interfaces should comply more with established interface standards
- Often the users of complex vector-based systems are using the systems for simple tasks. These complex systems should therefore be optimized for simple, most commonly used tasks.
- Novice users need better support and guidance by the software e.g. through prompt messages and consistent interaction procedures

- Long GIS training courses do not compensate for poor usability
- The customization of GIS should avoid introducing inconsistencies into the system and the documentation
- The perfectly generic user interface for GIS probably does not exist.

In the second study the researchers visited 21 people working with GIS in companies and organizations in order to get a more qualitative view of how users were using the systems (Davies and Medyckyj-Scott, 1996). During each visit the GIS user was filmed while he was doing normal tasks. After these tasks a semistructured interview followed where aspects of what was observed were discussed. The conclusions of the study reinforced the findings of the previous study. In addition Davies and Medyckyj-Scott (1996) state that

- System response times were generally poor. Users spent on average one third of the task time waiting for the system
- Some evidence was found that users of customized GIS were more productive
- There was some evidence that screen reflections had an influence on the user's performance
- The user's productivity tended to be lower where the user's interface was cluttered or visually unclear.

After Davies' and Medyckyj-Scott's studies it appears that HCI-related research in the GI-community changed its focus from interface-design and usability related issues towards cognitive aspects (Haklay and Zafiri, 2008). Furthermore also the development of geospatial systems changed its emphasis from monolithic desktop-GIS to distributed systems, web-services and online geospatial systems. These trends incited the community focus on the usability of geographic information itself (Hunter *et al.*, 2003) with a discussion of aspects such as spatial data accuracy. Moreover the discussion about the usability of web-based geospatial systems (also known as web-mapping systems, webGIS or webcartography-systems) emerged. (These systems will be explained further in the next chapter.)

A Public participation Geographic Information System (PPGIS) was the subject for a usability study conducted by Haklay and Tobon (2003). The nine test-users were filmed with a video camera while carrying out four different tasks involving navigation, displaying different layers, comparing map themes and finding particular information. Haklay and Tobon (2003) state that they were able to identify some usability problems (for instance a symbology and layer representation that made it difficult to read the map at some zoom levels). The conclusions of the study were that usability engineering and particularly the user-centered system development approach are useful for PPGIS and that only appropriate testing with real-world users are able to reveal whether something is easy to use or not.

Skarlatidou and Haklay (2006) presented a study where in one session 20 users tested the so-called way-finding systems Multimap[3], Google Maps[4] and MapQuest[5]. In the second session five users evaluated the systems MSN maps[6], Yahoo maps[7], ViaMichelin[8] and StreetMap[9]. Skarlatidou and Haklay (2006) used the Think Aloud Protocol (see section 2.4.2). Moreover the task completion time, the total number of clicks and the success rate for the four tasks that were given to the test-users were counted. After the two sessions Skarlatidou and Haklay (2006) compared all mapping sites with each other according to the different parameters collected and stated that Google Maps showed the highest success rate. Other findings were that advertisements disturbed the users and although many sites offer a wide range of functionalities, users tend to avoid most of these functionalities.

In another study Wachowicz *et al.* (2008) measured the two usability aspects user satisfaction and user performance (the speed of performance, the rate of interactions and the rate of error) of the way-finding systems Mappy[10] and Map24[11] with eight participants. The authors came to the conclusion that users, after having used one of the two systems, tried to use the same strategy while interacting with the second system to solve the same task that was given. According to Wachowicz *et al.* (2008) this suggests that users generate familiarity during the use of a system and that this fact could give both positive and negative effects.

Another evaluation with the way-finding systems Google Maps, MSN Maps, MapQuest and Multimap was conducted by Nivala *et al.* (2008). In this study the authors focused on finding usability problems and on proposing guidelines for the user interface design, map design, search operations and help and guidance design. The study was conducted with 24 test users (eight 'general' users, eight experts in cartography and eight usability experts) and more than 400 usability problems were detected. Furthermore, the authors stressed the importance of familiarity with such applications which can have effects on the interaction and satisfaction (for instance that users can be attracted by new features and ideas resulting in good satisfaction). However users can be unsatisfied if a new system does not react in the same way as previous systems that they are familiar with.

Cöltekin *et al.* (2008) have compared two online geospatial systems (The National Atlas of the United States[12] and an interactive map published on carto.net [13], a website for developers of SVG-based mapping systems). The authors used eye-tracking equipment to analyze the usability measure effectiveness. The interactions of 30 participants (11 females, 19 males; having a high level of ex-

[3]http://www.multimap.com
[4]http://maps.google.com
[5]http://www.mapquest.com
[6]http://maps.msn.com
[7]http://maps.yahoo.com
[8]http://www.viamichelin.com
[9]http://www.streetmap.co.uk
[10]http://www.mappy.com
[11]http://www.map24.com
[12]http://www.nationalatlas.gov
[13]http://www.carto.net

perience regarding operating systems and the Internet and a fair experience in using graphical and spatial data) with these two systems were recorded using the eye-tracking equipment. Cöltekin *et al.* (2008) identified some usability issues regarding the two systems by analyzing eye-scan paths and eye-fixations.

A different approach in evaluating web mapping systems was presented by You *et al.* (2007). The authors analyzed the most essential navigation functions of a web mapping site: zoom and pan. You *et al.* (2007) found out that there are different manners in which these functions are implemented and used in today's systems. For the zoom functions these are:

- zoom by re-center (the map zooms to the point that has been clicked on the map) and original center (the map zooms to the center of the map)
- zoom-in by marquee (the map zooms to a rectangular area that has been selected)
- zoom by fixed scales (the user has the choice of some fixed scales)

For the pan functions there are four possibilities:

- pan-buttons that are grouped around one location
- pan-buttons that are distributed around the map
- clicking on the map re-centers (pans) the map
- moving the map by dragging it pans the map

You *et al.* (2007) put up an inventory of ten different web mapping systems in order to find out how pan and zoom functions are implemented. The comparison showed that in all cases at least two different zoom functions were available. Furthermore in nine of ten systems at least two different pan-functions were implemented. In order to compare the different functions' efficiency, the authors implemented four web mapping systems showing the same (fictive) map. The four systems were at the same time capable of recording user interactions (clicks). The following functions were compared: original center zoom vs. re-center zoom and grouped pan buttons vs pan buttons around the map. The 96 users who evaluated the system were all students (graduate and undergraduate).

The most important results of the study were:

- the original center zoom is more efficient than the re-center zoom (however there was no significant difference in terms of satisfaction)
- the participants found that the zoom icon (a magnifier) fitted the original center zoom better than the re-center zoom
- inexperienced users may think that they are to move the map with the pan-buttons, but not the frame; distributed pan-buttons might help the user to move in the right direction; however the distance that has to be done with the mouse is longer than with grouped pan-buttons.

User-centered development approaches to geospatial systems

Several researchers (e.g. Lanter and Essinger (1991); Mark and Frank (1992); Vora and Helander (1992); Haklay and Tobon (2003); Davies *et al.* (2005)) have considered the user-centered system development (UCD) approach (presented in section 2.4.2) to be useful for the development of geospatial systems.

Kramers (2007) describes the development of the Atlas of Canada according to the UCD-model. The most important objectives of this process were:

- To identify and profile the future users
- To measure user satisfaction regarding static and interactive maps
- To asses the usability and content of the system
- To understand the behavior of the users
- To find out about the user's unmet needs

According to Kramers (2007) the UCD approach was used in three case studies to address the graphical design of the interface, the design of map navigation tools and the integration of topographic maps in the system. Kramers (2007) concludes that applying the approach has led to some additional time and costs, yet it also resulted in the Atlas being the right product for the right users, right reasons and right cost.

Tsou and Curran (2008) have proposed a framework for the development of online geospatial applications according to the UCD process. Tsou and Curran (2008) refer to Garrett's five design identification stages (Garrett, 2002) which take into account that a web-based system does have two important sets of components: components related to the user interface design (functions) and components related to the content.

Within the context of web-based geospatial systems Tsou and Curran (2008) have proposed to consider thus:

- The geospatial system's user interface design (functions)
- The geospatial system's content (map, map layers, legend, etc.)

Tsou and Curran (2008) used Garrett's five stages (Strategy, Scope, Structure, Skeleton, Surface; further explained in section 2.4.2) for both the system's interface and the system's geospatial content (see table 2.1)

Tsou and Curran (2008) conclude that it is important to separate between the geospatial interface and the geospatial data. Furthermore Tsou and Curran (2008) indicate that many geospatial web-services offer poorly designed content and that the integration of such services could result in a decreased usability of the system. Especially considering the application of the UCD approach to web-based geospatial systems Tsou and Curran (2008) point out three challenges:

	User Interface design	Geospatial content design
1. Strategy	**User needs:** e.g. browsing of geospatial data of a specific region	
2. Scope	**Functional specification:** We need map navigation tools and tools to query geospatial data	**Map content requirements:** We need to display real-time content on a map
3. Structure	**Formalized function list:** e.g. Map display functions, spatial identify functions, query functions	**Itemized data objects:** e.g. Roads (from a database), water bodies (from shapefiles), etc.
4. Skeleton	**Grouping functions:** e.g. grouping of map navigation tools, grouping of map query tools	**Arrangement of map layers:** e.g. our base layers are aerial images, on top we will display roads
5. Surface	**Graphical arrangement and look:** e.g. where do we put the map? (e.g. left-right), where do we put the navigation tools? how shall the icons look like?	**Map semiology and look:** e.g. what symbols and colors shall we use for which layer?

Table 2.1: Garretts's five design stages applied to online geospatial systems (adapted after Tsou and Curran (2008)

- Web-technologies change rapidly. This fact thereby requires the developers and designers to carry out several UCD-loops.
- The users of web-based geospatial systems are very diverse (for instance in terms of their cultural background) Taking the diversity of users into account and producing several interfaces might result in inconsistencies and confusion for general users.
- The UCD-approach does not facilitate innovative, revolutionary interface design due to the fact that the UCD is an iterative process which takes time.

2.5 Summary

In this chapter we have presented various scientific theories and research results regarding the inter-disciplinary combination of the two disciplines Human Computer Interaction (HCI) and geospatial sciences. This literature-review represents the theoretical foundation of the research presented in this thesis. We have structured these theories according to main fields of interest in Human Computer Interaction:

- **Cognitive sciences** are investigating how the human brain functions and how humans perceive, store and use information, artifacts and technology. In geospatial sciences especially the cognition of space (cognitive maps, spatial reasoning) has been addressed.
- **System design** reflects design aspects of software systems such as graphical design or interaction design. In the field of HCI several guidelines have been but up aiming at optimizing an interface. Considering geospatial systems it has been pointed out that the design of the geospatial content ("the map") matters. One important concept is "Geovisualiza-

tion" (GVIS) where the exploration of geospatial data is a central point of interest.

- **Usability** aims at increasing aspects of a software system such as a system's effectiveness, efficiency and user satisfaction. Different methods are presented in order to reach this goal. Within geospatial sciences some relevant studies analyzing usability aspects of geospatial systems have been conducted.

3

Online geospatial systems

3.1 Introduction and definition

In this chapter we define and categorize online geospatial systems. First we describe the nature of these systems and give a brief historical overview. Thereafter we explain different technological concepts and architectures.

Online geospatial systems are known under different terms: webGIS (often also abbreviated WGIS) is one of several terms for describing geospatial systems that are accessible through a web-browser. Other common terms are web mapping systems or web cartography. Neumann (2008), distinguishes the terms web mapping and web cartography by defining that web mapping deals with technological issues while web cartography deals more with theoretical aspects such as the use of web maps. Furthermore Neumann (2008) states that webGIS and web mapping systems are often used as synonyms, and that the boundary between these two terms is blurry.

Although the terms webGIS, web cartography and web mapping stand for similar systems and research fields, we argue that the terms are much used depending on their focus and context of its developers: the term webGIS is often used in a GIS context (at conferences, in books and articles) with a focus on technological or analytical subjects (e.g. Brovelli *et al.* (2006)) the term web cartography is often used in the context of cartography with a stronger focus on the map and map visualization.

In the context of this thesis we have decided to use the term *online geospatial systems* as geospatial systems that are accessible through the world wide web and a web browser (such as Mozilla Firefox, Microsoft Internet Explorer, Safari or Google Chrome). Although the usage contexts, technologies and architectures may vary, there is one common feature that all online geospatial systems share: A mapping system, enabling the user to interactively browse the contents of a map online.

3.2 The history of online geospatial systems

The very beginning of online geospatial systems can be marked as the point when the world wide web or Internet was conceived. The exact date of the establishment of the Internet is difficult to determine since the term Internet itself stands for a combination of different technologies and definitions such as the TCP/IP protocols, the hypertext markup language HTML and a web-browser. In some publications 1990 is given as the year the first combination of todays Internet components was operational at the CERN in Switzerland. Since that year it has been possible to send static maps as images through the world wide web. However it was not until 1993 when the Mosaic browser was introduced (Peterson, 2008) that images could be graphically displayed within a web-page. That year Steve Putz (Putz, 1994) at the Xerox Palo Alto Research Center developed the first dynamic web mapping platform based on CGI-script. The CGI-script technology was capable of producing images in the GIF format depending on the location of the map the user clicked on.

The next step from static maps onwards was the establishment of HTML 2.0 in 1995. With HTML 2.0 interactive elements such as forms, buttons and image-maps were introduced. These elements made dynamic web mapping systems possible and first commercial systems such as MapGuide[1] and MapQuest[2] were developed.

As Peterson (2008) points out the time between 1993 and 1996 was also dominated by another trend: the scanning of paper maps which suddenly made a large number of maps available from everywhere in the world.

The possibilities of interactive web-pages and systems were increased by the introduction of javascript and first plug-ins for web-browsers such as Flash in 1997 (Peterson, 2008). In 1997 the UMN Mapserver[3], an open-source environment for developing web mapping applications, was released. Still today a variety of different systems are based on this software.

At that time commercial enterprises such as ESRI[4] and Autodesk[5] saw the possibilities and opportunities of such systems and either released their own software (ESRI in 1998) or acquired existing technologies (Autodesks acquisition of MapGuide in 1996).

Another milestone in the development and establishment of web mapping systems was Google's introduction of Google Maps[6] in 2005. This system had a huge impact on the field of web mapping due to the following facts: - it was based on the new AJAX (Asynchronous JavaScript and XML) technology which made map-navigation fluid and fast and it offered soon after its introduction high-quality data of the entire world (Ingensand, 2005b). Later Google released an API which made it possible to develop new applications based on Google Maps and to integrate other data that were not provided by Google.

[1] http://mapguide.osgeo.org
[2] http://www.mapquest.com
[3] http://mapserver.org
[4] http://www.esri.com
[5] http://www.autodesk.com
[6] http://maps.google.com

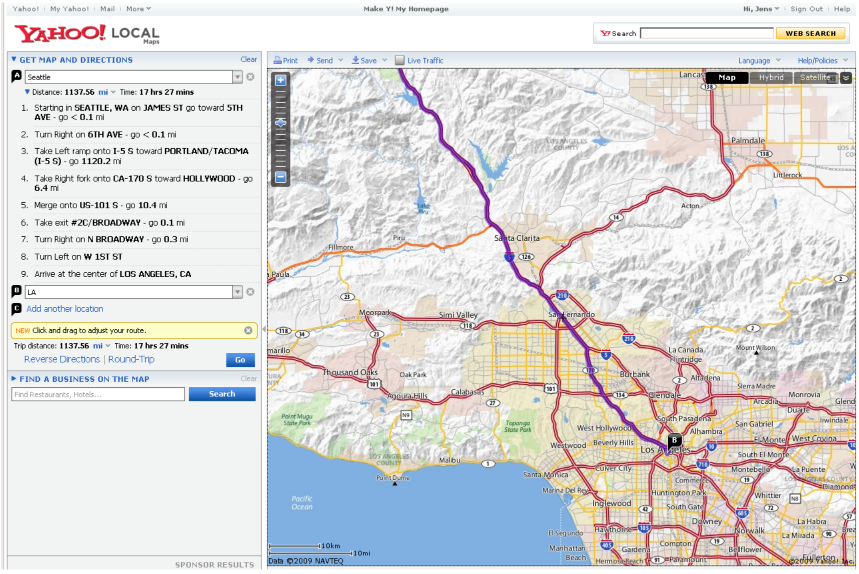


Figure 3.1: Yahoo Maps

3.3 Characteristics of online geospatial systems

Web-based geospatial systems are today used in a variety of different contexts, offer diverse functionality and are based on different technologies and architectures. We can thus distinguish the systems according to:

- their contexts of use
- their functionality
- the technologies / architectures they are based on
- the commercial concept

3.3.1 Contexts of use

One way to define usage contexts is to ask who the *targeted users* are. Systems can be conceived for the public (for everybody) or for a restricted group of users. The restriction to specific groups of users can either occur through the interface-language, through the spatial extent of the data available, through the range of available data layers, through the usability of its interface, or through the possibility to identify a user through an account.

So called **way-finding systems** can be taken as an example for systems that are conceived for the public. These systems offer the possibility to find a way from a start point to an end point and to display this trajectory on a map. In most cases these systems cover the whole world. Examples of such

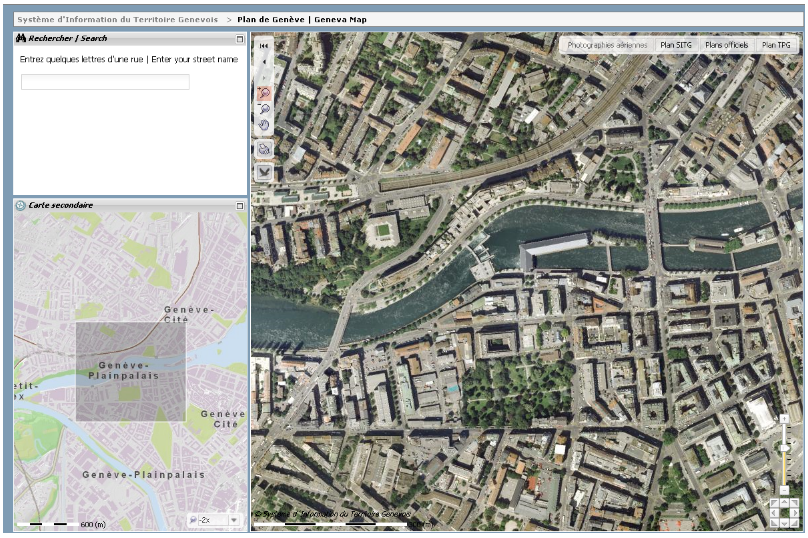


Figure 3.2: Genevas geoportal SITG

systems are Google Maps[7], Yahoo Maps[8], see Figure 3.1, Microsoft Bing maps[9] or MapQuest[10]. In recent years the usage context of these systems has also shifted from pure way-finding capabilities to geospatial showcases that are used to virtually visit and explore places.

Interactive atlases are systems that are able to visualize different thematic data layers (such as natural hazards, population structure etc.) of a country or a region. The targeted users of such systems are mainly found in education (e.g. schools). Such systems are optimized for the end-users in terms of functionality and design (Kramers, 2007). Examples of interactive atlases are the Atlas of Canada [11], and the United States National atlas [12]. However interactive atlases are not always available as web-sites, some are installable software-packages, e.g. The Atlas of Switzerland.

The term **geoportal** stands for systems that provide a variety of different data layers. These systems are often deployed by national and local governments in order to provide an information service for its inhabitants. Examples are the French government's geoportal "Géoportail"[13] or the Swiss canton of Geneva's geoportal SITG[14].

[7] http://maps.google.com
[8] http://maps.yahoo.com
[9] http://www.bing.com/maps
[10] http://www.mapquest.com
[11] http://atlas.nrcan.gc.ca
[12] http://www.nationalatlas.gov
[13] http://www.geoportail.fr
[14] http://etat.geneve.ch/sitg

Spatial collaborative systems are a recent and emerging trend in the field of web-based geospatial systems. It is rooted in the ideas coming from PPGIS (Public Participation GIS) (Sieber, 2006) and aims at enabling its users to add or modify spatial information by interacting with an online map. The use of such systems is for instance spatial decision making and planning; moreover such systems can be used for the production of spatial data by a community. However such systems require several users to participate and imply that data controls (either automatic controls or management-structures) have to be developed. Examples for such systems are Open Street Map[15] and Wikimapia[16].

A fifth category of systems are systems that are not pure geospatial information systems, but **systems with a geospatial component**, e.g. for the digitization of a spatial attribute or the visualization of data layers. An example is the homepage of the Swiss Federal railway company SBB[17] - it possesses a very basic web mapping system, displaying train stations.

3.3.2 Functionality

There are several types of functionality that online geospatial systems can be equipped with. We have identified the following tools and features:

- Basic map navigation tools
- Advanced map navigation tools such as tools to navigate to specific places, e.g. through keyword-search
- Tools to query spatial data, either through direct interaction with the map or through indirect interaction such as through menues
- Tools to add or modify spatial data
- Tools to perform advanced spatial operations
- Tools to in- or output spatial data, e.g. through the upload of files containing spatial data

3.3.3 Technologies and architectures

The fact that online geospatial systems are based on the Internet implies an architecture that divides between a client and a server. A client is thus a web-browser that is installed on a computer with access to the Internet. A server is a computer that is being accessed by the client. There are several common and less common web-browsers on the market with different features and interfaces. Most web-browsers use definitions on how web-content needs to be interpreted. These definitions are maintained by the world wide web consortium, W3C[18]

[15] http://www.openstreetmap.org
[16] http://wikimapia.org
[17] http://www.sbb.ch
[18] http://www.w3.org

On the client side there are certain well-established formats and scripting-languages that most web-browsers are capable of interpreting without the need of a plugin.

- HTML; the Hyper Text Markup Language the most basic component of a web-page
- Images; formats such as GIF and PNG
- CSS; cascading style-sheets: documents that contain information about how a HTML-page needs to be displayed (e.g. type of font, etc.)
- Javascript; a scripting language that adds dynamic features to HTML

The first three formats represent static files that do not change their appearance once they are loaded into the web browser. Javascript adds dynamic features such as for instance hiding and making static content appear. Javascript can be executed according to events that are linked to HTML. Examples for such events are onload (e.g. the script is executed when the HTML-page is loaded) and onmouseover (e.g. the script is executed when the mouse-cursor navigates over an HTML-feature such as a table).

In recent years plugins have become more and more popular. Plugins are small programs that are loaded by the web browser for displaying interactive content. The main reason for the existence of plugins is that the four basic formats (HTML, Images, CSS and Javascript) do have limits in terms of the interactivity that is possible and the effort that is necessary to develop interactive content. The main advantage of plugins is thus that specific interactive content can be developed more easily and offers more functionality. The disadvantage however is that some plugins only are available for certain web-browsers and that the installation often requires administrator-rights on the computer where the plugin needs to be installed. Examples for the most popular plugins are: Java[19] (Java-applets), Flash[20], Silverlight[21] and SVG[22] (SVG is today included in many web-browsers by default).

On the server side the main component of any web-based system is a webserver. A webserver is a program, installed on a computer, that gives access to a folder on the server-computer through the Internet. The webserver listens to incoming traffic if a client-computer requests for instance a page, the webserver sends the page, that is located in the specified folder, to the client. A webserver is further capable of forwarding content, that is stored in the folder containing the web-content, to other applications or programs, installed on the same computer for interpretation. After the interpretation, the webserver forwards the content to the client. Today the most popular web-server software is Apache[23] and Microsofts' IIS[24].

[19] http://java.sun.com
[20] http://www.adobe.com/products/flash
[21] http://silverlight.net
[22] http://www.w3.org/Graphics/SVG
[23] http://httpd.apache.org
[24] http://www.iis.net

Content such as standard HTML content or Images can be produced dynamically, e.g. at the time the client sends a request, on the server. The dynamic production of such content can be done using different scripting languages such as PhP[25], ASP[26], JSP[27] or CGI-script[28]. PhP or ASP for instance are capable of producing HTML pages, depending on information that is stored in a database or information that has been fed in by the user. CGI-scripts are often used for the dynamic production of images.

By considering the functional requirements of online geospatial systems we can state that

- online geospatial systems need a certain degree of interactive functionality
- online geospatial systems usually access and display huge quantities of data

These two statements raise the two questions that each developer of online geospatial systems needs to consider:

- Which technologies need to be used to offer dynamic functionality, e.g. javascript or plugins on the client-side or/and dynamic content production on the server-side?
- How much data can be sent to the client at a time and which formats shall be used to send the data, e.g. raster or vector formats?

According to the type of data that is sent between the server and the client we can categorize online geospatial systems into

- *Vector-only systems:* data is sent in a vector format; the advantage is that vector data usually takes less bandwidth; the disadvantage is that the client needs to be sophisticated in interpreting and displaying vector-data, another problem is that backgrounds such as aerial images cannot be used.
- *Raster-only systems:* data is sent in a raster format (images); the advantage is that images are more easily interpreted by the client since any GUI-based web browser is capable of displaying images; the disadvantage is the bandwidth (large images take a certain amount of time to load)
- *Mixed raster-and vector systems:* data is sent in raster and vector format; the advantages and disadvantages of both systems apply.

Another distinction that is closely related to the question of data-types is the distinction of how computation power is distributed. Since it would be difficult to conceive systems where all available data are sent to the client at once, a vast majority of online geospatial systems only display a small amount of data at the

[25]http://www.php.net
[26]http://www.asp.net
[27]http://java.sun.com/products/jsp
[28]http://www.w3.org/CGI

time. It takes thus computing power to assemble data layers, to render vector-data layers to images and to cut the layers into pieces that will be displayed by the client. Computing of these three tasks can be executed:

- on the server; depending on the area and the data layers requested, the server clips the data of the existing data sets and sends the data either layer per layer or as an assembly, e.g. an image, to the client. The server either renders vector-data layers itself (by producing an image) or sends the requested region to the client as a vector-object.
- on the client; many clients support rendering of several data-layers (raster or vector) to one image that is displayed for the user. Moreover several clients exist that cache a larger region around the visible map-area in order to display it in case the user moves the map
- before the actual usage of the system. A technique called tiling is used to produce small pre-produced map-tiles by assembling several data layers and by cutting the layers into small tiles. The tiles are then requested and assembled by the client, depending on the region the user wants to see. The advantage of this technique is that little computing power (both on the client and on the server side) is needed and that such systems display a map faster than other systems. The disadvantage is that it is more difficult to integrate real-time information, since all tiles need to be reproduced. This technique is fairly recent and used in an increasing number of systems.

A third way to distinguish online geospatial systems is by the kind of technologies that are used to create the interactivity that is required, e.g.:

On the client-side:

- Plugins such as SVG, Java, Flash, Silverlight are used for interactive maps and tools to add or modify information
- Javascript is used for producing interactive clients. In recent years the AJAX technology which is based on Javascript and XML has become a widely-used framework

On the server-side:

- Technologies such as MapServer (Kropla, 2005) (producing images) and scripting languages (such as JSP, ASP and PhP) are used for the dynamic production of the interface. The client receives data that is already in a format that is adapted to web-browsers.
- Webservices have become increasingly spread in the world of webGIS. Webservices are based on standardized protocols and are able to send and receive geospatial data in both vector and raster formats. Examples of such webservices are WMS (Web Map Service), a standard defined by the Open Geospatial Consortium (OGC)[29], serving raster-data and WFS (Web Feature Service, defined by the OGC[30]) serving vector-data.

[29]http://www.opengeospatial.org/standards/wms
[30]http://www.opengeospatial.org/standards/wfs

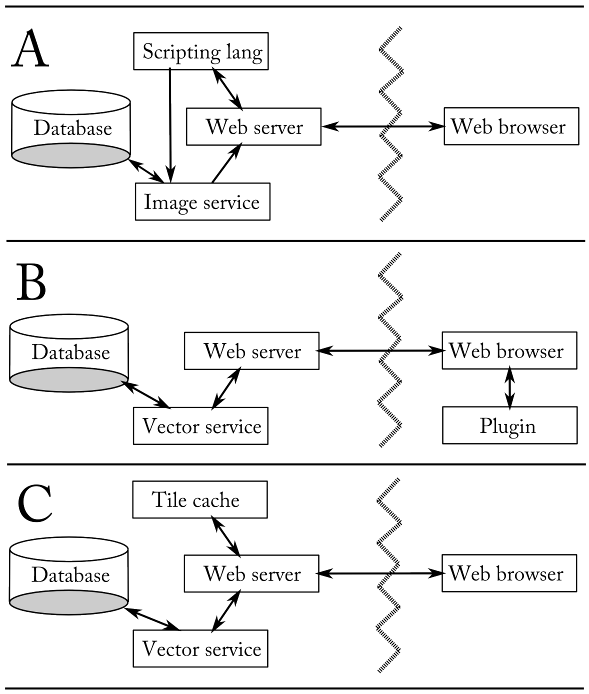


Figure 3.3: Open geospatial systems architectures

- Specific sever-technologies serving clients via specific protocols with data. As an example the XML-RPC protocol can be cited which sends its data to e.g. a Java-Applet through XML-files.

Figure 3.3 illustrates three common architectures of online geospatial systems:

- **A** This architecture is a classic architecture of online geospatial systems. The system consists of a webserver who forwards the client's requests to a script (such as ASP or PhP). The script then calls a map-generating service who produces an image from the data that is stored in a database or in separate data-files. The webserver sends the final map along with the page containing the map to the client. This architecture poses high processing requirements on the server (due to the fact that each request must be processed by a scripting-language and the map-generating service) and low requirements on the client since the content that is sent back only consists of standard elements (HTML code and images). An example for a system based on this architecture is the Atlas of Canada

- **B** This system architecture is based on a web-server and a service that provides vector-data. Since a web-browser only with difficulty is able to interpret large quantities of vector data, many systems of this type use a plugin, that a user needs to install locally on his computer in order to access the data. The advantages of this architecture are low requirements on the server in terms of computing power. On the other hand the plugin, installed on the client can need more processing power and memory. The way-finding system Map24 is an example for a system which uses a Java-applet as a plugin in order to display vector data.

- **C** Architecture C is a more recent way of creating online geospatial systems. It uses a so-called tile-cache; a stock of pre-produced images that are cut into tiles. On the client side Javascript (AJAX) is used to assemble these tiles to a map and to display smaller quantities of vector-data. Depending on the area the user wishes to visualize, the AJAX technology automatically requests the image-tiles that are needed. A particularity of architecture C compared to architecture A is that the tile-cache needs to be created before the system becomes usable. A tile-cache can thus require a considerable amount of storage capacity on the server due to the fact that images at different scales need to be stored. On the client side the architecture puts slightly higherer requirements on the web-browser due to the fact that javascript needs to keep track of all the tiles that need to be loaded and in many cases needs to calculate and visualize vector-data. An advantage of this architecture is that it becomes significantly faster since no immediate processing power is needed on the server; the server basically only sends the image-tiles and the javascript-code to the client. The fact that a tile-cache is used also improves the usage of the available bandwidth. Google maps is a prominent example for this type of architecture.

In recent years different API's (Application Programming Interfaces) have appeared on the market which enable developers to build online geospatial systems without a complicated dedicated server architecture. These API's can be considered as the client-part of an online geospatial system's architecture and are often based on Javascript (AJAX). A developer can for instance configure API's to connect to web-services (such as WMS or WFS or tile-caches) and thus take advantage of external data-sources. Examples for such API's are the open-source framework OpenLayers[31] or the Google Maps API[32].

3.3.4 Commercial concepts

Most major providers of GIS software also offer software that is able to create online geospatial systems. Examples for such products are ESRI's ArcGIS Server[33] or Manifold's Internet Map Server[34]. The advantage of these products is that they are optimized to work with other components of the same provider and that they thereby facilitate publishing of geospatial data that has been produced in for instance a desktop GIS of the same company.

In the mid-1990 several open-source projects appeared who enabled developers to create online geospatial systems. Some of these projects had the goal to develop a specific component that were useful in online geospatial system

[31] http://openlayers.org/
[32] http://code.google.com/apis/maps/
[33] http://www.esri.com/software/arcgis/arcgisserver
[34] http://www.manifold.net/info/ims.shtml

architecture; such as the UMN Mapserver[35] or the GDAL-project[36] which enabled developers to prepare and optimize their data for such systems. Erle *et al.* (2005). Around these components a community emerged who is today offering different services for the development of online geospatial systems. In this commercial concept the product itself becomes free (in terms of license costs) but the configuration, data-preparation, customization and support are gainful.

Also considering geospatial data different commercial concepts can be distinguished. Several providers for instance offer geospatial web-services free of charge (e.g. the Atlas of Canada, through a WMS-service), some with advertisements (e.g. Google) and some for a fee.

3.4 Towards 3D systems and real-time information

Online geospatial systems that are designed to explore spatial content are increasingly often enabling the user to browse the data using 3D views. In such systems users can navigate in three dimensions and view objects and landscapes from all angles. Especially the competition between the major companies Microsoft and Google appears to accelerated both the development of this functionality and the acquisition of high-resolution data and 3D-models (such as for instance buildings in 3D). According to Leberl and Gruber (2009) Microsoft has developed an method to produce complete 3D models of every building in a city at a rate of about 300 cities a year. The two concurring products Google Earth[37] (which is also available within a web-browser) and Bing Maps[38] are today capable of displaying complete cities in 3D. 3D geospatial systems however have not only been developed by commercial companies, but also by open-source software projects. A famous example is NASA's World Wind[39] virtual globe.

Notable features in this context are also Google's Street View (a feature that allows the user to browse 360 photographies of the world) and Bing maps bird's eye view (see Figure 3.4)

Another recent trend in the development of online geospatial systems is the integration of real-time information. Today systems are able to display traffic information and the weather data in real-time on online-maps. Moreover the fusion of Internet-based services and mobile devices (such as cellular phones) enables people to access geospatial data through location-based services (LBS) and display this data as augmented-reality applications (e.g. for tourist information).

[35] http://www.mapserver.org
[36] http://www.gdal.org
[37] http://earth.google.com
[38] http://www.bing.com/maps
[39] http://worldwind.arc.nasa.gov

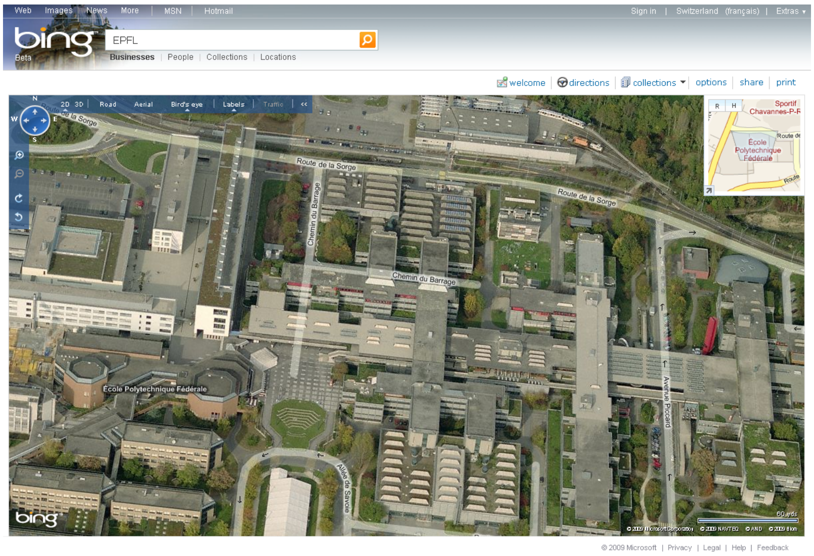


Figure 3.4: Bing Maps - showing the EPFL in the bird's eye view-mode

3.5 Summary

Online geospatial systems are known by different terms such as webmapping systems, webGIS or web cartography. In this chapter we explain the history of these systems from the first interactive mapping system in 1994 to recent trends and technologies. Furthermore we provide a categorization of these systems according to their context of use: way-finding systems, interactive atlases, geoportals, spatial collaborative systems and online-systems with a geospatial component.

There are different technologies and architectures to build this kind of applications: on the client's side developers often use plugins (such as Java-applets) or Javascript-enhanced technologies (e.g. AJAX) to accomplish interactivity. On the server side map-processing services (where the map is produced upon each user interaction) and map-tile caches (where all map-layers are pre-produced tiled images) are frequently used concepts. The architecture and technologies are usually chosen according to the context of use.

Systems allowing the user to view geospatial data in real time or in three dimensions are recent trends in the development of online geospatial systems.

4

The interaction with online geospatial systems

4.1 Introduction

In this chapter we describe the formal conceptual framework established in this thesis in order to categorize, analyze and evaluate real-world users and their interaction with online geospatial systems. The framework is founded on various findings in the literature, described in chapter two, and particularly addresses the complexities involved in characterizing users' interaction with online geospatial system. To capture these complexities in the conceptual framework, we identify and classify, as completely as possible, the components and variables of the interaction process.

In chapter three we saw that there is a vast variety of different online geospatial systems with different architectures and interfaces on the market. The purposes and contexts of utilization change from system to system and the target users of one system are different from the target users of another system. In order to analyze the interaction of users with such systems the framework needs to take all parameters that may influence the interaction into account. The most essential parts of this framework are thus the user and the system.

Interaction is the process of a user using a system over a period of time. In the context of geospatial systems used within a web-browser, the interaction is restricted by the physical interface of the user's computer. The physical interface of a computer that is used for accessing an Internet-based system usually consists of a display of varying size, resolution, contrast and color-depth and input devices such as mouse, keyboard, touch-pad or the screen itself (touch-screen). Other input and output devices such as microphones (e.g. for speech control), cameras and loudspeakers are today very rarely used in the context of online geospatial systems. The feedback that such systems provide to the user is in almost all cases only visual and the possibilities to physically interact with a system are therefore restricted to the input devices attached to the computer.

4.2 Conceptual framework

The interaction of users with Internet-based geospatial systems is a complex field of study. Usability problems, for instance, may have several causes that are not only related to the design of the interface in terms of the functions or the graphical design, but also to an earlier experience with similar systems.

In order to address the complex nature of this interaction-process, we propose a theoretical framework that is based on the assumption that the basic entities of the interaction (the user and the system) can be characterized by a set of parameters. Arhippainen (2009) for instance has used different fields of parameters in order to describe user experience in the context of mobile devices. The basic fields in her framework are: the user (with parameters such as demographics, prior experience), the product (e.g. functions, size, weight, etc.) three fields of user context (social, cultural and physical) and the interaction. A similar framework has been proposed by Mutlu (2006) for the design of social products.

Within the field of usability, the focus of interest is clearly on the improvement of computer systems. Aspects such as the user's satisfaction or productivity (by increasing user performance in terms of speed and errors) are the main focus. We have seen in chapter 2, that a widely used method to improve a system's usability is to detect, describe and analyze usability problems. Once a usability problem has been detected, the system's interface can be adapted and the system's efficiency and effectiveness can be increased.

The usability-approach is proven to work well for any system since the nature of the system can be generic. When we consider just one well-defined group of systems (in our case online geospatial systems) we find ourselves in a context where many basic functions and interface features are implemented in all online geospatial systems. Examples of such functions and interface features are a map or navigation tools (e.g. zoom tools).

Several researchers who have analyzed the usability of online geospatial systems (Wachowicz *et al.*, 2008; Nivala *et al.*, 2008; Skarlatidou and Haklay, 2006) have detected and described a variety of different usability problems. We argue that studies of this kind are indeed essential for the improved usability of online geospatial systems since they result in guidelines and recommendations on how specific online geospatial systems should be implemented and designed.

Many studies however have one important weakness: they focus on the interface itself and not on the actual users who were available for the study. Wachowicz *et al.* (2008) for example did not exactly specify who the users were in terms of their age, experience, expectations, gender and so forth. Nivala *et al.* (2008) on the other hand chose 24 test users based on their background and experience (eight 'general' users, eight experts in cartography and eight usability experts) in order to detect usability problems of different interfaces.

If we consider the quantity of usability problems detected by Nivala *et al.* (2008) from the user-centered system development perspective (see section 2.4.2) the reason for a products' failure to please the users, e.g. during a usability test, must lie within the development process. This means that the developers of the systems were not sufficiently taking into account the user and his context, and did not sufficiently involve the end-users in the actual development process.

There are many authors, e.g. Kuniavsky (2007); Preece *et al.* (2002), who have stressed the fact that it is essential to know and to understand the user before starting to design and to develop a new product. Yet within the research domain of geospatial systems it has been stated that the developing community knows very little about the actual end-user (Mark and Frank, 1992; Unwin, 2005). Tsou and Curran (2008) and Goodchild (2007) argue that more attention should be paid to user-centric approaches and to individual and group differences (Slocum *et al.*, 2001). In addition Tsou and Curran (2008) state that users of web-mapping applications are even more diverse and unknown than traditional GIS users and that most users of such applications do not have any GIS training or cartography knowledge.

In this conceptual framework we therefore do not want to approach the user-system interaction complexity by criticizing the usability problems of an existing system. Instead we want to approach it from a different, more balanced, point of view by asking the following questions:

- Who are the users who are interacting with the system? For instance how old are they? What do they do?
- What is the system the users are interacting with? E.g. what kind of functions are implemented? What data is available?
- Why do the users interact with the system the way they do?
- Why are the users satisfied, alternatively unsatisfied, with the system?

By asking these questions we re-consider the development process of online geospatial systems and start with an analysis of a user and his tasks. The four questions result in the four main categories of our framework: the user, the system (here we consider the conglomerate of an online geospatial system AND the user's computer through which he accesses it.), the interaction and the satisfaction. Each of these categories can be defined by a set of parameters which might influence one or several parameters from another category. (The idea behind this categorization was conceived during a discussion with Hedley (2006)).

In order to refine the basic conceptual framework that we have proposed above we will therefore consider each of the main categories (the user, the system, the interaction and the satisfaction) as a set of parameters. In the following subsection we will identify the parameters of each category and analyze whether these parameters might have an influence on the parameters of other categories.

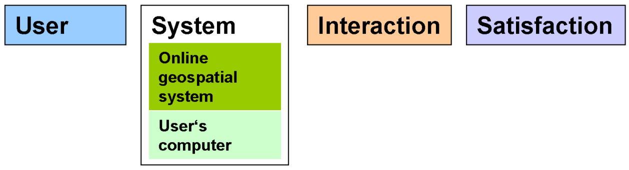


Figure 4.1: Categories of parameters

4.2.1 The user

A specification of users into parameters that might influence a users' interaction with a system is a complex task since the human being, with her superior mental capabilities, is perhaps the most complicated form of life inhabiting this planet. Moreover human behavior is not static and varies when influenced by various factors in the external world. As we have discussed in chapter two, a range of researchers involved in social sciences, psychology (e.g. Hegarty *et al.* (2006), anthropology, cognitive sciences (e.g. Hutchins (2001); Norman (1993); Sweller (1988); Johnson-Laird (2005)) have analyzed the human being from very different angles.

In order to find out which parameters are likely to have a significant influence on the user's interaction with online geospatial systems, we make the hypothesis that parameters characterizing the user are relevant if they relate to one of the following groups:

- demographics (age, gender and handedness etc.)
- the user's knowledge and skills (mental models, etc.)
- the user's context (cultural, social and physical)

Gender:

Simon (2001) states that several empirical studies have shown that there are significant gender differences across a variety of tasks that were carried out by both men and women. Some of these differences were:

- Men are better on spatial orientation tasks
- Females are better on verbal or linguistic tasks
- Men and women have significant differences in perception of images.

Kitchin and Blades (2002) have evaluated gender differences concerning the establishment and use of cognitive maps. Males are thus considered to be able to better organize configurational relations and distances. Cooper and Kugler (2007) enumerate a number of studies where the conclusion was that Females know less about information technology, enjoy using the computer less than male students and perceive more problems with the activities carried out with computers in schools. However this fact is not related to the usage of computers in general - in 2003 63% of the working women used computers at work, while only 51% of men did use computers at their work place (Cooper and Kugler, 2007). According to Cooper and Kugler (2007) the disparity between males and females is related to gender stereotypes that are imprinted in society. The male stereotype likes to use computer technology, while the female stereotype does not.

Since many researchers have found significant differences between genders, we consider gender as a relevant parameter for our conceptual framework.

Age:

A considerable amount of publications have focused on the design and development of products for groups of a certain age such as children or elder people.

Bruckman *et al.* (2007) have focused their research on children and state that a child's physical and cognitive abilities increase over time. This development takes place in a series of stages defined by Piaget (1970) (referred by Bruckman *et al.* (2007)) ranging from a sensorimotor stage ($\leq$ 2 years) over a preoperational stage (2-7 years), a concrete operational stage (7-11 years) to a formal operational stage ($\geq$ 11 years). Bruckman *et al.* (2007) argue that it is for instance difficult to develop software for children at the first stage as they focus on what their senses immediately capture. Preece *et al.* (2002) mentions that children as compared to adults have problems learning abstract concepts.

Elder people (older than 60 years) on the other hand experience a decrease of their physical and cognitive abilities (Czaja and Lee, 2007).

Age however cannot be considered as an isolated parameter when it comes to computer technology. We argue that the evolution of computer technology and the contact with this technology at a certain age must be taken into account as well. In a very early study (Smith *et al.*, 1979) state that computer experience was largely restricted to a group of 20-29 year old people. With the increasing introduction of computer technology into peoples lives (e.g. the IBM personal computer in 1981), more people grew up with this technology. We thus conclude that elder people are less likely to have a good experience in computer technology due to the fact that they did not grow up with it.

When it comes to spatial cognition and navigation, Salthouse and Siedlecki (2007) state that elder people are less efficient in selecting routes through a maze. On the other hand young adults tend to perform better in learning to navigate to real and virtual environments (Salthouse and Siedlecki, 2007).

Considering the findings of other researchers, age is thus likely to be a parameter that substantially influences the interaction with online geospatial tools.

Handedness:

There have been several studies analyzing a human's preference of hand (left, right or both (ambidexterity)) and a possible correlation with abilities and skills. Mascie-Taylor (1980) for instance compared handedness to the I.Q. and found out that left-handers verbal I.Q. is significantly higher than their performance I.Q. while it is the opposite correlation for right-handers. Miller (1971) and Levy (1969) (as cited in Mascie-Taylor (1980) and Deutsch (1980)) have found out that left and mixed handers score lower in visual-spatial performance tests than right handers. On the other hand left handers have better auditory skills such as tonal pitch (Deutsch, 1980).

In the domain of Human-Computer Interaction the issue of handedness has been discussed since the early 1990'ies. Kabbash *et al.* (1993) for instance tested pointing and dragging tasks with three different input devices (mouse, trackball and a tablet-computer with a stylus) and measured user performance. The study suggests that the preferred hand is more efficient for small distances and small targets. For large distances and targets, both hands perform equally. Hoffmann *et al.* (1997) on the other hand did not find any evidence for the hypothesis that left-handed users, using a mouse on the right side of the computer, were disadvantaged compared to right-handed users.

The evidence found by Miller (1971) and Levy (1969) suggests that handedness has an influence on performance with online geospatial tools.

The user's knowledge and skills:

We consider the user's knowledge as a term that stands for everything that the user has in mind at a given point in time (e.g. things that have been learned or experienced). Skill are the abilities that are based on knowledge, e.g. the skill to write or to read (Dictionary, 2009).

User knowledge however is complex since humans organize what they have learned in different manners depending on the type of knowledge being acquired. We have seen in chapter 2 that cognitive sciences have proposed theories and models of how the human mind works and how it stores information.

One concept that is relevant for the user's knowledge is the theory of mental models. Mental models help humans to operate devices or systems they have never used before (Payne, 2007) and these models are based on previous experience (see section 2.2.5)

Since previous experience is considered as a mental-model-building factor, we infer that experience with similar systems or similar information in the past must help the user to operate a new system or device. We therefore propose that previous contact with similar systems is relevant as a form of user's knowledge. By similar systems we mean systems that either fit the definition of online geospatial systems or systems that share a common functionality with such systems, e.g. car-navigation systems, games with spatial navigation, or GIS.

Both Wachowicz *et al.* (2008) and Nivala *et al.* (2008) have pointed out the importance of familiarity in interactions with a new geospatial system.

Shneiderman and Plaisant (2009) point out that the user's knowledge and skills are crucial for identifying different design goals. They propose a categorization of the user into:

- *Novice or first-time users.* This type of user carries out a task for the first time, but has in many cases already a conceptual vision of how to proceed.
- *Knowledgeable intermittent users.* This user category has stable task concepts and broad knowledge of interface concepts, but difficulty retaining menu structures or locations of features.
- *Expert frequent users.* These users are very familiar with both the task and interface concepts. Rapid response times, brief feedback and shortcuts are very important interface features.

Since all (online-) geospatial systems per definition deal with geospatial data, a user gets into contact with this data and encodes this spatial information into cognitive maps (Kitchin and Blades, 2002) (see also section 2.2.7). On the other hand spatial information that the user has acquired from the real world also gets encoded into his internal cognitive map of the reality. This cognitive map of the real world is then compared with the information in the geospatial system.

Therefore the knowledge of spatial information, either encoded through the use of geospatial information systems, through the experience of the reality or through other abstractions such as maps or oral descriptions, must influence how a user interacts with an online geospatial system.

User context:

Dourish (2004) states that the context is a central factor for HCI and interactive systems, but that the notion of 'context' is difficult to define. To illustrate the difficulty, Kaenampornpan and O'Neill (2004) have made an inventory of the existing uses of the term 'context' in HCI:

- Benerecetti *et al.* (2001), cited in Kaenampornpan and O'Neill (2004), have divided context into cultural and physical context
- Schmidt *et al.* (1999), cited in Kaenampornpan and O'Neill (2004), have established the categories physical environment, human factors and time
- Lieberman and Selker (2000), cited in Kaenampornpan and O'Neill (2004), classify 'context' into the categories user environment, physical environment, computing environment and time
- Hull *et al.* (1997), cited in Kaenampornpan and O'Neill (2004), argue that the important categories are physical environment, information on the user and device characteristics

- Chalmers and Sloman (1999), cited in Kaenampornpan and O'Neill (2004), classify the term into location, computing environment, social context, user activity and device characteristics
- Lucas (2001), cited in Kaenampornpan and O'Neill (2004), states that the important categories are physical environment, computing environment and user environment
- Dey and Abowd (2000), cited in Kaenampornpan and O'Neill (2004), categorize context into location, information on the user, user activity, time and device characteristics
- Chen and Kotz (2000), cited in Kaenampornpan and O'Neill (2004), made a completely different categorization based on passive and active context, where the active context influences the behaviors of an application, and that passive context is relevant, but not critical, to an application

These classifications of context, however, include elements that are sometimes overlapping with other elements, for instance the physical environment, which, in some definitions, includes the location or the conditions (Kaenampornpan and O'Neill, 2004). Some definitions, e.g. Lieberman and Selker (2000), even include the device that a user is interacting with, for instance to access an software system, into the scope of context.

We argue that the reason why there are so many categorizations of the term 'context' is that authors stress the importance of some elements in the definition depending on the kind of systems that the authors have in mind, e.g. mobile systems (Chalmers and Sloman, 1999). In this work, we are interested in the elements of context that are relevant for the interaction with online geospatial systems. We therefore focus on the characteristics of online geospatial systems - spatial systems that are accessible through the Internet.

As the Internet can be considered as almost ubiquitous (a user can theoretically be in any country or region of the world, at home or at work, or at a public place) we consider the following two elements as important:

- Cultural context
- User environment

Cultural context:

Simon (2001) has conducted a study about website perception and satisfaction depending on the country of origin of the user, and the gender. He states that in a world where an increasing number of people in all regions of the world have access to the Internet, cultural differences become an important factor. Especially companies who for instance want to sell products worldwide through the Internet, the adaptation of their web-pages to specific cultural regions is necessary. Simon's (2001) study relies on Hofstedes dimensions of classification of cultures, previously declared by Hofstede (1991) (referred by Simon (2001)) and summarized later in Hofstede (2009).

- *The power distance dimension* which deals with the extent to which a society accepts unequal distribution of power in institutions and organizations. (Hofstede, 2009) People from cultures with a higher power distance (Simon (2001) cites Egypt, India, Malaysia and Nigeria as examples) might respond in socially desirable ways in order to please those in higher positions of power. On the other hand people from countries with a low power distance, e.g. Austria, Sweden or the U.S.A. (Simon, 2001), might feel more free to express their own opinions.

- *The individualism dimension* is the degree to which people are integrated into groups. Individualism reflects how much people are expected to look after themselves. In collectivist (the opposite of individualist) societies for instance individuals are integrated into strong groups such as extended families which protect its members. (Hofstede, 2009)

- *The masculinity dimension* refers to the distribution of roles between genders. In countries which are considered more 'feminine', the differences between how women's and men's roles are considered are lower than in more 'masculine' countries, where the consideration of roles differs more. (Hofstede, 2009)

- *The uncertainty avoidance dimension* which addresses how cultures deal with high levels of uncertainty and ambiguity in the environment. Individuals from cultures with a high uncertainty avoidance might respond, in situations where they are exposed to uncertainty, according to their belief of how the large population might respond and thus reduce personal risk(Hofstede, 2009). As examples Simon (2001) cites countries such as Argentina, France, Mexico, Egypt or Greece. On the other hand in countries such as Denmark, England, India or Canada, people might be more reflective and less in need of social approval.

- *The long-term versus short-term orientation dimension* deals with the virtue regardless of truth (Hofstede, 2009). A long-term orientation is associated with values such as thrift and perseverance. A short-term orientation is associated with values such as respect for tradition and fulfilling social obligations. Hofstede (2009) mentions that a long-term orientation is mostly found in east Asian countries, such as China, Japan or South Korea.

Simon (2001) recruited 160 subjects that had their origins in four cultural regions of the world - North America, South America, Asia and Europe - to evaluate four different web sites (Reebok Shoes, British Airways, CapEx Investments and Godiva Chocolate). For each web site the subjects were asked to answer questions about their perception and satisfaction.

The author of the study found that there were similarities between North American and European answers regarding the satisfaction and perception and between Asian and South American answers. Simon (2001) thinks that this finding is related to the fact that the Internet is primarily a European / North American creation and that countries which start to be connected to the Internet therefore tend to respond similarly.

Europeans and North Americans were more critical about aspects such as user-friendliness or web site navigation while Asians suggested the use of less bright colors. Asian users showed a higher level of trust concerning the information provided on the websites, while European and North American users remarked on erroneous information. (Simon, 2001)

User environment:

We consider the user's location at the time of interaction with the system as an important element. The location can be for instance at work, at home or at a public place. Each environment has its own set of parameters that influence the user.

- Physical parameters such as light, smell or noise, e.g. Mayhew (2003). These parameters have an influence on the user's senses and might disturb the user.
- Social parameters such as being in close proximity to other people. Persons at close range may influence a user's privacy, but may also influence the way a user interacts with a system. These issues are widely discussed by researchers within the domain of collaborative systems. Within the domain of geospatial information systems it has been addressed e.g. by Golay and Nyerges (1995)
- Time constraints such as time-constraints at the workplace or free time at home, but also frequency of usage. Preece *et al.* (2002) for instance states that users can be classified into several categories such as primary users (likely to be frequent hands-on users of a product), secondary users (occasional users or those who use a product through an intermediary) and tertiary users (those who are affected by the product indirectly). The clients, who order a product from a company, are thus often less likely to be directly affected by the product.

4.2.2 The system

The system that a user is interacting with is the second important entity of our conceptual framework. We claim that the specific properties of the system substantially influence the way a user interacts with it. In chapter 2 we showed that a variety of researchers has addressed a systems' properties by conducting usability evaluations. The results of these evaluations were general guidelines such as for instance Shneiderman's "Eight Golden Rules of Interface Design" (Shneiderman and Plaisant, 2009) or Nielsens "Ten Usability Heuristics" (Nielsen, 1990).

The usability of online geospatial systems has been the subject of research of several publications (Harrower *et al.*, 1997; Haklay and Tobon, 2003; Ingensand, 2004; Skarlatidou and Haklay, 2006; Haklay, 2006; You *et al.*, 2007; Nivala *et al.*, 2007, 2008; Cöltekin *et al.*, 2008; Wachowicz *et al.*, 2008). Most of these publications focused on the evaluation and critique of such systems according to general usability guidelines. Nivala *et al.* (2007) proposed a categorization of usability problems:

- problems related to user interfaces (look, advertisements, etc.)
- problems related to maps (contrast, symbols, etc.)
- problems related to map tools (zoom tools, pan tools, etc.)
- problems related to search operations (direction, address and place searches, result visualization)
- problems related to help and guidance (e.g. error messages)

We think that this categorization can serve as a base for the establishment of a set of system-related parameters that we argue might influence interaction and satisfaction:

Graphical design:

One basic parameter of graphical design is the cognitive load that an interface puts on its user (Shneiderman and Plaisant, 2009). This implies for instance that an interface should be kept simple and not contain too many elements. Interfaces that are for instance too loaded with features result in a lower user performance or satisfaction. Other important factors that are likely to influence the interaction and satisfaction are colors, graphics (such as logos) and fonts. (Robbins, 2000)

Interaction design:

When we consider web-based geospatial systems, interactivity can be accomplished by a set of different geospatial elements and tools:

- *Navigation tools:* These tools offer the possibility to navigate the map (e.g. zooming and panning). You *et al.* (2007) have evaluated in depth the functionality of these tools.
- *Spatial tools:* As spatial tools we consider all tools that allow the user to interact with the spatial information presented in the map, such as tools for querying the map, tools for adding spatial information, and tools for modifying or deleting spatial information. A digitization tool is an example of this category.
- *Map information tools:* These tools present information that help the user to interpret the information displayed on the map. Examples are legends, scalebars and tools that visualize the viewpoint.
- *Search operations:* Many web mapping sites offer the possibility to search for spatial information and to display this information on the map. There are several ways in which such operations have been implemented (e.g. keyword-search in text-boxes or browsing through categories that display alternatives)
- *Help and guidance:* Help tools in online geospatial system can be implemented in several ways: for instance help buttons that lead the user to an explanation of how the system can be used, or contextual help tools such

as tooltips that provide information about how a feature can be utilized. Help and guidance tools Nivala *et al.* (2007) also include messages (such as error messages) that explain to the user what is happening.

Another important factor in the consideration of a web-based geospatial system is the logical design. As a system's logical design we understand the design of different sequels of actions. A sequel of actions is necessary to solve complex tasks. Within the field of HCI complex tasks have been addressed for instance through the use of scenarios (e.g. Carroll and Rosson (1992)). This parameter might be less important for simpler systems with limited functionality, but as tasks get more complex, the importance of the logical design increases.

Map design and visualization:

As discussed earlier in chapter 2 the design of maps, sketches, drawings and plans is a subject that has been discussed by many cartographers (e.g. MacEachren and Cai (2006)) and especially the design of maps for the display on computer displays (e.g. Jenny *et al.* (2008)). As within graphical design, elements such as colors and fonts are important, but also the quantity of features displayed at a certain scale. Moreover the design of thematic maps (e.g. chloropleth maps) is highly subjected to features such as colors or statistical classification methods. (Monmonier, 1991)

In addition to the above parameters stated in the literature, we argue that there are three more parameters that influence interaction substantially: The system's speed, e.g. response time to user actions, the user's computer system and the logical design of a system.

System architecture and performance:

In chapter three we described a variety of different architectures and technologies that online geospatial system can be based on. Depending on the choice of architecture, different requirements are put on the system's server infrastructure (e.g. in terms of computing power, system memory) and on the user's client computer. As we have stated in chapter three, the choice of architecture is dependent on the amount of data, the kind of data, the budget, the infrastructure, etc.

The system's architecture and performance is thus an important factor that influences the system's speed.

System speed:

As Shneiderman and Plaisant (2009) have pointed out, the system's speed is considered as an important parameter for expert users of a system. For online geospatial systems this parameter is an interesting issue since the developers of such systems are not able to fully control the speed of a system. In chapter 3 we have shown that there are different architectures and technologies on the market and that these substantially influence the system's speed. Moreover the internet connection speed (the bandwidth) between the server and the client is a factor that the developers have no control of. We think that the system's speed is a factor that has often been neglected in usability studies about online geospatial systems.

The user's computer:

Today computers come in many shapes and forms. A computer that is able to connect to an online geospatial system can for instance be a cellular phone, able to display web pages, or a powerful desktop computer with a 23" computer screen. The user's computer system is thus a parameter that developers of online geospatial systems cannot control, yet it is through these private computers that users access the system. We argue that the following features of a computer influence interaction substantially:

- The type of computer(notebook, desktop, cellular phone, etc.)
- The computer's screen properties (size, color depth, resolution, contrast, etc.)
- The computer's input device (mouse, trackball, touchpad, etc.)
- The computer's performance (processor speed, memory size, etc.). This factor is also likely to influence the system's speed.
- The computer's Internet connection speed (e.g. modem connection and broadband connection). This factor influences the system's speed.

Computer type:

A computer's type (e.g. desktop computer, notebook, tabletop, palmtop, cellular phone, or netbook) or a computer's physical design (e.g. colors) are concepts that should be mentioned in the scope of system-related parameters. If a computer for instance is a cellular phone, it is likely that a mouse is not the standard input device. Moreover the type of computer also has an influence on the computer's performance (a desktop computer for example is more likely to have more computing power than a cellular phone) or a computer's screen (e.g. a notebook has a larger screen than a netbook).

We suggest that all these features of a computer are likely to influence user satisfaction indirectly due to the hypothesis that a user who is satisfied with a given computer system (for instance because he likes the physical design) is also more satisfied with computer software running on that computer system.

Screen:

In section 2.3.4 we have stated that the computer's screen is an important factor to consider when designing maps for the use in computer systems, as opposed to paper maps. In this work, the following parameters of a screen are important:

- The number of pixels displayed
- Size (the physical size of a display)

- Color depth (ranging from monochrome to 16.7 million colors)
- Contrast and brightness

Laarni (2002) conducted a study with ten subjects where text was presented on different displays, e.g. a laptop display and a PDA display. The most important result of this study was that the screen size has an important influence on text reading efficiency, but also on user satisfaction. Jenny *et al.* (2008) have stressed the fact that screen resolution, color depth and contrast are important parameters to consider in the design of digital maps. Map visualization on computer screens is very different to paper maps due to the low resolution of today's computer screens. The human eye is thus capable of identifying individual pixels on a computer screen, if the color contrast between pixels is high enough.

The screen's physical parameters are thus likely to influence the user's satisfaction with the graphical elements of an online geospatial system. Here the graphical elements include both standard graphical elements of the system's user interface and graphical elements of map visualization.

Moreover (based on the findings of Laarni (2002)) we consider the screen's properties as a parameter that may influence interaction efficiency (task completion time, errors and rate of interaction).

Input device:

Today there is a variety of different input devices on the market. However, within the context of online geospatial systems, we only consider pointing devices as relevant for our conceptual framework, since online geospatial systems are commonly less optimized for other input devices (such as keyboards, microphones or video cameras). The most common pointing devices are:

- Mouse (the most common desktop pointing device)
- Trackball
- Touchpad
- Touchscreen
- Pointing stick
- Stylus
- Joystick

Within these categories of input devices, the differences in terms of functionality and design vary even further. A mouse commonly has between one (e.g. the Apple Macintosh mouse) and three buttons (e.g. the Microsoft wheel mouse) and many models integrate a scrolling wheel. Moreover mice can vary in terms of the tracking technology used (e.g. a laser-mouse or a mouse with a ball capturing the movements) and in terms of their size and design.

Kabbash *et al.* (1993) have performed a study where the user's performance for three types of input devices was analyzed: A mouse, a stylus and a trackball. Kabbash *et al.* (1993) measured dragging and pointing time for all three devices and came to the conclusion that the stylus was the fastest device for pointing and dragging, and trackball the slowest for both measurements.

MacKenzie *et al.* (2001) have measured the accuracy and movement for four pointing devices: mouse, trackball, joystick and touchpad. In their study the path of the pointing device cursor was categorized according to the movement variability, movement error and movement offset. The conclusion was that the mouse is superior as a pointing device, both in terms of accuracy and speed, compared to the touchpad, trackball and joystick devices. The touchpad was as fast as the trackball, but the trackball was found to be a less accurate input device.

Based on the findings of the studies presented, we consider the type of the input device as very relevant for the evaluation of user performance (task completion time, errors, rate of interaction). Moreover it is also very likely that the input device has an influence on the interaction strategies (both task completion strategies and spatial interaction strategies) since we consider the device's accuracy as an important factor for how users interact.

Computer performance:

The computer that a user utilizes to access and to navigate an online geospatial system is not only defined by its in- and output devices, but also by its internal processing capabilities. In chapter three we saw that different system architectures put different requirements on the server side, but also on the client's side. Computer performance thus becomes important when considerable amounts of data have to be visualized. For example the visualization of vector data needs more computing power than the visualization of non-compressed bitmap-images. Parameters such as processor type and memory size are therefore important. However also the type of operating system can be an important factor that influences the performance. The performance of the user's computer is therefore very likely to influence the system's speed and thus also user performance (task completion time, errors, rate of interaction), but also user satisfaction (with the speed).

Internet connection speed:

The bandwidth of the Internet connection between the user's computer and the system's server is furthermore an important parameter that influences system speed. This is mainly due to the fact that online geospatial systems (on the client's side) do not display all the data that is available on the server side, but only the data that the user is interested in. During the interaction, the system therefore successively needs to transfer the data from the server to the client. The Internet connection speed therefore has an influence of the system's speed and thus also user performance (task completion time, errors, rate of interaction), but also user satisfaction (with the speed)

4.2.3 The interaction

In this work we consider two distinct ways of interacting with online geospatial systems: task-driven (e.g. the user needs to solve a task using such a system) or exploratory-based (e.g. the user explores maps and the spatial information provided by the system).

In sections 4.2.1 and 4.2.2 we mentioned a series of factors that we argue influence the way users interact with a system. In order to define 'the way a user interacts with a system' we therefore establish another set of quantitative and qualitative parameters that define the interaction.

For both types of interaction (task-driven and exploratory-based interaction) we consider the following aspects:

- Spatial interaction strategies, e.g. Spatial navigation: the manner in which a user navigates spatial information (e.g. how a user navigates a map from point A to point B)
- The user's interest in the feedback provided by the system, e.g. what features of the system are viewed more often than others

Spatial interaction strategies:

We define spatial interaction strategies as the interaction that a user has with the virtual space displayed in the system. A very important part of spatial interaction (that is implemented in all online geospatial information systems) is spatial navigation. Other spatial interaction is for instance querying spatial information (get information about the associated data), digitizing and modifying spatial information.

Spatial navigation:

We claim that the navigation of spatial data in a computer system is closely related to cognition and perception of space, e.g. through cognitive maps (Kitchin and Blades, 2002) or cognitive spaces (Montello, 1993; Montello and Golledge, 1999) - further explained in sections 2.2.7, 2.2.6 and 2.2.8.

We suggest that navigation in a virtual environment (depicting the real world) is related to navigation in the real world, since a user needs to compare the displayed virtual world with his cognitive map of the real world and decide how to navigate, e.g. which direction to move or at which scale to navigate.

Other spatial interaction:

Besides spatial navigation there are also other ways to interact with the data that is made accessible through online geospatial systems. The other possibilities are:

- Data visualization (e.g. adding spatial data layers to the map)
- Data querying (e.g. getting information about the associated data)

- Data modification (digitizing, deleting information, modifying meta-data, performing spatial operations, etc.)

- Data in- and output (e.g. extracting information from the system to a file / uploading geospatial information)

Depending on the purpose of an web-based geospatial system, the implementation of these other spatial interaction approaches can vary.

The user's perception of geospatial data displayed by the system:

Online geospatial systems provide feedback through the display of geospatial information. This information is perceived and categorized by the user. Information that stands out as more interesting might for instance trigger actions to investigate this information more closely (especially in exploratory interaction). Mac Aoidh *et al.* (2008) have analyzed users' interest in specific features displayed in a geospatial system.

For a task-driven interaction we consider the following parameters (often considered as the elements composing 'user performance')

- Task completion time

- Rate of interaction (how many time a user takes a specific action)

- Rate of errors

- Task completion strategies (e.g. the choice of tools - which tools and features a user utilizes (and which tools a user does not utilize))

Task completion time:

Each task that a user needs to complete takes a certain amount of time. This time depends on parameters such as the system's response time or the time it takes to figure out a strategy to solve the task.

Rate of interaction:

Each action that a user takes (for instance clicking on a tool or scrolling a mouse-wheel) results in feedback provided by the system. The rate of interaction is thus a measure for how many times a user needs to take certain actions in order to fulfill the task. Earlier studies (e.g. Ingensand and Golay (2008) have shown that the rate of interaction has an influence on task completion time. Furthermore we argue that the rate of interaction is also connected to the strategy that a user choses in order to solve a task. Navigating from point A to point B can for instance be done by simply panning the map until the point has been reached (possibly resulting in many interactions) or by zooming out, panning the map and zooming in (possibly resulting in fewer interactions).

Rate of errors:

Completing a task represents a goal that the user wants to reach. If a user fails to reach this goal (entirely or partially) it can be considered as an error. Errors however can have several causes, for instance that the user fails to solve a task due to the strategy he has chosen or due to an error produced by the system itself.

Task completion strategies:

Most software systems, including online geospatial systems, offer several possibilities to take actions and to solve tasks. For instance a web mapping system in most cases provides several ways of navigating the map (You *et al.*, 2007). We suggest that the choice of tools is influenced by several 'user' and 'system' related parameters (e.g. the user's knowledge or the graphical design of the tools) and that the choice of tools itself can influence parameters such as the time it takes to complete a task, or the rate of errors.

4.2.4 Satisfaction

User satisfaction is generally accepted as one of the basic components of usability. (ISO, 1994; Shneiderman, 1998; Nielsen, 1993). According to Doll and Torkzadeh (1988) it can be defined as the *affective attitude* of a user towards a specific computer application. General satisfaction with a specific computer application however can be subdivided into several parameters. Several researchers (e.g. DeLone and McLean (1992) or Cheung and Lee (2005)) propose to distinguish between the satisfaction with the quality of the system itself and the content that is made accessible through the system:

- Concerning the satisfaction with a system's contents, Cheung and Lee (2005) list the parameters *information understandability* (e.g. in terms of clearness and goodness), *reliability* (if the information represented is accurate and consistent) and *usefulness* (referring to the likelihood that the information enhances the user's decision).

- Regarding the satisfaction with the system itself, DeLone and McLean (1992) have made an inventory of twelve scientific studies discussing the elements of system quality. The most important elements of this inventory were the system's response time, flexibility, reliability, ease of use and learning and usefulness. Cheung and Lee (2005) describe the quality of web-based systems with three factors: access (referring to the speed of access and availability), usability (Cheung and Lee (2005) use the term *usability* for describing if a system is visually appealing, consistent and easy to use), and navigation (which deals with the links to needed information and orientation in the system).

If we thus view user satisfaction with web-based geospatial systems with the division between content and system in mind, we can state that the central part of the content represented in geospatial systems is the map. Jenny *et al.* (2008) have listed four essential requirements that need to be fulfilled by digital maps: legibility (referring to the graphical design of the map), unambiguity, learnability (a map must be easy to remember), and trust (a map reader must trust the map).

In order to find the variables that define satisfaction with the online geospatial system itself we use the model proposed by Cheung and Lee (2005). Access to the system (in terms of system speed and availability) appears to be a widely acknowledged variable DeLone and McLean (1992), moreover we consider the consistency of the system as an important factor. Furthermore we argue that visual appeal, the ease of use and navigation are all variables that are defined by the system's design. The graphical design defines if a system is visually appealing and a system's interaction design decides upon navigation and thereby the ease of use. As a last variable we argue that it is important to discuss the user's satisfaction with the system's functionality as well.

Satisfaction with the content:

- Satisfaction with maps

Satisfaction with the system itself:

- Satisfaction with the access to the system (the system's speed and availability)
- Satisfaction with the system's graphical design
- Satisfaction with the system's consistency
- Satisfaction with the system's functionality
- Satisfaction with the system's interaction design

For many of these parameters a possible correlation with the parameters that we have categorized under the field *the system* (section 4.2.2) is obvious. For example a poor graphical design is likely to result in a decreased user satisfaction with the graphical design. We argue that the relation between different types of satisfaction and other parameters can be very complex and dependent on a causal chain. For instance a dissatisfaction with the map navigation might depend on a poor graphical design of a map navigation tool which gives a poor impression of the functionality that a user might expect when pressing a given button.

An idea that has been put forward by some researchers is that an increased user performance (e.g. speed of performance, rate of errors, etc.) might lead to an increased user satisfaction (Wachowicz *et al.*, 2008). For instance, if a user is able to solve a task in a shorter time by using system A than by using system B, he will perhaps be more satisfied with system A than with system B. Although the correlation seems intuitive, it has not been proven to be correct.

4.3 The framework of parameters

Figure 4.2 summarizes our framework of parameters. The framework lists all parameters that we consider relevant for the interaction with an online geospatial system. Arrows represent the notion "has an influence on...". Several "chains of influence" have been identified within the framework such as Internet connection speed which has an influence on the system's speed which in turn must have an influence on "task completion time" and satisfaction.

Many parameters that we have identified are parameters that could be used in the context of other (non-spatial) online systems, however the following parameters are very specific to web-based geospatial systems:

- Spatial interaction strategies
- Perception of spatial features
- Map design and visualization
- Satisfaction with maps (clearness, reliability, usefulness)

Within the other parameters certain aspects are very specific for online geospatial systems such as the user's knowledge and skills (for instance in terms of previous contact with geospatial information or with similar systems), the system's architecture and performance (as we have mentioned in section 3.3.3) or the interaction design (e.g. the interaction design of navigation tools).

If we consider the framework from the perspective of a system developer or designer, the parameters related to the online geospatial system are the only parameters that the developers and designers are able to adapt and to modify. The developer's goal is thus to optimize the online geospatial system by addressing the parameters related to the interaction and the user satisfaction. The parameters related to the user and the user's computer are the parameters that a designer or developer needs to take into account in order to conceive the system.

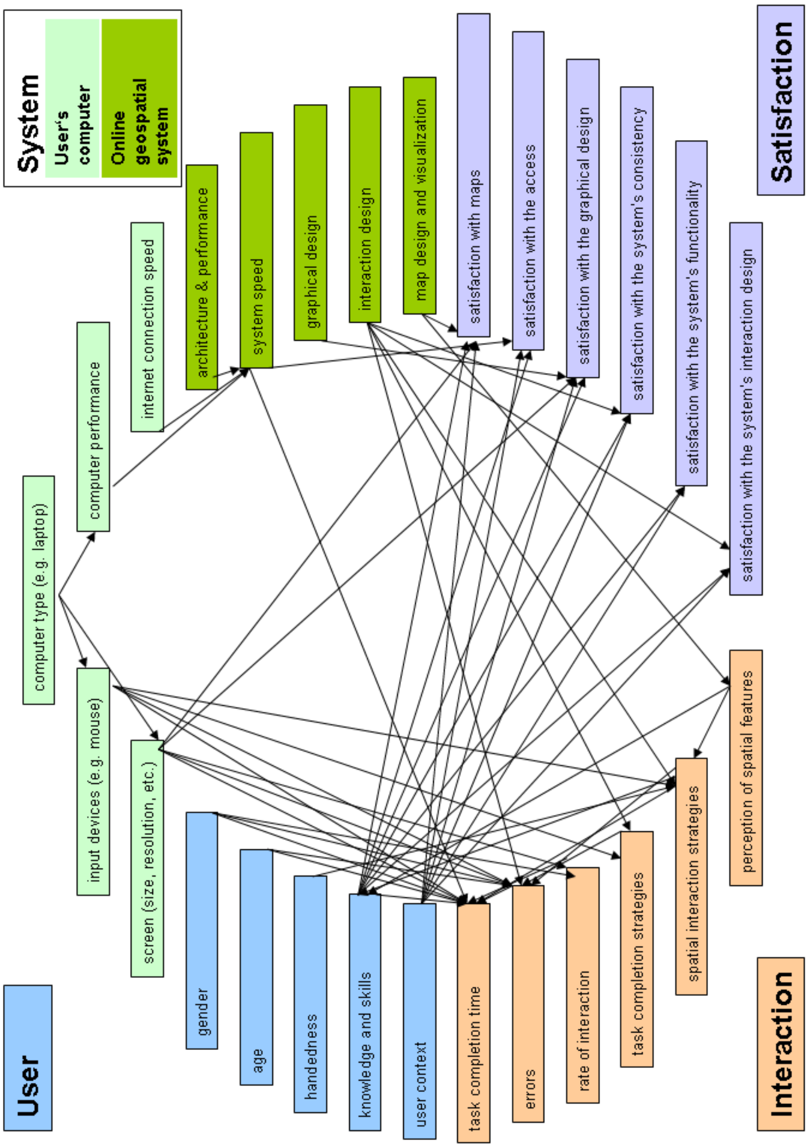


Figure 4.2: Framework of parameters

4.4 Summary

In this chapter we have established a conceptual framework of parameters that describes the interaction between a user and an online geospatial system. The framework can be divided into four major fields: The user, the system, the interaction and the satisfaction. We argue that each of these fields of parameters has a substantial influence when considering the interaction with online geospatial systems. The parameters we have identified in each field are:

- The user: gender, age, handedness, the user's knowledge and skills, the user's cultural context and the user's environment
- The system: (including the online geospatial system itself and the user's computer) the user interface's graphical design, the user interface's interaction design, the design and visualization of maps, the system's speed, the system's architecture and performance. On the side of the user's computer: the type of the computer, the input device, the screen, the Internet connection speed and the computer performance.
- The interaction: spatial interaction strategies, task completion strategies, the user's perception of geospatial data displayed by the system, task completion time, rate of interaction and rate of errors
- The satisfaction: satisfaction with map clearness, reliability and usefulness, satisfaction with the access to the system (the system's speed and availability), satisfaction with the system's graphical design, satisfaction with the system's consistency (the logical design), satisfaction with the system's functionality (ease of use, usefulness) and satisfaction with the system's navigation (navigation within the system and especially map navigation)

5 Hypotheses

5.1 Introduction

In the previous chapter we described the complex process of a user interacting with an online geospatial system. Some researchers have addressed this process by analyzing the usability of such systems with usability evaluations. These evaluations however were only focusing on the usability problems of one or several specific systems without taking into account the users who were actually testing the system. We argue that several user-related parameters have a significant impact on the way users interact with online geospatial systems. In contrast to previous approaches, we have identified four distinct fields of parameters (user-related parameters, system-related parameters, interaction-related parameters and satisfaction-related parameters) and pointed out possible connections between these parameters (see Figure 4.2).

This chapter specifies a set of hypotheses and research questions that we test in order to validate the framework of parameters. Each hypothesis addresses a given connection between pairs of parameters. The approach taken in order to accept or reject the hypotheses is to analyze data from multiple case studies and, based on the analysis, answer the research questions that are associated with each hypothesis.

Given the vast field of online geospatial systems, the hypotheses and research questions try to be general in the sense that they are applicable to a variety of different systems, but also specific in terms of our four key fields of parameters. Figure 5.1 shows an overview of how the different hypotheses, which we specify in the subsequent sections, address the relationships of our four fields of parameters.

- The first and the second hypothesis address the field of interaction. First we want to analyze if there are identifiable differences among users in terms of interaction strategies and user performance. Thereafter we want to analyze whether the parameters within the interaction field have an influence on each other (e.g. the rate of interaction on task completion time)
- The third and fourth hypotheses address whether parameters from the user field and system field have a significant impact on interaction-related parameters.

- Hypotheses five and six address user satisfaction and whether both user-related parameters and system-related parameters have a significant influence on satisfaction.

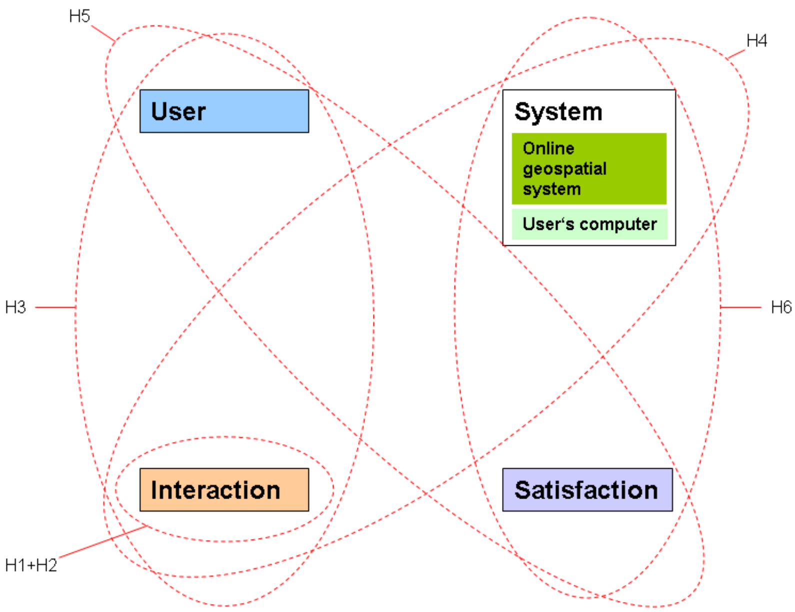


Figure 5.1: The hypotheses applied to the framework of parameters

5.2 Hypotheses and research questions

5.2.1 The interaction

H1 Users show different strategies during interaction with a system

- **H1RQ1** Is it possible to distinguish different kinds of spatial interaction strategies?

- **H1RQ2** Is there any evidence to suggest that the user's perception of spatial features influences spatial interaction strategies.

By asking these two research questions we want to show that there are different manners in which users solve tasks and interact with spatial information. We argue that the developers of web-based geospatial systems often implement different approaches for using a system. Users can combine these different possibilities in order to solve a task or to interact with spatial information. If we are able to identify different strategies, these findings would be helpful for optimizing a system.

H2 Users perform differently when interacting with a system

- **H2RQ1** Are there differences in task completion time, rate of interaction and rate of errors?
- **H2RQ2** Is there an identifiable connection between task completion time, the number of errors and the rate of interaction?
- **H2RQ3** Which interaction strategies result in better performance?

User performance is one of the key concepts for addressing usability since it addresses efficiency, errors and to a certain amount the learnability of a system. By asking the three research questions we first want to show that there are individual differences in user performance. Second we want to show that the parameters characterizing user performance are related with each other. Last, given that different interaction strategies can be differentiated, we want to analyze if these result in a different performance.

5.2.2 The user and the interaction

H3 User-related parameters have a significant influence on user performance, user strategies (spatial and non-spatial) and the perception of spatial features

- **H3RQ1** Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their performance?
- **H3RQ2** Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their strategies?
- **H3RQ3** Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their perception of spatial features?

The third hypothesis and the associated research questions is very important, since user-related parameters in our opinion have been neglected both by the developers of online geospatial systems, and by researchers who have conducted usability-tests on these systems. If we are able to show that these user-related parameters have a significant influence on the interaction, a user-analysis becomes very important for any development of web-based geospatial systems.

5.2.3 The system and the interaction

H4 System-related parameters have an influence on user performance, user strategies (spatial and non-spatial) and perception of spatial features

- **H4RQ1** Is there any evidence that some interface features cause higher cognitive load?
- **H4RQ2** Is it possible to identify a connection between the system's graphical design, interaction design and map design, and user performance?

- **H4RQ3** Is it possible to identify a connection between the systems graphical design, interaction design and map design, and user interaction strategies (spatial and non-spatial)?
- **H4RQ4** Is there any evidence to suggest that parameters related to the user's computer have a significant influence on user performance and user strategies?

This hypothesis is more related to the findings of several researchers who conducted usability studies with web-based geospatial systems - the influence of system-related parameters, especially features related to the user interface, on the interaction (e.g. so-called usability problems). The fourth research-question addresses an important factor that we also believe has been neglected in many hands-on evaluations of web-based geospatial systems - the influence of the user's computer (as part of the system) on the interaction.

5.2.4 The user and satisfaction

H5 User satisfaction depends on user-specific parameters

- **H5RQ1** Is there any evidence to suggest that users, depending on their age, gender, handedness, knowledge, skills and context are more or less satisfied?

In chapter four, section 4.2.1 we have shown that user-related parameters (such as the user's cultural context) are suspected to have an influence on satisfaction. By asking the related research question we want to build further knowledge about the importance of these user-related parameters.

5.2.5 The system and satisfaction

H6 System-related parameters influence user satisfaction

- **H6RQ1** What is the connection between the systems' graphical design, interaction design, map design, the user's computer and user satisfaction?

This hypothesis and associated research question is again related to more classical usability-research. Depending on the system's features, design etc. users are more or less satisfied.

5.3 Summary

In this chapter we have established six hypotheses and associated research-questions that we utilize for the validation of our conceptual framework described in the previous chapter. The hypotheses are on one hand built on the assumption that parameters characterizing the user, the system, the interaction and the satisfaction have an influence on other parameters, on the other hand they are constructed on the premise that we are able to collect these parameters in experiments involving real-world users interacting with online geospatial systems.

The first two hypotheses are essentially addressing interaction parameters. The following hypotheses are built on pairs of comparisons: the user and the interaction; the system and the interaction; the user and satisfaction, and the system and satisfaction.

In the following chapter we will describe how all four fields of parameters (the user, the system, the interaction and satisfaction) can be addressed, formalized, gathered and analyzed.

6 Analytical methods

6.1 Introduction

In this chapter we specify how the parameters we have identified in chapter four can be collected using evaluations involving real-world users.

We argue that it is necessary to address the interaction of real-world users with an online geospatial system by conducting actual evaluations rather than by reasoning with theoretical concepts, as it has been proposed in the early 1990'ies (e.g. by Medyckyj-Scott (1992). We argue that evaluations can be useful not only for detecting usability problems (e.g. Nielsen (1994) or Dumas and Redish (1999)), but also for discovering how users, and specific groups of users, actually use a web-based geospatial system. Most systems offer several possibilities for solving a specific task or taking a specific action and evaluations make it possible to analyze which users choose which possibility and why. Evaluations thus permit to measure a variety of different parameters in the interaction between real-world user and systems.

In our conceptual framework we have defined four fields or parameters that we want to gather in evaluations with real-world users. These fields are: the user, the system, the interaction and the satisfaction. We will hereafter analyze how the parameters of each field can be collected and compared with other parameters.

6.2 Means to characterize the user

We have identified the following user-related parameters that are susceptible to influence parameters related to the interaction and satisfaction:

- The demographic parameters gender, age and handedness
- The user's knowledge and skills
- The user's context

Demographic parameters can be detected by asking questions to the user (e.g. using a questionnaire), however the detection and analysis of the user's knowledge and skills and the user's context is more complex. We argue that the user's knowledge and skills, relevant for the interaction with an online geospatial system can be categorized into two dimensions:

- Geospatial content: A dimension that takes into account the user's knowledge of the content that is made accessible through the system.
- Geospatial systems: The user's knowledge of similar systems and technologies and skills in interacting with these (e.g. systems implementing similar interaction-approaches)

We have seen that there are several theories about how knowledge of geospatial content is acquired (see section 2.2.6), stored (see section 2.2.7) and used (see section 2.2.8). In order to elicit information about the user's knowledge of geospatial content we suggest to ask the user to which degree he has used material displaying spatial information. Examples for such material are maps, plans or computer systems.

We argue that the usage of material displaying geospatial content also has the influence that the user acquires knowledge about how the real world can be depicted (e.g. using symbols, legends, etc). Moreover we consider it relevant to know the origin of the user. For example, a user who is living in the region displayed in the system is certainly more likely to know its spatial configuration than a user who has not lived in the region.

In order to obtain information about the user's skills in interacting with geospatial systems we suggest to ask the user to which degree he has used other geospatial systems (such as GIS or GPS-enabled car navigation devices) and particularly other online geospatial systems.

In chapter four we suggested to take both the user's cultural context and the environment into account. Of course it is difficult to measure a user's cultural context and environment due to the fact that humans travel and move from place to place. Yet there are some indicators that we argue reveal some of the elements of the user's context. One of these indicators is the location of the user (e.g. at home, at work, in a specific country, etc.). This parameter however cannot be used in laboratory-based evaluations. On the other hand, in remote-testing environments, the user's location can be detected using the user's IP-address, a unique identifier for computers connected to the Internet, and databases which are able to translate an IP-address to a location. Another relevant indicator is the user's language. This indicator that can be gathered either by asking the user, or if several languages are supported by the system, by detecting in which language the system had been used.

6.3 Means to analyze the system

In our theoretical framework we have identified parameters that are likely to influence both the interaction with online geospatial systems and the satisfaction with these systems. Due to the fact that an online geospatial system is a system that is used through the Internet, we claim that the user's computer is part of the system as well. Parameters we consider relevant for the system as a whole are thus:

- Design aspects (graphical design, interaction design, map design)
- System speed (which depends on the system's architecture, server performance, the connection speed to the Internet and the performance of the user's computer)
- The screen size and resolution of the user's computer
- The input device attached to the user's computer

As discussed in section 2.4.2 there are several manners for inspecting a system's design. One concrete way to analyze aspects related to the system's graphical- and interaction design is to use heuristics such as Shneiderman's Golden Rules (Shneiderman, 1998), or Nielsen's usability heuristics (Nielsen, 1990), and guidelines, e.g. Watzman's guidelines for graphical design Watzman and Re (2007) or Bertin's visual variables for the design of maps (Bertin, 1973) with the enhancements of DiBiase (1992) and MacEachren (1995) concerning geovisualization (GVIS).

The system's speed can be elicited by measuring how much time it takes to process the user's command until the final result is visible, e.g. a change of the scale which results in the processing of a new map. However this measure is suggested to be highly dependent on the Internet connection speed and the performance of the user's computer. We therefore suggest to analyze or measure both of these two parameters. For example, a notion of the Internet connection speed can be obtained by analyzing the IP-address of the user's computer and using that information to derive the Internet provider and the type of connection (such as an ADSL connection).

The properties of the screen and the input device attached to the user's computer can be obtained by asking the user through a questionnaire.

6.4 Means to analyze the interaction

In our conceptual framework we have identified the following interaction-related parameters:

- Task completion time
- The rate of interaction
- The rate of errors
- Spatial interaction strategies
- Task completion strategies
- The user's perception of geospatial features displayed by the system

In chapter four we stated that the interaction with online geospatial systems can be categorized into task-driven interaction (with concrete tasks that the user needs to fulfill using the system) and exploratory-based interaction (the user decides himself what to do with the system).

Dix *et al.* (2004) have proposed a framework that describes the interaction of a user with a system. (see Figure 6.1) The interaction is thus considered as an iterative process with four steps:

1. The user formulates a task to achieve a goal. The task is then articulated by the user in the system's input language
2. The input is provided by the user in the system's input language
3. The system translates the input as operations to be performed. After the operations have been performed by the system, the results are presented as output.
4. The output presented is observed by the user who again formulates a task.

The interaction thus iterates until the user has reached the goal. The framework defined by Dix *et al.* (2004) will serve us as a base to explain the components of the interaction with online geospatial systems.

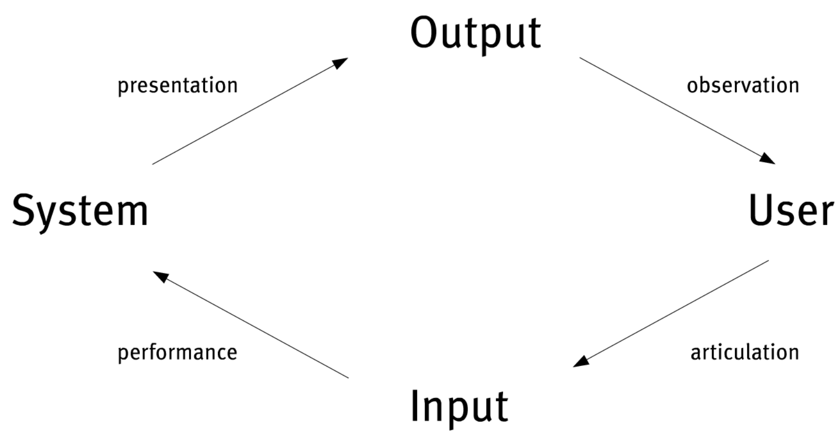


Figure 6.1: Dix et al's interaction framework (adapted after Dix *et al.* (2004))

6.4.1 Capturing the interaction

A crucial part in the measurement and analysis of the interaction is that the interaction needs to be captured and formalized. Only with the interaction captured and formalized it becomes possible to collect information about the different parameters of our framework that relate to the interaction. Since the interaction is defined by user input and system output (see figure 6.1 it is important to capture both parts.

Capturing the output

The output that is provided by the system is only visual. It is therefore necessary to capture the user's screen in order to verify:

- What the output of the system was at a given moment of time and
- if the system has been working correctly during the interaction

In all three case studies that we will present in chapter seven, we have used and implemented different technical tools in order to capture the user's screen.

Capturing the input

The input to the computer system is provided by the user through an input device. As mentioned in chapter four (4.2.2) we will only focus on pointing devices such as mice, touchpads, and trackballs. Pointing device actions that can be captured are thus:

- Clicking (where and when)
- Scrolling (when)
- Moving

Clicking and scrolling can be counted as interactions defining the *rate of interaction*

In chapter seven we will present different tools that enabled us to capture, visualize and analyze the user's input. These tools were built with the concept in mind that the data that a user chooses to visualize (e.g. different layers or different regions) only represents one piece of the whole geospatial information that is made available through the system. From the point of view of a system's architecture (see chapter three, figure 3.3) the client sends a request to the server to send the data that is requested by the user (e.g. which data layers and which extent). Our idea was thus to capture these requests using a software tool and to retrace the user's input through an analysis of the data traffic between the client and the server.

Filming the user

A method that is frequently used in usability tests is filming the user. Especially if the think-aloud protocol is used, it is important to analyze what the user said.

6.4.2 Task analysis

In task-driven interaction the parameters *task completion time*, *task completion strategies* and *errors* are the important parameters. Task completion time is the time it takes for a user to solve a task from the moment he gets to know the task until the goal of the task has been reached.

For complex tasks there are often several ways to reach the goal. For instance the task to find the nearest airport could be solved through a text-based search (the system parses the text that the user has entered manually and finds the airport), through a selection of values in drop-down menus, or simply through browsing of maps. A *task completion strategy* are thus the choices a user has made in order to solve a given task.

Errors can occur at several levels during the interaction session. On the task level errors can be categorized as follows:

- The user fails to solve the task
- The user solves the task, but the result is not correct or accurate
- The user solves the task only partially
- The user solves the task completely

Furthermore, on the interaction design level, errors can occur if the user fails to use a feature or tool as it was intended by the developer. We argue that errors committed by the system (e.g. system crash) should also be mentioned in this context although they are not necessarily caused by the user but by the hardware or the computer software.

In order to analyze and categorize the interaction we propose to formalize the interaction using interaction protocols. Formalized protocols are a frequently used tool in HCI sciences. Within the domain of user interface analysis, protocols are used to describe how an interface may be used by describing in detail the cognitive processes behind each action (with the associated time) and the actions themselves. Examples of such protocols can be found in the GOMS (Goals, Operators, Methods, and Selection rules) analysis methods, for instance the Keystroke-Level Model (KLM) which is often used to estimate execution time for a task (see figure 6.2) (John and Kieras, 1996). The KLM protocol knows six operators: K stands for pressing a button, P to point with a mouse, M to mentally prepare for taking the action, D to draw a line segment on a grid, H to home hands on the keyboard or other device and R represents the system response time. The KLM protocol thus takes two important actions into account that happen in between the user's physical actions: the time that the user needs to mentally prepare for taking an action and the system response time. (John and Kieras, 1996)

In our approach, we do not attempt to estimate execution time (by thinking of all possible ways to solve a task). Instead we want to describe how an online geospatial system is used. This implies the visualization of the task and the strategies that the user chose. Moreover we want to integrate parameters that specify user performance (such as task completion time and the state of the interface at the time when an action was taken). The elements of an interaction process that we want to visualize in a protocol are thus:

- Who was interacting (e.g. specified through a user identifier in order to compare this information to other user-related parameters)

Description	Operator	Duration (sec)
Mentally prepare	M	1.35
Move cursor to beginning of phrase	P	1.10
Click mouse button	K	0.20
Move cursor to end of phrase	P	1.10
Shift-click mouse button	K	0.28

Figure 6.2: Example of a Keystroke-Level Model (KLM) protocol: A user selects text.

- The task that the user was doing (e.g. task 1: navigate to Zurich)
- The action (e.g. clicking on the map)
- The time of the action (both absolute, e.g. 3 P.M., and relative, e.g. 30 seconds after the beginning of the task)
- The area on the screen where the action occurred (e.g. on a button, clicking on a specific spot on the map)
- The scale of the map when the action occurred

6.4.3 Spatial interaction strategies

As mentioned in chapter four (4.2.3) we distinguish between spatial navigation and other space-related interaction: data visualization (e.g. adding spatial data layers), data querying (e.g. getting information about the associated data), data modification (e.g. digitizing, deleting information, modification of meta-data, spatial operations) and file in- and output (e.g. extracting information from the system to a file / uploading of geospatial information).

Spatial navigation

Spatial navigation is a very important component of the interaction with online geospatial systems. The process of moving through space and changing the scale enables the users to get an integrated view of very large structures and its contents. Furnas and Bederson (1995) have proposed a space-scale diagram (see figure 6.3) that visualizes the user's view of two-dimensional spatial information at different scales.

In task-driven interaction, the goal of spatial navigation is for instance to navigate from a certain point in space to another specific point in space (on the map) using the tools that are available in the system. This task is fundamental since every user who uses such as system presumably finds an initial map (the map that the system presents for the user at first) which is displaying a different region and a different scale than the object that the user wants to visualize. The task to reach the point can thus be described as

- minimizing the distance to the object to reach

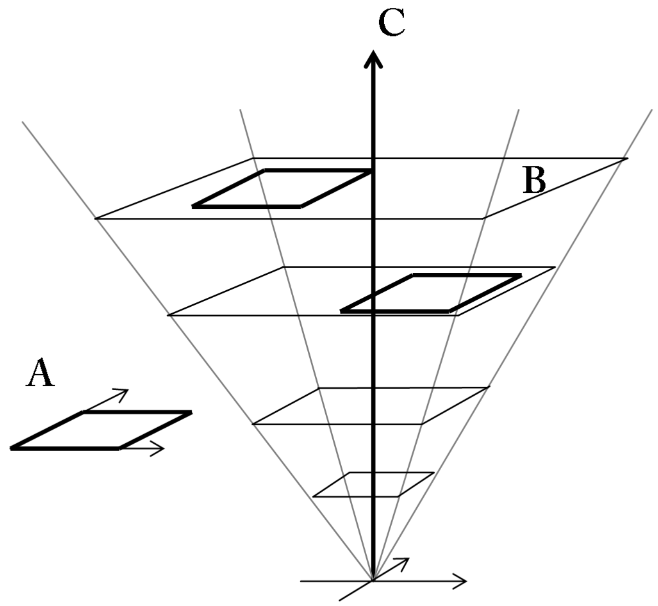


Figure 6.3: A space-scale diagram showing: A: the viewing window; B: a 2D surface at a specific scale; C: the scale-vector (adapted after Furnas and Bederson (1995))

- adapting the scale of the map in order to show the object at an optimal scale

The task to point out objects has been addressed by Fitts (1954) (referred by MacKenzie and Buxton (1992)). Fitts found that the movement time (MT) to reach a target in a one-dimensional space (along a line) depends on the width W of the target and the amplitude (distance) A according to the following equation:

$$MT = a + b \cdot \log_2 \left(\frac{2A}{W} \right) \tag{6.1}$$

where:

- MT the average time to complete the movement.
- a the start/stop time
- b the speed
- A the amplitude (or distance) from the starting point to the center of the target.
- W the width of the target measured along the axis of motion.

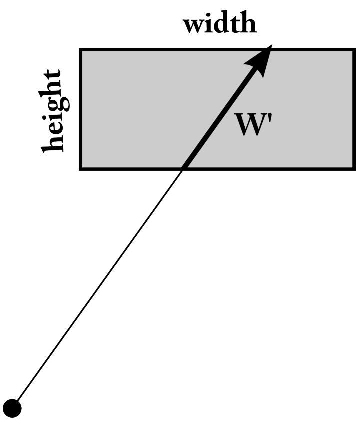


Figure 6.4: Fitts' law applied to 2D-objects

MacKenzie and Buxton (1992) have proven that it is possible to generalize Fitts' law to a two-dimensional space by taking into account that a two-dimensional object has both a height and a width. The authors found that there are two models that yield good experimental results:

- the "SMALLER-OF" model, where W in Fitts' law becomes the smaller dimension of an object (see figure 6.4). If the object's height is greater than its width, W will be the object's width.
- the "W" ' - model where a vector is drawn from the starting point of the movement through the object's centroid (see figure 6.4). W in Fitts' law becomes the part of the vector that traverses the object.

Bourgeois *et al.* (2001) have discussed whether Fitts' law could be used for the formalization of navigation in a multiscale-2D environment (such as online geospatial systems) and argue that two facts need to be taken into account: panning towards a target indeed decreases the distance A to the target, however depending on the zoom level, this distance varies. Moreover, depending on the zoom level, the width W of the target also decreases or increases. The essence in navigating to a target in a multiscale-2D environment is thereby to gradually reduce the ratio A/W.

As described by You *et al.* (2007), in online geospatial systems pan- and zoom functions are implemented in different ways. For instance panning can be implemented using pan-buttons or using a pan-tool You *et al.* (2007)). Zooming in or out can be accomplished by clicking on zoom buttons or by using the mouse-wheel. You *et al.* (2007) argue that Fitts' law is relevant for the consideration of an online geospatial system's interface as well. The user thereby needs to move the pointing device's cursor on different interface features (buttons, scale-choice bars or the map) in order to navigate.

If we thus consider the fact that zoom and pan-functions are implemented in different manners, the task of navigating to an object must result in different pointing tasks (either on the interface or on objects on the map). We can distinguish between different cases where Fitts' law applies:

- Buttons only: the objects that a user points on are pan-and zoom buttons; In this case Fitts' law is relevant for the size of the buttons and for the position of the buttons.

- Mouse-wheel zoom + pan-tool only: the user zooms using the mouse-wheel and moves the map using a pan-tool (direct interaction with the map). Fitts' law is relevant for the distance to the object on the map and the size of the object

- Mixed interaction: the user zooms and pans using different tools (e.g. for zooming he uses zoom buttons and for panning he uses a pan-tool)

In a case where we assume that a user knows the position of an object he wants to reach using an online geospatial system (if the object is not visible on the map), the user has to make two different considerations:

- A strategy for reaching the object in space (by zooming and panning)

- A way to realize the strategy

In order to visualize these strategies we propose a diagram that displays

- The distance of the map's centroid to the target on the left y-axis at a linear scale

- The scale at which the map is displayed on the right y-axis at a logarithmic scale

- The time

- The actions taken by the user (zooming or panning)

Figure 6.5 shows an example of an interaction diagram where a user navigates from a starting point to a target. At first the user zooms out to a higher map scale (e.g. to view objects of a higher order such as larger cities), then the user pans the map using a pan-tool, resulting in a reduction of the distance to the target. This pan-zooming process continues until the object is displayed at an appropriate scale. For tasks that require spatial navigation we will be able to use this type of diagram to visualize and distinguish actions that the user took to reach this goal.

Layer management

A very common interaction feature that is implemented in many online geospatial systems, especially interactive-atlases (see section 3.3.1), is the management of different data layers (see 6.3). The user has the choice to select or un-select different data layers and thus modifies the content of the map.

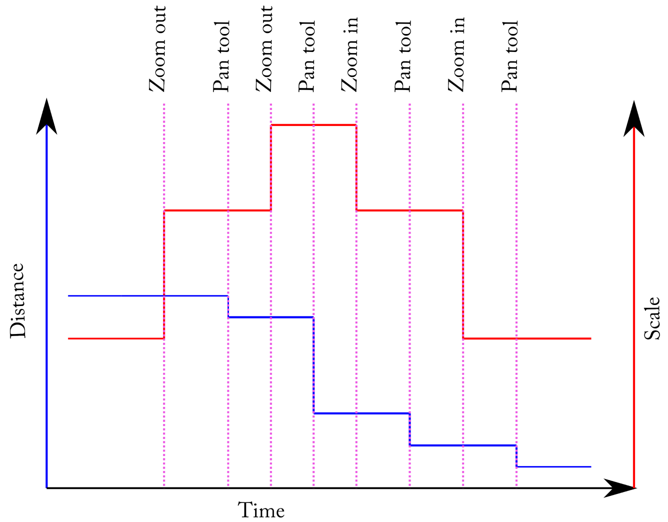


Figure 6.5: Scale-distance interaction diagram visualizing actions over time and their effect on the distance to the object and the scale

Concerning strategies to visualize different layers we can analyze

- The layers that the user chooses to visualize to solve a task
- The moment the user chooses to visualize a layer
- The approach the user chooses to visualize a data layer (if several possibilities exist)

Geospatial data modification

Data modification is a feature that has been implemented in an increasing number of online geospatial systems, particularly in collaborative systems (see section 3.3.1) such as public participative GIS (PPGIS), where users have the possibility to add new data or modify existing data. Data modification includes the modification of the spatial extent of a spatial entity or the modification of the data that is associated with the entity ("metadata").

Digitizing is the encoding process that is used to add spatial objects. In web-based geospatial systems this process is commonly implemented so that the user has the possibility to create, modify or delete spatial objects based on other data that is available in the system (e.g. digitizing on aerial images). Concerning the process of data modification we can analyze elements such as:

- The quality of the data (accuracy, completeness, correctness, scale at which it was modified, number of data points)
- The type of the data
- The moment it was added

Geospatial data analysis

Knapp (1995) has proposed a taxonomy for GIS-specific tasks according to four categories: "identify", "categorize", "compare" and "associate" (see section 2.4.3). In theory all tasks that are available in GIS could be implemented in online geospatial systems as well, however today there are few systems supporting more advanced operations. Yet there are two frequently implemented operations: data querying and identifying. Both operations use the attributes that are associated to a spatial entity. Both features are commonly used in way-finding systems (see section 3.3.1) and other systems where attributive data are important (e.g. interactive atlases). Within this context we can analyze:

- Which features the user chooses to query or identify
- The moment the user chooses to query data

6.4.4 Perception of spatial features

Map reading is according to Brodersen *et al.* (2001) *the necessary actions in order to answer questions or to solve tasks* regarding spatial problems. It is thereby a cognitive process where a user perceives the contents of a map and takes actions (e.g. moving the map or looking at another spot of the map). Due to the fact that a map is a composition of different spatial features, e.g. symbols with different design (see section 2.3.4), spatial features help the user to orientate himself on the map, e.g. through objects such as cities, landmarks or water bodies.

Several researchers have investigated the cognitive processes of map perception, especially the perception of digital maps, using different methods. Brodersen *et al.* (2001) have analyzed eye-movements using eye-tracking equipment to analyze a user's perception of spatial features on paper maps. The authors have categorized movements into the following categories: fixations (if the spectator views an area of 12*12 mm between 100 and 1000 milliseconds), saccades (the movements between two fixations), areas of interest (AOI, predefined areas on the map) and dwells (if the eye spends at least 200 milliseconds within an AOI).

Cöltekin *et al.* (2008)'s study of two online geospatial systems (see section 2.4.3) used a similar eye-tracking system. In their study eye scan paths and eye fixations were used to generate gaze-plots and fixation patters in selected AOI's. These plots and fixation patters were then used to detect both visual attention and usability problems. For example, while a user was looking for a specific tool, it was analyzed where exactly the user was looking for it.

Mac Aoidh and Bertolotto (2007) have used mouse interactions for analyzing interest in spatial features. Mac Aoidh and Bertolotto (2007) refer to several researchers in the HCI community such as Cooke (2006) and Chen *et al.* (2001) who have discussed the correlation between eye movement and the mouse cursor. In Cooke (2006)'s study the mouse movement matched 69% of the eye movement. Chen *et al.* (2001) found out that in 75% of cases the eye will follow the mouse.

We claim that an analysis of the user's perception of spatial features helps understanding the users actions. We therefore suggest to discuss if it is possible to detect objects that the user focuses on (e.g. landmarks, infrastructure, etc.) and whether these objects play a role in spatial navigation strategies. It is however important to note that in web-based geospatial systems the content displayed on the map changes with each navigation-action the user takes. If we thus want to track either the user's eyes or mouse movements, we must also keep track of the data displayed on the map at any time (and thereby the zoom level and the area displayed).

6.5 Means to measure satisfaction

In our framework of parameters we have defined the following variables as relevant parameters for the analysis of user satisfaction with online geospatial systems:

- Satisfaction with maps
- Satisfaction with the access to the system (the system's speed and availability)
- Satisfaction with the system's graphical design
- Satisfaction with the system's consistency
- Satisfaction with the system's functionality
- Satisfaction with the system's interaction design

In HCI there are two widely used approaches for eliciting user satisfaction - either by questionnaires or by conducting interviews.(Preece *et al.*, 2002) Many of the usability-studies where satisfaction with geospatial systems was measured were based on questionnaires (e.g. Haklay and Zafiri (2008); Cöltekin *et al.* (2008). Davies and Medyckyj-Scott (1996) on the other hand conducted interviews in order to find out the satisfaction of professional GIS users. Both interviews and questionnaires allow for gathering feedback of a quantitative nature (e.g. the participants rate their satisfaction with a feature on a scale) or of a qualitative nature(e.g. the user gives comments or explanations) (Preece *et al.*, 2002)

Questionnaires, as opposed to interviews, have the advantage that they can be distributed to a large number of people (Preece *et al.*, 2002). Moreover, Kirakowski (2000) argues that questionnaires are a good way to gather data that is more easily quantifiable. Since we want to compare user satisfaction with other parameters that we have gathered (e.g. user-related parameters such as age or gender) we need to collect quantitative aspects of satisfaction that are more easily comparable to other quantitative data. Furthermore we aim at proving the statistical significance of these comparisons, therefore we need a maximum number of participants. We have thus decided to use questionnaires for assessing user satisfaction.

In the domain of HCI several research-teams have elaborated standardized questionnaire systems that enable the gathering of user satisfaction:

- the Questionnaire for User Interaction Satisfaction (QUIS), a tool designed to assess user's subjective satisfaction with specific aspects of the interface (Harper and Norman, 1993; Wallace *et al.*, 1988). It consists of a demographic questionnaire, a measure of overall system satisfaction along six scales and measures of four interface factors (A: screen factors, B: terminology and system feedback, C: learning factors, and D: system capabilities). QUIS uses nine-point likert-scales (with the possibility to omit a question)

- the IBM Computer System Usability Questionnaire (CSUQ), a questionnaire system that addresses the overall satisfaction, system usefulness, information quality and interface quality (Lewis, 1993). Questions are asked in such a way that the user can choose the corresponding answer on a seven-point likert-scale; moreover the participant can add a comment to each question which allows for gathering qualitative data as well.

- the System Usability Scale (SUS), a questionnaire that is based on ten questions which participants can answer on a five-point likert-scale. (Brooke, 1996)

In a study where QUIS, CSUQ and SUS and two other questionnaire systems were compared, Tullis and Stetson (2004) found that SUS, although it is the shortest questionnaire, yielded the most reliable results. Yet in order to design a questionnaire that is adapted to the study of user interaction with online geospatial systems (and not only with the goal to improve a given system) we argue that standardized questionnaires (such as QUIS; CSUQ and SUS) are not optimized for our purpose. We claim that elements such as the division into "information quality" (the spatial information presented) and "system quality" (the system itself), or the fact that the complexity of online geospatial systems can vary, justify the need for specifically adapted questionnaires. However, following the suggestion of Kirakowski (2000) we also want to offer the possibility for the participants to give more qualitative, unstructured feedback by adding the option to comment an answer.

6.6 Experiment design

In order to design a testing condition where real-world users interact with a web-based geospatial system, we have described how each of the fields of parameters (the user, the system, the interaction and the satisfaction) can be collected and analyzed. Yet we claim that the following considerations notably influence an experiment's design

- The temporal order the data is gathered

- The manner in which data is gathered during the interaction

- The place where the data is collected

In most questionnaire systems (e.g. QUIS) demographic questions are placed in the beginning. Moreover it is a widely accepted rule to order questions according to their difficulty (e.g. Preece *et al.* (2002)). Therefore questions related to the users' satisfaction are usually placed after demographic questions. Yet within the context of this thesis we have decided to design our experiments using two questionnaires; one questionnaire before the actual interaction where demographic parameters and the user's knowledge and skills are investigated and a second questionnaire after the interaction with the system where questions related to the user's satisfaction and attitude towards the system are asked. We motivate this choice with the fact that a user, after having encountered problems using a system, might respond differently to a question such as ("how would you estimate your computer skills?").

One important issue in the design of experiments is the method that is used during the interaction. In chapter two, section 2.4.2, we have presented four commonly used usability-testing techniques. Yet due to the fact that our primary goal is not to improve a specific system's usability, but to analyze the influence that several parameters might have on the interaction (e.g. speed of performance) and the satisfaction, these usability-specific methods are not necessarily the most appropriate. Verbal protocols for instance were used in the usability study of different way-finding systems by Skarlatidou and Haklay (2006), yet according to Dumas and Redish (1999) the method has the disadvantage that performance measures might be biased (some users might talk more than other and thus need more time). On the other hand verbal protocols enable the evaluator to yield qualitative data that is valuable for understanding how users interact with a specific system.

Another important consideration is the place where an experiment is conducted. Most experiments where the usability of online geospatial systems was tested were conducted in laboratory-based environments (e.g. Skarlatidou and Haklay (2006); You *et al.* (2007); Nivala *et al.* (2008); Cöltekin *et al.* (2008)). This method has the advantage that all users use exactly the same computer equipment (and thus making the results of each user more comparable to the other users' data). Moreover more advanced capturing techniques (such as video-recording) can be used. Tullis *et al.* (2002) have discussed whether laboratory-based experiments could be replaced by remote-testing evaluations. In a case study the authors found that the behavior of test users within lab conditions is very similar to that of remote users and that the potential larger number of users in remote testing can produce more reliable results. One drawback of the remote-testing was according to Tullis *et al.* (2002) that remote testing of web-based systems usually requires the remote-user to install a specifically adapted web-browser that is capable of recording the user's clicks and the user's interface.

We argue that the remote-testing of online-geospatial systems is an interesting method since each user utilizes a different computer equipment. These differences (e.g. different pointing devices) need to be captured as well and must be taken into account when analyzing the data.

Designing the experiments so that users get to solve realistic scenarios is one general idea that we aim to adopt from other usability-tests that have been conducted by different researchers (e.g. Wachowicz *et al.* (2008); You *et al.* (2007)). Such scenarios however need to be carefully planned and constructed.

6.7 Summary

In this chapter we describe the ideas and methods that we intend to use in order to gather the parameters related to the user, the system, interaction and the satisfaction in evaluations with real-world users. Moreover we have outline the design of evaluations.

User-related parameters can be gathered by asking the user specific questions regarding demographic parameters, concerning their previous experience with geospatial information and technologies. In laboratory-based experiments parameters related to the user's context can be considered as equal conditions, yet in remotely conducted evaluations several indicators for context-relevant parameters can be captured interactively.

The system that real-world users utilizes during a hands-on evaluation can be described by analyzing their design (graphical design and interaction design) and the technologies and architectures that are behind the user interface. Moreover design guidelines (such as the well-known "eight golden rules of interface design") can be used to critically analyze the different parameters.

Parameters related to the user interaction can be categorized into performance-measures, user strategies and the perception of geospatial features. We present several concepts for the formalization (for instance Fitts' Law for pointing task) visualization (e.g. interaction protocols and diagrams) and capture (e.g. input device movement gathering) of these parameters.

There are several methods for the acquisition of user satisfaction. In real-world evaluations the satisfaction can be captured during the evaluation itself (for instance through direct feedback of the user in experiments using verbal protocols) or afterwards through questionnaires.

Evaluations involving real-world users can be conducted in laboratories where all users for instance get to use a system under controlled conditions or in remotely designed evaluations where participants use their real-world computer equipment. In order to ensure that for instance performance measures can be statistically compared after the evaluation we suggest to use scenarios that reflect a natural use-case of the system to be tested.

7

Case Studies

7.1 Introduction

In this chapter we describe three different case studies that we use to validate the hypotheses and research questions presented in chapter five. The three case studies represent evaluations of three online geospatial systems with real users. The three systems were developed for specific communities and contexts:

- The first case study involves a system called "RIV" (Réseau Interactif en Viticulture, translated Interactive Network for wine- cultivation) that was created for professionals involved in wine-growing in the Swiss canton of Vaud.
- The second case study involves a system called "Géocommande" for ordering spatial data on-line.
- The third case study involves a system that was developed as a spatial module for an online survey application. Its main functionality was to point out locations on an online map.

The three systems vary substantially in terms of the functionality offered, the technologies used and the users for whom they had been developed. At this point we need to mention that the incitements that led to the development of these systems were not rooted in our experimental approach, but in actual needs that came from the industry, different associations, the government and the school. We have used these opportunities to validate our conceptual framework.

Due to the different natures of the systems and the users, the evaluation methods we have used differ substantially. However, they all respect the settings described in chapter six, section 6.6. Moreover due to the difficulty to find test-users, different number of users were recruited for the three case-studies: the evaluation of the wine-cultivation system featured 20 test-users that tested the system during a hands-on evaluation using verbal protocols. The second evaluation included 34 users who evaluated the data-ordering system in three session (with several users at a time). The third evaluation had 331 participants who evaluated the system remotely from their own computers. Table 7.1 shows an overview of all three case studies.

	RIV	**Spatial data ordering system**	**Mobility inquiry interface**
Number of test users (having successfully completed)	10+10	30	331
Kind of users	Winegrowers	Students in geomatics engineering	EPFL staff and students
Evaluation method	Think-aloud sessions (one user per session)	Supervised sessions (four sessions)	Remote testing
Interaction captured	User input (clicking), system output (screenshots and system state), filming	User input (clicking), system output (system state and screenshots)	User input (all pointing device actions (movement, clicking, etc.), System output (state)
Questionnaires	Written questionnaires	Written questionnaires	Online questionnaires
Time	ca. 2h per user	ca. 1h per user	ca. 20 min per user

Table 7.1: Overview of the case studies

In the following sections we first describe each system's purpose and design. For the first and the third system we also illustrate the development process which represented a substantial part of the work in this thesis. Thereafter we explain the context of each of the evaluations by specifying the method used, the users who participated and the data that was captured during the evaluation. Finally we analyze the data of each of the three case studies using the theoretical framework described in chapter four, the hypotheses we have established in chapter five and the analytical methods explained in chapter six. The results and conclusions of these three case studies reflect not only the influence of each of the parameters of our framework of parameters (see figure 4.2), but also assess the usefulness of the different methods that we used for each evaluation. Due to the fact that the three case studies are substantially different regarding the systems to be tested and the participants, we only discuss the hypotheses and research questions that are relevant for each case study.

7.2 RIV - a system for wine-cultivation

7.2.1 Context

The context of the first case study is a system called RIV. RIV is an abbreviation for French "Réseau interactif en viticulture" which translates "Interactive network for wine-cultivation".The system is targeted for different actors involved in wine-growing and wine-making in Switzerland. It focuses on the spatial aspects of wine-growing (e.g. where parcels - the smallest spatial wine-growing entities - are located, what microclimate surrounds the parcel, what type of soil, etc.) and is entirely accessible through the internet.

Wine-cultivation in Switzerland is, compared to countries such as France, Italy or Australia, driven at a small scale. Switzerlands wine-regions are divided into many small parcels with only a few acres.

In recent years wine-cultivation in Switzerland has undergone deep changes. The new national and European policies in terms of traceability (the possibility to trace the path of the wine from the plantation - to the winery - to the bottle), the changes of consumer practices and foreign competition generate a significant pressure on wine-cultivation. Today many winegrowers in Switzerland have other part-time jobs in order to survive.

To help the winegrowers in the Swiss Canton of Vaud to make their wine-cultivation more profitable, the project terroirs viticoles (Wine Soils) (Pythoud and Caloz, 2001) was initiated. The goal of this project was to characterize and to collect information about all relevant natural resources in all winegrowing regions of the canton and to help the actors of wine-cultivation to organize and use this information in order to make wine-making more efficient and more competitive. The 15 data layers that had been collected included layers showing the soils, the sun radiation, slopes, altitude and winds.

The syntheses of this first project were distributed using reports and a CD-ROM to the main actors of the branch. The cds that had been distributed to the participants of the project did not reach all actors involved in winegrowing and winemaking in the canton. At that time, in 2003, it was therefore proposed that the data-layers should be made more easily accessible for all actors using an online geospatial system.

Another reason to create an online geospatial system was the need to offer a tool for help winegrowers to manage their parcels. The tool would allow them to assemble their parcels "virtually" and to correlate the data-layers from the terroirs-viticoles project with their parcels.

7.2.2 The first prototype, Viti-Vaud

To meet the needs of various actors in the wine-growing business, a first prototype of an online geospatial system was developed, called "Viti-Vaud". The prototype was capable of visualizing all the data layers (see figure 7.2) and

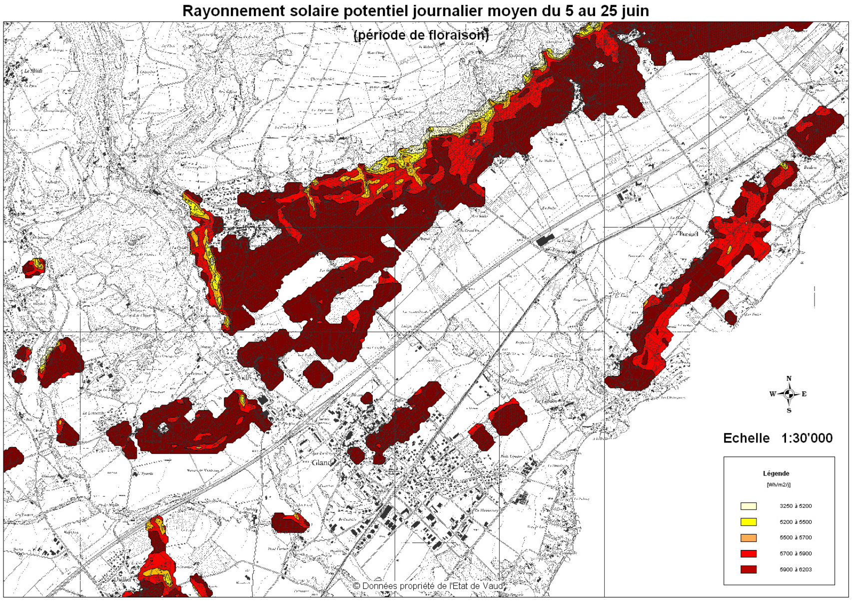


Figure 7.1: A sample of a data-layer from the terroirs viticoles-project showing sun-radiation

moreover it offered the possibility to digitize parcels on top of aerial images with the support of the legal cadastre (see figure 7.3).

Technically the system was implemented using Java-applets, offering map navigation and digitization functionality. MapServer (see section 3.3.3) was utilized for map-visualization. PostreSQL/PostGIS served as a spatial database for storing the digitized content and PhP enabled the dynamic creation of web-content. One of the goals of the development of the first prototype was also to evaluate whether the methods and ideas from the field of HCI could be applied to online geospatial systems. The prototype was therefore first examined using heuristics such as the "eight golden rules of interface design" (Shneiderman, 1998), see section 2.3. Thereafter the usability of the prototype was examined with five winegrowers.

One important weakness that was identified in the system after these first evaluations was that the system's interface had been built using different components (Java-applets, PhP scripts) which all had some manners of interaction design implemented. It was thus difficult to unify the design (in terms of graphical design and interaction design) of these different components. Moreover the evaluation of the prototype showed that users thought differently about the interaction than the developers had originally intended, and that it often took a considerable effort for users to learn how the system worked. (Ingensand, 2005a)

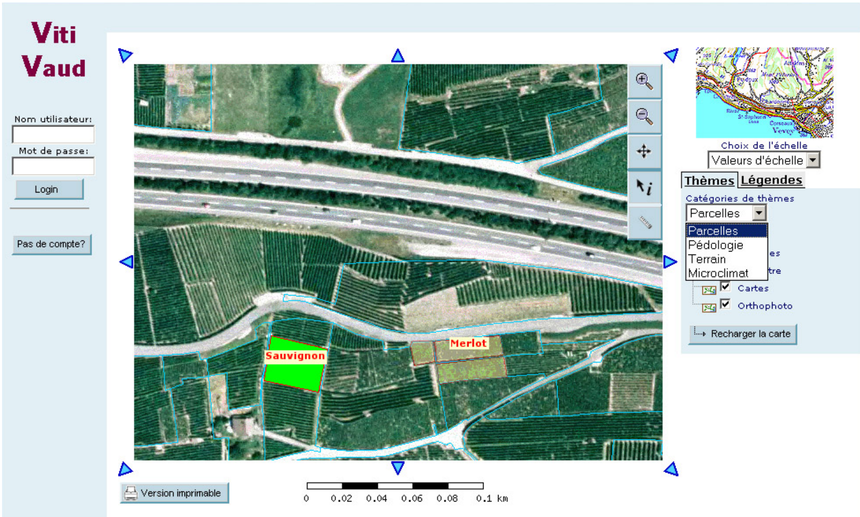


Figure 7.2: A screenshot of the first prototype of RIV - “Viti-Vaud”

7.2.3 The evolution of RIV

The successful development of the first prototype and the pronounced requirement by the actors involved in winegrowing and winemaking led to the conception of the RIV-project. Several partners collaborated to form the new project.

- The winegrowers association (represented by the association Prometerre)
- Agridea (a non-profit resource and management building organization)
- The Federal Institute for Agricultural Research (RAC- Agroscope)
- A software development company specializing on geospatial systems
- The GIS research lab at EPFL (LASIG)

The proposal that was put forward by this committee was to create a web-based geospatial system that integrates not only a management tool for winegrowers and their parcels, but also a system that all the actors involved in winegrowing and winemaking shall use. These actors are:

- The winegrowers, who use the system to share data about their parcels, type of grapes grown etc. to other actors to make it possible to trace the production path of the wine - from the plant to the bottle.
- The winemakers (small and medium scale winemaking companies), who obtain the data from winegrowers and use the system to add further information about the wine-making process.
- The Swiss Federal Institute for Agricultural Research who uses the system to analyze the data, that has been shared by the winegrowers and

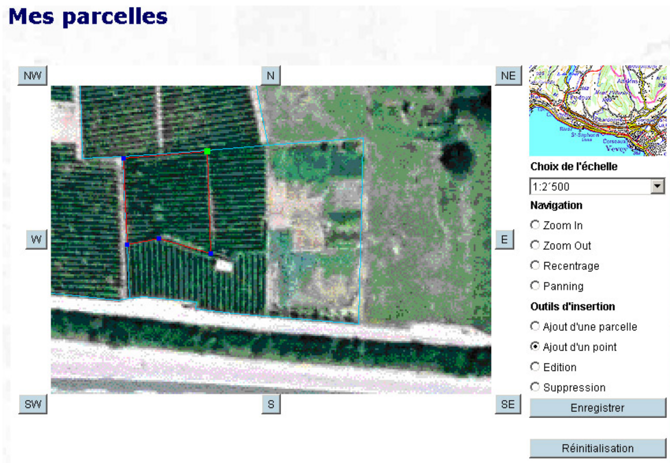


Figure 7.3: Digitization of an owned parcel in the first prototype of RIV

the winemakers, as part of their research on optimizing wine-growing processes. It was also proposed that the institute should use the system to manage their own wine-related data (such as measurements).

It was thus suggested to develop three different modules for the system (one module per actor) and to manage the modules through user accounts. Moreover all the data from the "terroirs viticoles" project should be integrated in the new system in order to give winegrowers and winemakers access to this data. The three different modules had thus the following requirements:

Module for the winegrowers:

- Digitizing parcels using ortho-images
- Parcel management (e.g. grouping of parcels, adding interventions such as yielding)
- Querying the information stored in the database (e.g. finding all parcels with specific spatial and non-spatial attributes)

Module for the winemakers:

- Production management of the wine-making process
- Automatic generation of forms (e.g. for tax declaration)
- Running queries (e.g. finding all parcels with specific spatial and non-spatial attributes)

Module for the Swiss Federal Institute for Agricultural Research:

- Dynamic creation of new data-layers to integrate measures
- Management of the measures

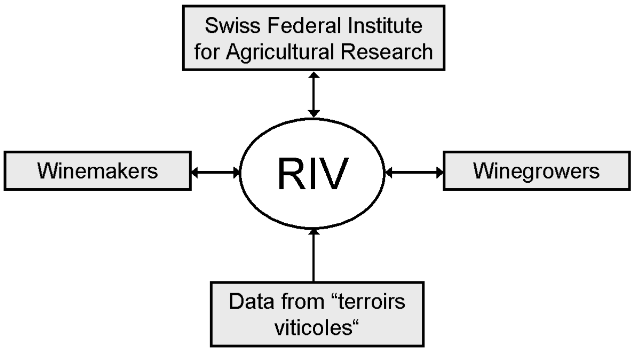


Figure 7.4: Model of the RIV-network

One of the important goals of the RIV project was to develop the application together with the end-users of the system according to the user-centered system development process UCD (see section 2.4.3). Different mock-ups were thus developed and presented to potential end-users. Before the development of the system had started, all possible user interfaces for all different modules had been integrated in a final mockup that defined both the graphical design and the interaction design for the whole system.

During 2005 and 2006 the final system was implemented at the GIS research lab. It was exclusively built using the following open-source components:

- MapServer was used as a dynamic map rendering engine
- PostgreSQL/PostGIS was used for storing all vector-based data layers, but also for the storage of all data that had been provided by users
- PhP was used for the programming of the user interface, moreover Javascript added dynamic functionality to the interface, especially to the interaction with maps.
- Apache was used as a web-server
- Linux was the server’s operating system

Contrary to the first prototype (“Viti-Vaud”) we only used PhP and Javascript to implement the new interface. This made it possible to create an interface that did not interfere with predefined interaction manners of components that had been implemented before. Figures 7.6 and 7.7 show two examples of RIV’s interface.

In the RIV-system the user has a choice of five different spatial navigation-tools (see figure 7.5):

- The zoom-in tool which allows the user to zoom-in the map by first selecting the tool and then by drawing a rectangular area of the zone the user wants to zoom in to (“zoom by marquee”, You *et al.* (2007))

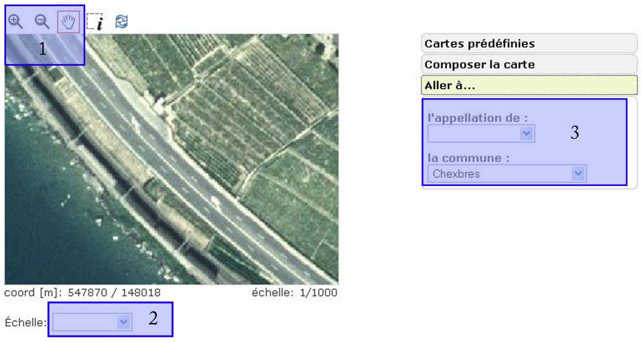


Figure 7.5: RIVs navigation tools
1: Zoom in, zoom out and pan (the selected tool is highlighted)
2: The scale choice list with a selection of 16 scales
3: scrollbars with direct access to the growing region and villages

- The zoom-out tool which the user first selects from the tool bar and then clicks on the map to zoom out.
- The pan-tool which allows the user to move them map by dragging.
- The scale choice list with 16 scales
- A drop-down menu that allows the user to choose a given growing region or village. The system then automatically navigates to the selected growing region or village.

RIV's mapping system offers a variety of different data layers. As base-layers the user can either choose topographical maps or aerial images. On top of these layers the user can overlay the layer containing his own parcels, the legal cadastre and all the data from the "terroirs-viticoles" project. Layer selection is implemented in two ways:

- The user has a choice of five pre-defined layer-selections (e.g. a selection of the base-maps and his parcels or a selection of the base-maps, his parcels and the layers showing the type of soil). For each layer-selection, the legend is displayed beneath the layer-selection button.
- The user can activate and de-activate each layer manually using check-boxes. Each time the user clicks on a checkbox, the corresponding layer is added or removed from the map. Due to the quantity of the "terroirs-viticoles" data layers, the layers are grouped into three themes: the soils, different zones (e.g. growing regions), and the microclimate and terrain. The user can thus choose one of the layer-groups through a drop-down menu. The legend for each of the layers can be visualized using small '+' signs next to the checkboxes.

Figure 7.6 shows RIV's layer management system with the manual layer selection activated. The legend for the layer "Altitude" is visualized.

Figure 7.6: Layer visualization in RIV

Figure 7.7: Digitization of a parcel in RIV

The digitization of parcels was implemented in a separate mapping-interface which includs the map, the navigation tools mentioned above and a digitization-tool. Once selected, the user can click on the extents of the parcel. Figure 7.7 shows an example of a digitizing process.

Before the release of the final system, the system was thoroughly tested with 20 end-users. The evaluations with the end-users is described in the following sections.

7.2.4 The test-users

The test-users were selected using a database that was offered by the winegrowers association. All winegrowers listed with email-address were selected as potential test-persons (175 people) Out of these 175 winegrowers, 100 were selected together with a representative of the winegrowers association. The invitations were sent in two series (50+50) with a 2 months interval. For each of the series 10 winegrowers answered the call to evaluate the system. The average age of these users was around 45 years. In each series involved two female users and eight male users. In the second series one winegrower was left-handed.

7.2.5 Evaluation setting

The evaluations took place in an office at EPFL. Each evaluation session was attended by two persons the evaluation expert and the test user. All sessions used the same computer, an Intel Pentium 4 computer at 3Ghz with 1GB of memory and a 19" CRT computer display at a resolution of 1280*1024 pixels. The pointing device was a standard wheel-mouse.

The evaluation was structured as follows:

- First the test-user was asked to complete a questionnaire with demographic questions (age, education, computer use) and questions regarding their experience with maps and online geospatial systems.
- The second part was the hands-on evaluation where the user was asked to complete a set of ten tasks. All tasks had been discussed with experts in the domain prior to the evaluation to make sure that the scenario proposed was realistic and reflecting the users regular work tasks. The user was encouraged to think aloud and say what he was seeing and doing. During this hands-on evaluation, the interaction was captured using the tools described in the next subsection.
- The third part of the evaluation was a questionnaire regarding the user's satisfaction.

The ten tasks that users were given to solve by interacting with the system were:

1. Digitizing one parcel on top of aerial images
2. Digitizing at least one more parcel

3. Displaying a map of the user's own parcels
4. Displaying a map of the parcels and the soils
5. Navigating to the Vully-region
6. Navigating to the user's village
7. Displaying different layers on the map (as mentioned, the user had the choice between a variety of different layers, or some predefined compositions of layers)
8. Selecting parcels on the map and save the selection as a group of parcels
9. Finding parcels between two specific height levels
10. Finding parcels on lime and save the selection as a group of parcels

7.2.6 Analytical methods

In order to analyze the interaction that occurred during the hands-on evaluation, we needed tools that captured all the important parts of the interaction. Since we had planned the evaluations as think-aloud sessions, we decided to film the user. Figure 7.8 shows a snapshot taken by a camera facing the user. Moreover, in accordance with the requirements specified in chapter six, we needed a tool that captured the system's output, and a tool that captured the user's input.

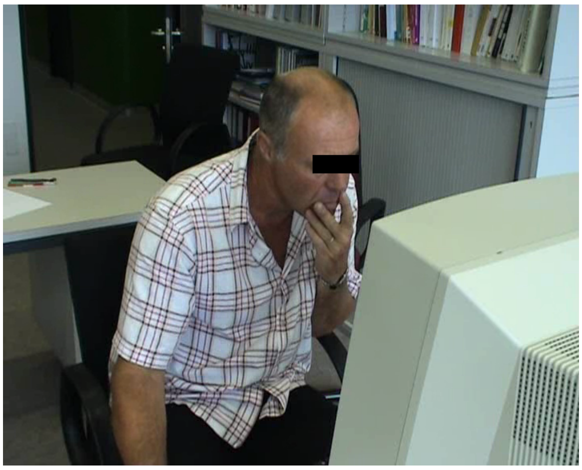


Figure 7.8: A snapshot of one user during an interaction-session

In order to capture the system's output, we installed a VNC-server[1] on the evaluation-computer. On another computer (physically in the same room as

[1] The Virtual Network Computing (VNC) system is a frequently used software framework to remotely control another computer. A VNC-server continuously transmits the computer's screen to a remote VNC client. The VNC client transmits user input (pointer, clicks and keyboard interaction) to the VNC server.

70.52.205.158 [1] - - [31/May/2006:15:53:46 +0200] [2] "GET [3]
/riv.php?bbox=561553.0320588425,137880.742787655;561553.0320588425,137880.7427876
55&tool=zoomin&layers=cartes,orthophoto,cadastre,parcelles&_= [4] HTTP/1.1" 200 [5] 20044
[6]

[1] The IP-address: Who tried to access the web-server
[2] The exact time when the access occurred
[3] The method that was used to access the server (GET or POST)
[4] The URL that the client requested
[5] If the query was successful or not (200 means successful)
[6] The amount of bytes that were sent back to the client.

Figure 7.9: A sample line in the log file of RIV's web-server

the evaluation computer) we installed a modified VNC client that streams the signal from the VNC-server directly to a video-file.

The user's input was gathered by RIV's web-server, Apache. This web server produces a log-file which stores specific information about all interactions between the client and the server. Figure 7.9 shows a sample of such a log-file's content.

This information enabled the reconstruction of the user's input, since each input (such as clicks) leave a trace in the log-file. In order to analyze the log-file we thus created a tool that parses the log-file and stores it into a database. Thereafter we created a second tool that extracts the information from the database and visualizes the whole interaction-session of each individual user in the shape of an interaction protocol (see figure 7.10) The different parameters of the log-file were thus translated into a more human-readable format, filtering unnecessary elements and emphasizing important elements:

- the time when the interaction occurred (with an absolute timestamp and a relative timestamp to be able to analyze the log-file synchronously with the recorded screen and video)
- what tools the user was using (e.g. zoom in, pan-buttons)
- what layers the user was requesting
- if there were delays (gaps) of more than 10 seconds in between the different queries

Before using our log-file visualization-tool for analyzing the users performance, we verified its functionality with the screen-shots that had been recorded during each session and assembled to video-files. Moreover we utilized the log-file visualization tool as an index for all evaluations that were recorded.

7.2.7 Parameters collected

Before presenting the analysis of the data that was collected, we give a brief overview of the parameters that we have at hand. We hereby refer to the framework of parameters (see figure 4.2) which was established in chapter four.

6:18/09:19:57	Zoom out	Layers: cartes,orthophoto,parcelles
6:21/09:20:00	Zoom out	Layers: cartes,orthophoto,parcelles
6:25/09:20:04	Scalebar 1:100000	Layers: cartes,orthophoto,parcelles
6:36/09:20:15	Pan Tool	Layers: cartes,orthophoto,parcelles
12		
6:51/09:20:30	Pan Tool	Layers: cartes,orthophoto,parcelles
20		
7:14/09:20:53	Zoom in	Layers: cartes,orthophoto,parcelles
7:22/09:21:01	Zoom in	Layers: cartes,orthophoto,parcelles
7:32/09:21:11	Zoom in	Layers: cartes,orthophoto,parcelles
13		
7:47/09:21:26	Pan Tool	Layers: cartes,orthophoto,parcelles
7:55/09:21:34	Zoom in	Layers: cartes,orthophoto,parcelles
13		
8:010/09:21:49	Pan Tool	Layers: cartes,orthophoto,parcelles
8:19/09:21:58	Zoom in	Layers: cartes,orthophoto,parcelles
8:24/09:22:03	Zoom in	Layers: cartes,orthophoto,parcelles

Figure 7.10: Output of the log-file visualization tool showing the columns time (absolute and relative; gaps of more than 10 seconds), the action the user took, the layers that were visible

User characteristics: With the first questionnaire we gathered the parameters *age* and *user's knowledge and skills*. Especially previous experience with similar systems, experience with geospatial information and experience with computer technology were asked. From the user's presence we collected the parameters handedness and gender. Since the test-users were all winegrowers from the same canton and the evaluations were carried out in a controlled lab-environment we did not address user context. Concerning the handedness of the users we did not specifically ask the question in the questionnaire; one of the users declared himself as left-handed during the evaluation and preferred the mouse to be on the left side of the computer screen.

System characteristics: The parameters interaction design, graphical design, map design and visualization, system architecture and performance have been discussed in section 7.2.3. Concerning the system's speed we can state that the test-user's computer was linked through a high-speed connection to the system's server. Moreover the test-users were the only users using the system during the time of evaluation. The response time of the system was less than one second for interactions that did not change the state of the map (such as clicks on menus) and about two seconds for interactions that did change the state of the map (such as map navigation or layer overlay).

Interaction characteristics: The log-file visualization tool enabled us to detect for each user the task completion time, the rate of interaction, task completion strategies (e.g. how many attempts were necessary to solve the task), spatial interaction strategies (e.g. which navigation tools the user was using) and what errors the user made during the evaluation (e.g. if he got lost in a menu that did not offer the functionality that was required to solve a task).

Moreover we used the gap-detection feature together with the videos (a view of the users screen in combination with a view of the user) recorded in order to determine what was happing when the user was hesitating at a specific moment.

Satisfaction characteristics: We used the user's comments that were made during the hands-on evaluation (we recorded both sound and video during the sessions) together with the data from the second questionnaire to analyze the different aspects of satisfaction.

7.2.8 Results

We structure our results according to the hypotheses and research questions that were specified in chapter five.

H1 Users show different strategies during interaction with a system

H1RQ1 Is it possible to distinguish between different kinds of spatial interaction strategies?

In order to respond to the first research question we started by analyzing the first task to navigate the systems maps, to find the right spot and to digitize a parcel. We considered map-navigation and digitization separately.

In terms of map-navigation we thus verified:

- how many navigation-clicks the user made
- what type of clicks the user made

Figure 7.11 shows the number of clicks with the different navigation tools. We noticed some differences in the frequency of use of the different tools:

- One out of 20 users tried out all tools during the first task
- Six users used four different tools
- Seven users used three different tools
- Six users managed to navigate to the right spot (where the parcel had to be digitized) with only two different navigation tools.
- Eight users clearly used the pair zoom-in and zoom-out for changing the scale (however some tried out other approaches as well).
- Five users used the scale choice list at least as often as the zoom-in zoom-out pair.

Further we noticed that users who only used few navigation-tools also needed few navigation-clicks to complete the first task. On the other hand, users who used many different navigation-tools also made many clicks.

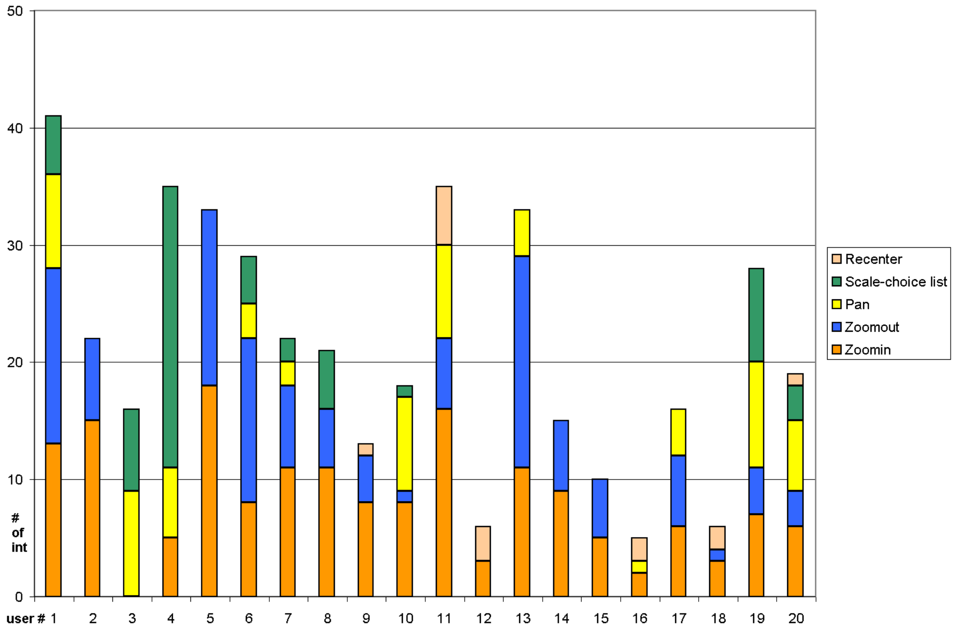


Figure 7.11: Number of clicks with the navigation-tools to navigate to a parcel

In ten cases we noticed that users tried to click on the zoom-tools without proceeding to click on the map and expected the system to zoom in simply by selecting the tool from the toolbar. Eight of those ten users later found that it is necessary to click on the map in order to zoom in or zoom out, whereas the other two users went over to other navigation-tools (such as the scale choice list and the recenter-tool)

During the first evaluation series all users had problems digitizing the first parcel (it took at least two and at most six attempts to digitize a correct polygon). The ten users of this first series had some problems in common:

- Five users tried to digitize the parcel as they would draw a line on a paper using a pen, by holding the mouse button clicked (see figure 7.12)
- Three users drew a complex polygon instead of following the outer border of the object. (see figure 7.13)
- Two users tried to paint the parcels interior with the digitization tool.

Due to these problems, the development team decided to help the user with the digitization functionality and followed the suggestion of one of the first ten users to write a small note on the page (that was actually taken from the help-pages) saying to

1. Navigate to the right place
2. Select the digitizing-tool

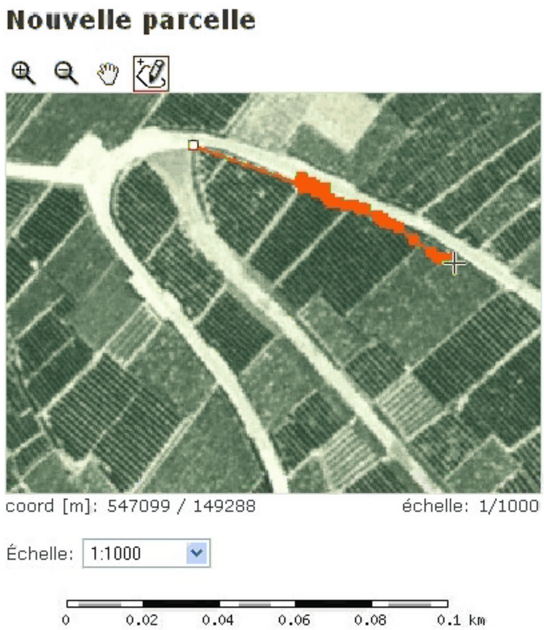


Figure 7.12: Problem *digitizing a parcel* - the user holds the mouse button clicked

3. Define the outer line of the parcel by clicking on the outer points
4. Click on the validation-button once the parcel is finished

During the second evaluation-series six users managed to digitize the parcel at the first attempt; at most it took three attempts to digitize it.

For the tasks 3-10 we did not find any particular differences regarding the users strategies compared to the first task.

H2 Users perform differently when interacting with a system

H2RQ1 Are there differences in task completion time, rate of interaction and rate of errors?

In order to analyze the users performance during the first task (navigate to the right spot and digitize a parcel), we analyzed:

- The task completion time
- Gaps of more than 10 seconds between the users clicks

Comparing and analyzing these measures against each other is, however, difficult due to the following facts:

Figure 7.13: Problem *digitizing a parcel* - the user draws a complex polygon

- this evaluation was using verbal protocols the user was encouraged to talk aloud while interacting with the system, thus gaps in the interaction with the system were frequent
- each user could freely choose the parcel he wanted to digitize (e.g. one of his own parcels). The parcels were thus not located on the same spot and each user had to navigate in different directions.

We thus decided to split up the task completion time of the first task into three different measures:

- Navigation time
- Digitization time
- Gap time

Navigation-time and digitization-time were measured as follows:

- A flow (many clicks in a row) with less than 10 seconds in between the clicks was counted from the beginning of the flow until the end of the flow.
- If the flow was a flow of navigation-clicks, we deduced two seconds for each click (due to the system's response time when a new map was created) from the final time.

- Single clicks with at least ten seconds before and after the click were counted as one second. For all users we thus accumulated flows and single clicks to one measure.
- Gap time was counted separately. If the gap occurred during navigation time, we deduced two seconds (due to the system's response time). The gap-time measures were accumulated.

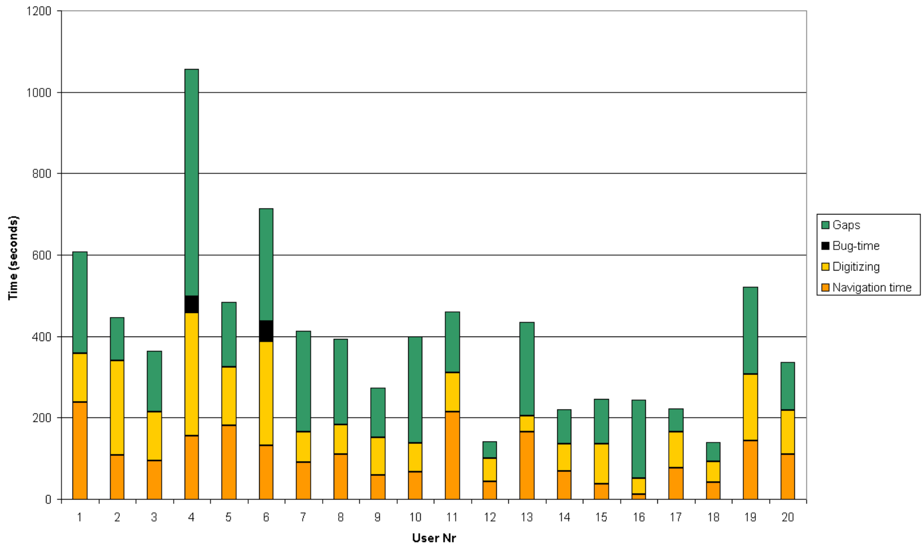


Figure 7.14: The task-completion times of all users for the task to digitize a parcel

Figure 7.14 shows, for each user, the task completion time to navigate the maps and to digitize a parcel. Two users of the first series unfortunately experienced system-related errors that increased the task completion time (the web browser suddenly shut down). Moreover, as mentioned above, users who digitized a complex polygon or who tried to "paint" the parcel's interior had to start over the digitizing process. Figure 7.15 shows the time to digitize the first and the second parcel (without gaps and navigation time). The difference between the two groups of users (users 1-10 and 11-20) becomes very obvious when we consider the time to digitize the first parcel. On the other hand the time to digitize the second parcel varies much less between the groups.

H2RQ3 Which strategies result in better performance?

Concerning different navigation strategies we found that users who used a combination of few navigation tools, e.g. zoom-in and zoom-out or scale choice list + pan or recenter-tool + pan-tool, needed much fewer clicks and overall navigation time than users who utilized four or more different tools. This result however is not surprising due to the systems response time on clicking and due

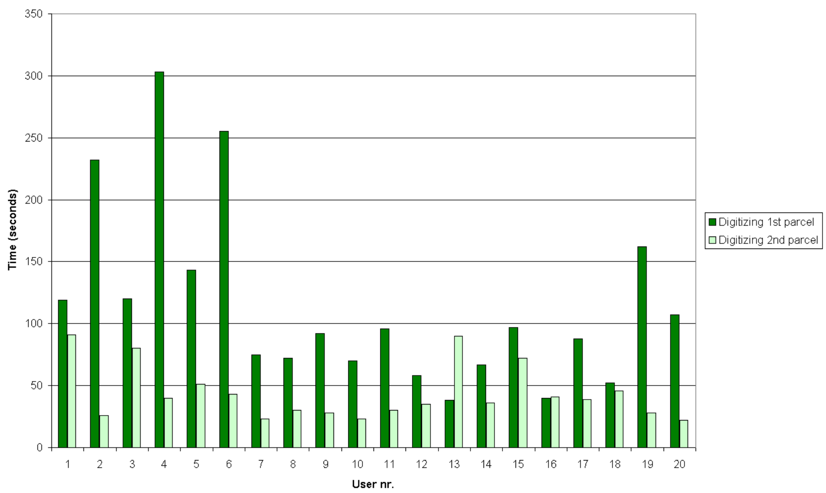


Figure 7.15: Time to digitize the first and the second parcel for each user

to the fact that each click produces a new map which requires the user to re-align himself and to figure out the next steps.

As a conclusion we can say that there is a strong correlation between the number of selected navigation tools and navigation time.

H3 User-related parameters have a significant influence on user performance, user strategies (spatial and non-spatial) and the perception of spatial features

Due to the fact that we had only a total of twenty users for our evaluations, we were not able to generate statistically significant results to respond to the third hypothesis. Yet we were able to identify phenomena that are relevant for responding to the first two research questions associated with the third hypothesis.

H3RQ1 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their performance?

In our first questionnaire we asked four questions that we consider as indicators of the users knowledge and skills regarding online geospatial systems:

- The user is a frequent user of paper maps
- The user has used online geospatial systems before
- The user has a high-speed Internet connection at home
- The user has taken courses in informatics

Above we have specified measures that we judge relevant for quantifying experience and skills. Our assumption is that users who have answered yes to all four questions are likely to perform better than users who have answered no to at least two questions.

We used the following measures for the first task (which was also the first time the users were exposed to RIVs geospatial system) as indicators for performance:

- the time to navigate to the parcel
- the number of navigation clicks to navigate to the parcel
- the time to digitize a parcel (keeping in mind that the second group had a written explanation of how to digitize)
- the number of attempts to digitize a parcel (also here keeping in mind that the second group had an explanation of how to digitize)

We found the following evidence in our data:

- The one user who had answered yes to only one question (that he has a high speed connection) performed worst in navigation time and navigation clicks
- The four users who performed best in navigation, had answered yes to three (2 users) or four (2 users) questions. All these users had used cartographic systems before

H3RQ2 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their strategies?

All but two users had used online geospatial systems before this evaluation, many users even 2-3 different systems. GéoPlaNet, the canton's official mapping system, was the most known one of the ten alternatives we had listed in the questionnaire. Moreover two users indicated that they had used some installable mapping systems before (Twixtel and ArcPad) and one user mentioned that he had used a GPS before.

All of the previously used systems were either way-finding systems (Mappy[2], ViaMichelin[3], Map24[4], Google Maps[5]), geoportals (GéoPlaNet[6], Swissgeo[7],

[2]http://www.mappy.com
[3]http://www.viamichelin.com
[4]http://www.map24.com
[5]http://maps.google.com
[6]http://www.geoplanet.vd.ch
[7]http://www.swissgeo.ch

Swissinfo[8] and MapSearch[9]), a system with specific information such as railway stations (SBB[10]) and a virtual globe (Google Earth[11]). All systems have different navigation-manners with different tools that are used to zoom in and zoom out or to pan.

As we found that especially navigation tools in RIV are problematic for many users, we analyzed how map-navigation is implemented in the systems cited. We analyzed if:

- The system reacts directly on clicks on the navigation-tools (the user is thus not required to first select a navigation tool and then to click on the map)
- There is a scale choice list that permits to zoom
- The system supports a zoom by marquee (as RIV or most desktop GIS such as ArcGIS)
- There are pan-buttons implemented (either around the map or gathered at one location)

System	Reacts directly on clicks on zoom in/out tools	Scale-choice zoom implemented	Zoom by marquee implemented	Pan buttons implemented
GéoPlaNet	no	yes	yes	yes
Swissgeo	no	yes	no	yes
Mappy	yes	yes	no	yes
Google Earth	yes	yes	no	yes
Michelin	yes	no	option	no
SBB	no zoom tools	yes	no	yes
Google Maps	yes	yes	no	yes
Swissinfo	no	yes, but not working	yes	no
MapSearch	yes	yes	no	no
Map24	yes	yes	yes	no
Has feature	6	8(9)	3(4)	6

Table 7.2: Online geospatial systems that users had used before the evaluation

Table 7.2 shows the results of this investigation. We found that four of ten systems do support zoom by marquee, however all but one of these systems do support zooming through the scale choice list (one systems scale choice list worked only partially at the time we tested it). We can further observe that six systems are offering map-navigation that does not involve clicking directly on the map these systems support pan-buttons for moving the map in each direction and a scale choice list.

[8] http://www.swissinfo.ch
[9] http://map.search.ch
[10] http://www.sbb.ch
[11] http://earth.google.com

We compared the approach each user chose for interacting with the system and analyzed:

- if users who used the zoom by marquee in RIV were in contact with other systems that also support this feature
- if users who had problems with that feature were mostly in contact with systems that support other navigation-styles
- if users who tried to click on the zoom tools without proceeding to click on the map were using systems that support that feature
- if users who frequently used the scale choice list were mostly in contact with systems that support that feature

We found the following evidence in our data:

- four out of five users who used the "zoom by marquee" approach stated that they had been in contact with systems supporting this feature
- nine out of ten users who had problems with the "zoom by marquee" tool had used systems that offer other possibilities to zoom (the tenth user had not used any cartographic systems before)
- eight out of ten users who initially expected the system to zoom immediately after clicking on the zoom tool had used systems before that support a direct zoom tool
- seven out of nine users who used the scale choice list had been in contact with systems supporting this features (the two other users had not been in contact with any cartographic system before)

We therefore can state that there seems to be a relation between the users background, in terms of knowledge and skills, and the way they interacted with RIV. Moreover there is a likely connection between the previous use of geospatial systems and the manner in which the users performed in this evaluation.

One interesting finding is that the left-handed user (who used the mouse with his left hand) digitized the parcels counter-clockwise. All other right-handed participants digitized the parcels clock-wise. This phenomenon could be related to the way users draw a polygon (or a circle) on paper using a pen. A right-handed person begins at the top of the polygon and continues rightwards (so that his hand does not cover the line). On the contrary, a left-handed person does the opposite and begins leftwards.

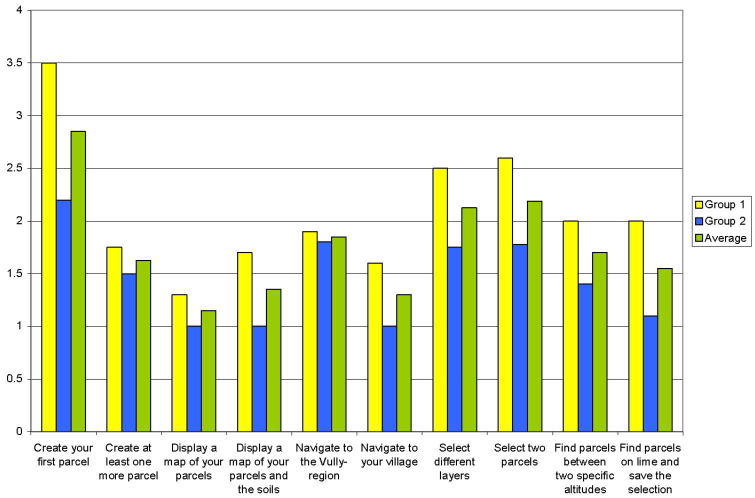


Figure 7.16: The difficulty of the different tasks rated by the users

H4 System-related parameters have an influence on user performance, user strategies (spatial and non-spatial) and perception of spatial features

H4RQ1 Is there any evidence that some interface features cause higher cognitive load?

In order to identify interface features that cause a higher cognitive load we used the following elements as indicators:

- The users comments on specific features (during the hands-on session and in the questionnaire concerning satisfaction)
- The users rating of the difficulty of a specific task

First we analyzed the level of difficulty that users had assigned to each task; the tasks with the highest difficulty rate were: Creating the first parcel, selecting two parcels (with the tool to select parcels), selecting different layers and navigating to the Vully-region.

Interface features that the users commented on were the navigation tools: to zoom in, to zoom out and to move the map (pan). As mentioned above these tools were configured to work in the following manner:

- the user selects a tool and then interacts with the map; if the user wants to change from the zoom-in to zoom-out, the user has to select the tool by clicking on it the user can then navigate the map by clicking on it with the selected tool
- the user uses the zoom-in tool by drawing a rectangle on the region that he wants zoom in (“zoom by marquee”)

- the user uses the pan-tool by clicking on the map and moving the map when the user releases the mouse button, the map is updated

Some users commented that the zoom-in tool was difficult to understand. In fact, only 5 of 20 users used the zoom-tool as intended ("zoom by marquee") and out of the remaining 15 users 10 had the problem that they accidentally drew a small marquee (by holding the mouse-button pressed on the map for a few seconds) and zoomed in to the maximum level. The main difficulty was that these users had to regain orientation on the map by figuring out different methods to zoom out again. Moreover users had the impression that they either did something wrong or that the systems zooming function was poor.

Furthermore, 10 users had a problem with the zoom-out tool (out of 20 users, 18 tried to use it). All 10 users expected the map to change by only selecting the tool from the toolbar. (The idea was, as mentioned, to select the tool and then to interact with the map). These users had to figure out alternative solutions: two chose the scale choice list, one the recenter-tool (recenter to a specific growing region or village). The other seven users discovered after a while that a click on the map was necessary in order to zoom out. Two of these seven users later adopted the approach to always zoom out by first clicking on the tool and then on the map (even if the tool was already selected).

The pan-tool was used by only 12 users - two users commented that they did not understand how it was supposed to work and another user said that he would have preferred small pan-buttons around the map in order to move it.

As a result we can say that the manner in which spatial navigation was implemented in RIV caused a high cognitive load due to the fact that the users had to figure out different strategies.

In parallel to the problem with the zoom-in-tool, the users had the same problems with the tool to select multiple parcels. The user could use the tool either to select one parcel by clicking on it or several parcels by drawing a rectangle around them. Out of 20 users only 6 users knew or found out how to use this tool to solve the task of selecting multiple parcels (by drawing a rectangle). The other 14 users were forced to find an alternative solution and used either the menu parcel groups, where they could choose the parcels from a list, or the tool to query parcels by selecting different criteria.

The task to digitize a parcel was interesting in terms of cognitive load of specific interface features, as half of the users had a small text that gave a hint of how to use the parcel-digitizing tool; therefore we analyzed these tasks for both groups of users (users 1-10 and users 11-20) separately. We noticed that the first group (who did not have the hint) needed much more time to navigate and to digitize than the second group. Only the digitizing-part took almost twice as much time for the first group than for the second group. Surprisingly when both groups were asked to digitize the second parcel, the first group digitized and navigated quicker than the second group.

As a conclusion we can say that the geospatial feature to draw a rectangle on a map (either with the zoom-in tool or the select-object tool) does cause a high cognitive load. In case of a problem the user has to find an alternative solution to solve a task that involves map-navigation or the selection of objects. Moreover the parcel digitizing-tool does cause a high cognitive load for the user as the user has to discover its functionality during the task.

H6 System-related parameters influence user satisfaction

H6RQ1 What is the connection between the systems' graphical design, interaction design, map design, the user's computer and user satisfaction?

In order to answer H6RQ1 we analyzed the data from the second questionnaire and the comments that users made during the evaluation. We found that

- Five users were not satisfied with the contents of the maps; especially the cadastre should be added by default in order to facilitate the digitizing process.

- Three users criticized the readability of the maps due to the colors and the small size of the map.

- One user found it not very intuitive that the aerial images were displayed only at a certain scale and argued that the map therefore should consistently display either topographical maps or aerial images but not change from topographical maps to aerial images when the scale was increased.

Regarding the user's satisfaction with the system's interaction design we had asked the users to rate if the series of operations were intuitive (e.g. the series of operations to digitize a parcel) on a scale from one (not intuitive) to five (very intuitive) and the users in both groups had given high rates (4.2 and 4.5 respectively). However the system's map navigation and digitization tools were often criticized:

- Seven users were not satisfied with the manner in which the navigation tools worked: three users preferred pan-buttons or scroll-bars around the map to move it; three users did not like the tool for zooming in by drawing a rectangle ("zoom by marquee") and two users did not like to first select a tool and then to click on the map to apply the tool's functionality.

- Seven users wanted to have more digitizing possibilities and controls: Three users would have preferred to first draw a large parcel and then to subdivide this parcel into smaller parcels. Two users wanted to have a "snapping" - functionality that automatically aligns a parcel (e.g. to the cadastre or to another parcel). One user wanted to be able to draw arcs (instead of lines) and one user missed the functionality to move the map while digitizing.

The graphical design was a minor source of dissatisfaction. The only problem that was remarked by some users was the visibility of some elements; two users proposed that the button for the contextual help should be more visible; three users wanted the button for creating the parcel (after a parcel had been drawn) to be more visible.

We had asked the users if they thought the system's design is helpful for its utilization. The users gave a high rating on this questions as well (4.3 and 4.7 respectively). Concerning the satisfaction with the system's access (speed, reliability) only one user criticized the system's speed.

7.2.9 Summary of results

To give an overview of all important findings of this case study we give a summary of the results that reflects the relationships defined in our framework of parameters (see figure 4.2).

Parameter	**Parameter influenced**	**Finding**
Rate of interaction	Task completion time	The rate of interaction appears to be related to the task-completion time in spatial navigation tasks due to the fact that each time the user makes an interaction (e.g. a click on the map), the map is re-processed; resulting in an increased interaction time
Spatial interaction strategies	Rate of interaction Task completion time	User who used several spatial navigation tools made more interactions (and thus needed more time)
Interaction design	Errors Rate of interaction Task completion time	The task to digitize a parcel represented major problems. The second series of test-users made less errors due to the fact that an explanation was given on how to digitize a parcel. The implementation of the zoom-tool "zoom by marquee" appeared to cause problems with the spatial navigation. Users had to find alternate ways to navigate.
Online geospatial systems experience	Spatial interaction strategies	Previous experience of using online geospatial systems appears to influence the way users navigate a new system.
Map design	Satisfaction with map design	The small size of the map was criticized (influencing readability negatively), moreover users did not like the fact that maps changed from topographical maps to ortho-images at a certain scale.
Interaction design	Satisfaction with the system's interaction design	Users were not satisfied with the way spatial navigation tools were implemented
Interaction design	Satisfaction with the system's functionality	Users would have preferred to have more possibilities for the digitization (e.g. snapping or clipping).
Handedness	Spatial interaction strategies	One left-handed participant digitized counter-clockwise; the other participants digitized clockwise

Table 7.3: Summary of results from the evaluation of the RIV system

7.2.10 Conclusions

In our evaluation we found evidence that supports some of our hypotheses. We were able to identify that the twenty participants of our evaluation did have different manners of interacting with the system and that some manners resulted in better performance.

The interaction-problems that occurred during the evaluations were certainly not only linked to one single cause, but had many specific reasons. We found evidence suggesting that users are highly influenced by their previous experience with geographical information and online geospatial systems. Users who did not recognize the interaction approach they were used to were forced to find alternative ways to interact with the system and therefore performed worse than users who recognized the interaction manners they were used to. This is especially true for the navigation tools.

Furthermore we conclude that the problems which occurred with these navigation tools were caused by two reasons:

- RIV, as any web-based geospatial system, is used in a web-context. In a web-context a click on almost all standard elements (hyperlinks, buttons, checkboxes, radio-buttons, menus, etc) has a direct effect (e.g. one click on a hyperlink makes the system navigate to the next page or to a different site). The interaction-manner of selecting a tool and then interacting with the map (e.g. selecting the zoom-out tool and then clicking on the map; as it is implemented in many desktop GIS such as ArcGIS) is therefore contradictory in the web-context. Also digitizing a polygon is a rupture of this context as all standard-objects that are clickable in a web-context are usually points the user is used to move the mouse to one feature (button, hyperlink, etc) and then to click on that feature. Digitizing a parcel in RIV implies to hold the mouse button for a longer time while moving the mouse.

- In RIV there was no possibility for the user to discover that the navigation tool could be used in this manner. Neither did the icon of the zoom-in tool suggest it, nor did a text indicate it.

We conclude that satisfaction, being an individual's subjective opinion, can be positively or negatively influenced by the user's previous experience. For instance:

- Users who were less used to computer systems and geographical information (and thus performed worse in terms of error rate and task-completion time) may still have been positively surprised to see that there were many possibilities for using the RIV system and were thus satisfied with the system.

- On the contrary, users who had previous experience of geospatial systems and were more familiar with the various tools in the system (and therefore performed better) may have expected more or different functionality and were thus less satisfied.

The RIV case study showed that the interaction of real-world users with online geospatial systems is complex. It requires cognitive strategies such as the navigation in a virtual space using specialized tools and the interpretation of specific maps. Although we could not show a statistical significance of the results, due to the limited number of users, we have found evidence that validates our framework of parameters (see figure 4.2).

The utilization of verbal protocols for this case study provided useful insights about how users think about the interaction with online-geospatial systems. The recordings of these verbal interactions, however, resulted in more qualitative than quantitative data. We conclude that the combination of recordings, automatic interaction-logging tools and questionnaires, that we developed to gather and analyze data about the interaction, provide the necessary means for validating the presence and level of connection between the different parameters of our framework.

7.3 Spatial data ordering system

7.3.1 Context

The association for spatial information systems in the canton of Vaud (Association pour le Système d'Information du Territoire Vaudois, ASIT-VD) is an organization that collects all kinds of spatial information from different public (e.g. the state, canton, communities) and private sources. If a person (private or public) needs spatial data for different purposes, he can order this information at the ASIT-VD.

Since 2003 the association distributes this data through an online platform that is accessible for everybody. As a user of this platform it is possible to browse a catalog of all the available data layers, including the meta-information associated with the data. Once the data-layer has been found, the user can select the zone for which he wants to order the data and choose how to transfer that data (e.g. by specifying the format and whether the data should be sent on CDs or downloaded directly). The users of ASIT-VD's online platform are mainly professionals from the canton, municipalities or enterprises.

In late 2007 it was decided that the existing platform's usability should be tested and evaluated in order to make the platform evolve. We used this testing opportunity not only to analyze the existing platform's usability (and to suggest improvements), but also to capture the interaction of the test-users. Moreover we wanted to refine the analytical methods that we had developed for the RIV-case study. In the following sub-sections we describe the systems' characteristics in terms of functionality, interaction-design, technologies and architectures. Thereafter we explain the experiment design and the tools we developed to gather the data during the evaluation.

7.3.2 System characteristics

Functionality and interaction design: The platform's interface consists of two components that are visualized sequentially:

- The first screen enables the user to browse through the database of available data layers. The user can for instance filter the data according to the data provider or according to the date the data had been updated (see figure 7.17). Moreover the user can click on the data layer's name and get information about the data layer (metadata, extent, scale, etc.). Once the user has found the data layer he wants to order he clicked on a small icon symbolizing a basket and proceeds to the second component of the interface.
- The second component of the interface (see figure 7.18) is a geospatial interface (see figure 7.19) for specifying the data's spatial extent. Once the extent has been specified the user can choose the way he wants to receive the data (e.g. the data format, on a CD-ROM or by downloading the data).

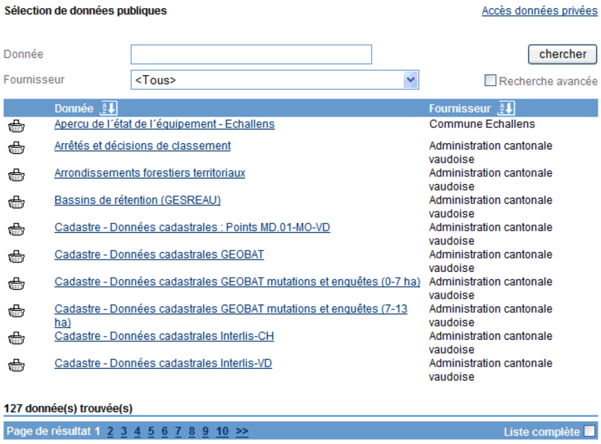


Figure 7.17: Browsing the ordering system's database

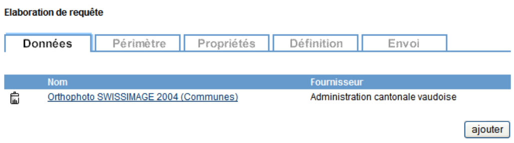


Figure 7.18: The interface that is used to define the spatial extent and the format of the data; it contains five steps that need to be completed before the order can be sent

The geospatial interface (see figure 7.19), which is used to specify the data's extent, contains a set of different tools for navigation and selection of the extent:

- Standard navigation tools such as zoom in, zoom out and pan. These tools were implemented as follows: first the user selects a tool (e.g. zoom out) and then applies its functionality on the map. For the zoom-in tool the user needs to draw a rectangle ("zoom by marquee", as it was implemented in RIV) of the region he wanted to zoom in to. The pan-tool's functionality is applied by clicking and dragging the map.

- Tools to define the spatial extent. There are two manners for defining the extent - either by digitizing one polygon or one rectangle on the map (using a rectangle-drawing and a polygon-drawing tool - see figure 7.20) or by selecting a zone that has already been defined. For the second alternative the user can choose (using a drop-down menu) between different layers that contain predefined zones, e.g. municipalities or cadastral parcels. Once the user has chosen one of these data layers, the layer is added to the map. Now the user has the choice of either three different spatial selecting tools (point, rectangle and polygon, see figure 7.21) that can be used to directly point out the zone on the map, or a tool that allows for selecting zones using a dialog-box (see figure 7.22).

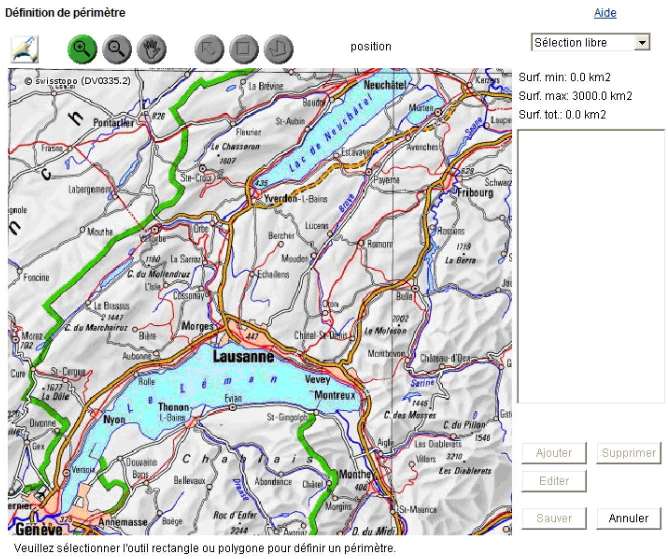


Figure 7.19: The geospatial interface that is used for selecting a zone for which to order data

Maps: The maps that are visualized in the system are the same as in RIV which are digitized paper maps made by the Swiss Federal Office of Topography. At the maximum zoom level the system displays ortho-images.

Technologies and architectures: The ASIT-VD system is implemented with two different technologies:

- Microsoft's ASP (Active Server Pages) technology (see section 3.3.3) is used for the dynamic creation of html-pages. In these pages users can browse the data that is stored in the database (e.g. to find out which data is available, what metadata, what source, etc.;)
- A Java-applet (see section 3.3.3) is used for the component of the system where the user defines the spatial extent of the region for which he wants to order the data. The Java-Applet provides a navigable map of the canton with several navigation tools and tools for selecting or drawing the extent of the region. (see figures 7.19, 7.20, 7.21 and 7.22)

7.3.3 The test-users

Since the ASIT-VD's ordering platform is mostly used by professionals, we wanted to find test users who are potential users of the system but have not used the system before. The users should thus be acquainted with:

- navigating maps
- utilizing a desktop GIS (since the data they will order is mostly used within a desktop GIS context)

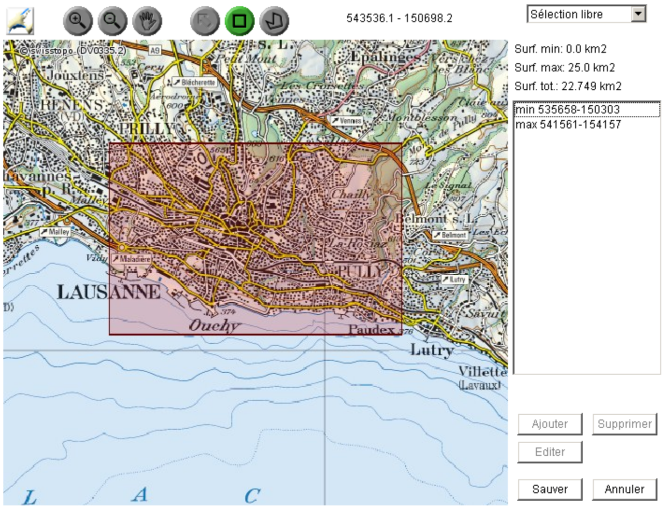


Figure 7.20: Digitizing a rectangle of the zone for which the data shall be ordered

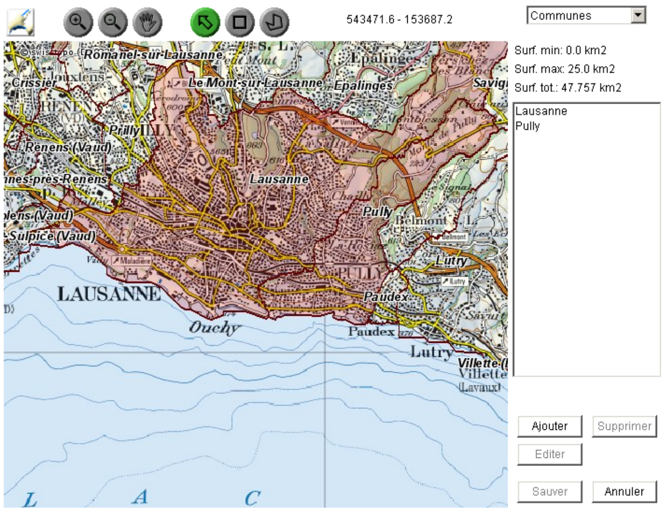


Figure 7.21: Selecting a predefined zone using a tool to point out the zone on the map

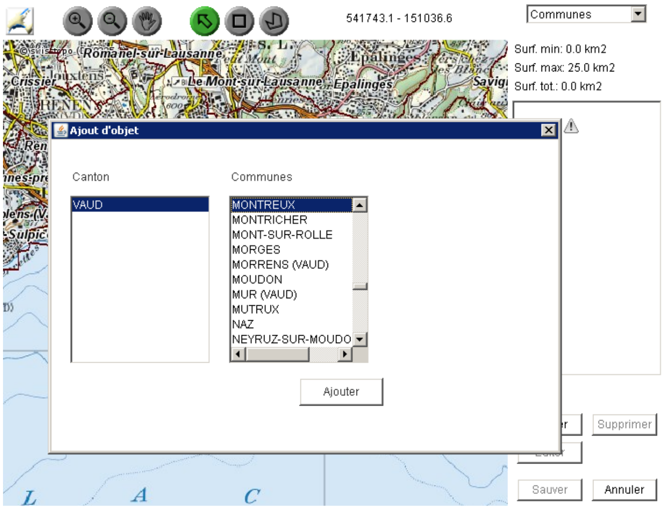


Figure 7.22: Selecting a predefined zone using a dialog-box

At the University of Applied Sciences Western Switzerland in Yverdon we found 21 students who were finishing the last year of the geomatics program. Moreover one assistant of the professor agreed to participate in the testing. However, in order to increase the number of test users and to make the results statistically more reliable, we decided to include 11 students who are enrolled in the environment program at the Swiss Federal Institute of Technology at EPFL. These students, also, follow courses in geomatics as part of their study program.

The total number of test-users were 33 students and one assistant. All the participants matched the required profile, defined for the testing of the system.

7.3.4 Evaluation setting and analytical methods

The evaluation was inspired by the evaluation of the RIV system and planned in three parts:

- First the test-user was asked to complete a questionnaire with demographic questions (age, education, computer use) and questions regarding their experience with maps and online geospatial systems.
- Second the users were asked to complete a scenario of four different tasks using the system. The tasks had previously been discussed with the administrator of ASIT-VD's system, in order to make the case study more realistic. During this hands-on evaluation the interaction was captured.
- Third the test-users were asked to fill in a second questionnaire regarding their satisfaction.

The scenario that we defined for the hands-on evaluation was a simulation of a typical use-case for the platform:

Imagine that you want to conduct a land-use study in the municipalities of Paudex, Pully and Belmont. For this study you need to use aerial images that are distributed by the cantonal administration. The images should be delivered in jpg-format on cd-roms

The tasks that were defined in the scenario were thus:

1. Connecting to the website using the URL www.asit.vd.ch and clicking on the heading GEOCommande"
2. Finding the relevant dataset
3. Ordering the data according to the specifications given

For each of the tasks the user was asked to rate the degree of difficulty.

Before the evaluation it was discussed whether the system could be tested with multiple users at a time. This question was raised due to several reasons: The students were only available for a certain period of time. It would take several days to conduct the study if using the same method that was used for the evaluation of the RIV system. Moreover during the analysis of the results of RIV we found that the verbal protocols in the evaluation interfered with the analysis of performance-related parameters (task-completion time and rate of errors) of our framework.

Finally the option multiple users at a time was chosen. It was also decided that the evaluation should be conducted as supervised sessions which means that at least one person controlled that the test-users did not look at each other's screens and thus influence each other. Moreover the test-users were placed in the computer-rooms with maximum space between the users. Yet, testing the ASIT-VD system with multiple users at the same time implied several technical problems:

- The monitoring of the users interaction with a user-screen streaming tool using the same technology that was used for the evaluation of RIV would have required the preparation of about 30 computers with the necessary software. Moreover the configuration of a server that is capable of receiving such an amount of data would have been difficult.
- The infrastructure that was used for the ASIT-VD system used a proxy server (a server through which Internet traffic passes). Due to this reason the log-file visualization tool that had been developed for the analysis of RIV would not have been able to collect the data, as it would have been impossible to separate the different interaction sessions. The log file would have registered the IP-address of the proxy server instead of the IP-address of each user.

The ASIT-VD system was therefore analyzed in order to find ways to capture the users interaction by other means: We found that the client (the users web-browser) communicates with the server of the system using the following technologies:

- The ASP-HTML-pages are transferred with the standard HTTP-protocol each time the user request a new page, the page is transferred to the user without encryption.
- The Java-applet communicates with the server using a protocol called XML-RPC [12]. This protocol implies that XML-files are sent between the client and the server. The client (the Java-applet) for instance produces a XML-file containing the extent of the region and the different layers to be displayed. The file is then transferred to the server which in turn replies with a different XML-file that contains the metadata of the layers of the map (e.g. the names of municipalities) and a link to a second server where the map (a picture), showing exactly the region and the layers that have been requested, can be downloaded. The applet then assembles all the information. It downloads the map and displays it along with the metadata.

The goal of the evaluation was to record as much as possible of the users interaction with the system. However, as we could not use a single server to capture all users in parallel we decided to analyze whether the users interaction could be recorded directly on the users computer and gathered after the evaluation. We therefore came up with the idea to capture the traffic between the server and the client on the client's computer. The captured traffic could then be stored into a file and analyzed after the evaluation. Furthermore, we wanted to capture the users screen directly on the user's computer.

We finally found two freely available tools that fulfilled the requirements:

- A capturing tool called Tcpdump [13] that can be launched by the command prompt. This tool stores all the traffic captured into a single file.
- A tool called Xnview [14] that takes one screenshot when it is launched by the MS-DOS command prompt using specific parameters.

We then implemented a script (a MS-DOS batch file, see figure 7.23) that is capable of starting both tools at the same time (the script started Xnview every second in order to ensure that the screen was recorded continuously). At the beginning of the evaluation the user starts the script which in turn prompts the user to enter his specific evaluation-number. All files created by the script (the screen-shots and the traffic) were then named by the script according to the number entered in order to be able to distinguish between the different sessions in the post-analysis.

[12] http://www.xmlrpc.com
[13] http://www.tcpdump.org
[14] http://www.xnview.com

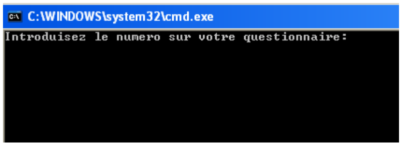


Figure 7.23: A batch-file script used to capture the user's screen and the traffic between the user's computer and the system's server

The script, together with the Tcpdump and the Xnview tools were copied to the users computers. After the evaluation had taken place we manually collected the data that had been recorded on each computer.

In order to analyze the gathered data about the internet traffic we used a freely available network protocol analyzer tool called Wireshark [15] a graphical user interface to the Tcpdump-tool. This tool allows loading and filtering the traffic according to the protocols that had been used (e.g. the http-protocol), but also according to the IP-adress of the server that the clients web browser communicated with. The filtered traffic data was then exported to a parsing tool we had developed. The parsing tool was similar to the log-file visualization tool that we had implemented for the RIV-case study. The major difference between the two tools is that the new tool does not take its data from a database, but from network-protocol files. It is thus capable of analyzing what the user was doing with the system and when exactly a user action took place:

- for all map-navigation actions (such as zoom in, zoom out etc.) the bounding box that was described in an xml file (e.g. "a smaller extent equals a zoom in"), created using the xml-rpc protocol, was used.

- for all selection activities the name of the tool that the user had used could be found in the xml-files

- for all http-traffic the content of the html files (produced by the ASP-server) was taken into account.

The parsing-tool then created both interaction-protocols (see figure 7.24), similar to the protocols that were used for the evaluation of RIV, and statistics (what functionalities were used, how many times, how much time the evaluation took, etc)

The screen-shots that had been taken by the Xnview-tool were assembled to video-files. These video-files were then used to verify the correctness of the interaction-protocols and to detect interaction strategies.

[15] http://www.wireshark.org

Session number: 8

T abs	T btw action	Action
15:33:17		Server sends base map
15:33:17	0	Init
15:33:25	8	Server sends base map
15:33:25	0	Zoom In
15:33:34	9	Server sends base map
15:33:35	1	Zoom In
15:33:42	7	Server sends base map and data layers Number of selected items:0
15:33:42	0	
15:33:56	14	Select by clicking on map. Selection using polygon tool Layer: communes
15:33:56	0	attributes are displayed
15:33:56	0	Server sends base map and data layers Number of selected items:1
15:33:56	0	
15:34:03	7	Select by clicking on map. Selection using polygon tool Layer: communes
15:34:03	0	attributes are displayed
15:34:03	0	Server sends base map and data layers Number of selected items:2

Figure 7.24: An interaction-protocol generated by the parsing-tool

7.3.5 Parameters collected

Before we present the results of this case study, we give an overview of the data and parameters that we have at hand. Out of all 34 test users there was unfortunately one user for whom data capture did not work (either the user did not manage to start the script properly or there was a problem with the user's computer). Out of the remaining 33 users three users were unable to finish all tasks which left a total of 30 users that we considered for the analysis. 23 users were male and seven female. The average age was 23.3 years; the oldest user was 27 years old and the youngest 19 years old.

During the evaluation there was one usability problem that occurred for about half of the test-users: in order to navigate from the first component of the interface, where users can choose the data-layer they are interested in, to the second component of the interface, where the users define the spatial extent of the data, it was necessary to click on an icon symbolizing a shopping-basket (see figure 7.17). This icon however was either not identified as a shopping-basket or the users did not figure out that the icon needed to be clicked on in order to continue the evaluation. During the evaluation it was therefore decided to reveal its functionality orally to users twenty minutes after the evaluation's start so that the test-users successfully could complete the evaluation. This fact needed to be taken into account for the analysis of the data that we had captured.

We collected the following parameters relevant for our framework (see figure 4.2):

User characteristics: The following parameters were collected using the first questionnaire:

- Gender
- Age
- Knowledge and skills, especially previous experience with similar systems, experience with geospatial information and computer use

System characteristics: The parameters interaction design, map design and system architecture that we collected are described in subsection 7.3.2. Further, regarding system speed we found that the system's response time is less than a second for the first component of the interface where the user browses the system's database and select data layers (see figure 7.17). For the second component of the interface, where the user defines the spatial extent of the data to order, the response time is about one second.

Interaction characteristics: The traffic visualization tool enabled us to elicit the following parameters for each user:

- The task completion time
- The rate of interaction
- Task completion strategies (e.g. how many attempts were necessary to solve the task)
- Spatial interaction strategies (e.g. which navigation tools the user was using, which technique the user had chosen to select spatial data)
- What errors the user made during the evaluation (e.g. if he got lost in a menu that did not offer the functionality that was required to solve a task)

Satisfaction characteristics: From the second questionnaire we collected the following parameters

- satisfaction with the system's graphical design
- satisfaction with the system's interaction design (especially the logical design, and spatial navigation)
- satisfaction with the access (especially system speed)

7.3.6 Results

We structure our results according to the hypotheses and research questions specified in chapter five.

For the comparison of some parameters we used the Wilcoxon rank sum test. The motivation is that it is robust for comparing samples where there is no hypothesis on the distribution. The null hypothesis to be tested is that two populations are identical with respect to their medians. A p-value smaller than 0.05 rejects the null hypothesis at a significance level of 5% (Gibbons, 1985), meaning that the difference between the groups is significant.

H1 Users show different strategies during the interaction with a system

H1RQ1 Is it possible to distinguish different kinds of spatial interaction strategies?

The analysis of the data that had been recorded by our traffic capturing script showed a very surprising result. The system's navigation tools (zoom in, zoom out and pan) were used very sparsely:

- 30% of the users managed to solve the tasks without even clicking on the navigation tools.
- 50% of the users solved the tasks with between one and four clicks on the navigation tools.
- The remaining 20% used between eight and 15 clicks on the navigation tools.

Figure 7.25 shows the clicks on the interface's navigation tools for each user. The 20% of users who clicked between eight and 15 times on the navigation tools stand out in this figure.

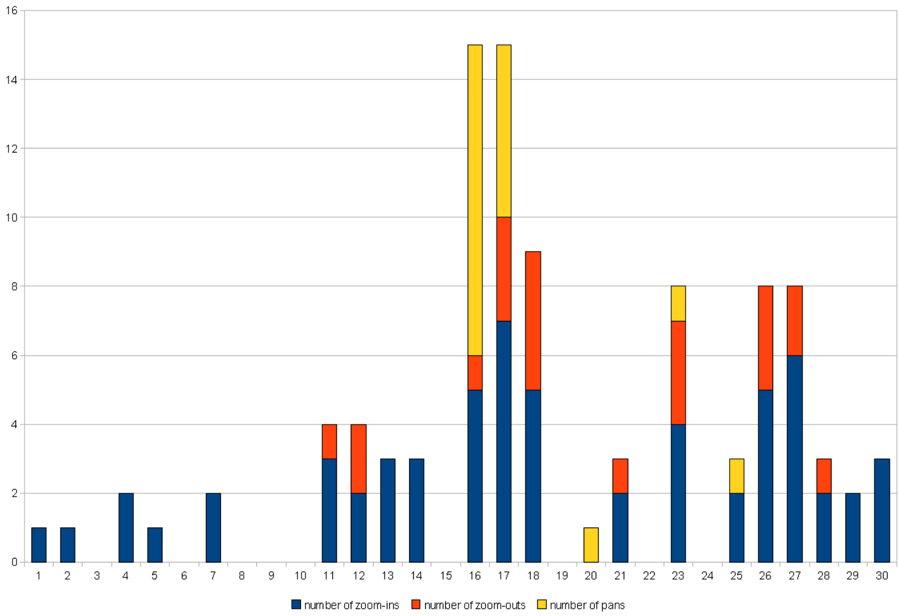


Figure 7.25: Number of clicks on the interface's navigation tools (zoom in, zoom out and pan) for each user)

The fact that few users used the navigation tools seems to be related to the manner in which users selected the data. By analyzing interaction protocols we found that

- only 10% of the users utilized the spatial selection tools (as shown in figure 7.21) to select the zones
- 13% of the users utilized both the spatial selection tools and the dialog-box (shown in figure 7.22) to select the zones
- the remaining 77% used the dialog-box to select the zones; no spatial navigation was thereby necessary

.

H2 Users perform differently when interacting with a system

H2RQ1 Are there differences in task completion time, rate of interaction and rate of errors?

When we analyzed the task-completion time for the different tasks we observed that 27% of the users were able to solve the first three tasks within five minutes (to go to ASIT-VD's homepage, click on the link of the ordering system, to select the data-layer and then to click on the shopping-basket icon). The remaining 73% were confused about the third task, selecting the shopping-basket icon. As previously mentioned, we decided to reveal the shopping-basket's functionality after twenty minutes in order to allow the test-users to successfully complete the evaluation. Due to this problem we decided to focus on the fourth task and compare the time it took to define the spatial extent of the data to be ordered.

In order to analyze this span of time we measured the time from the moment the Java-applet was started until the moment the user clicked on the button to save the selection. 77% of the users (see figure 7.26) managed to select the spatial extent within one to three minutes. Only five users needed more time and one user was faster than one minute.

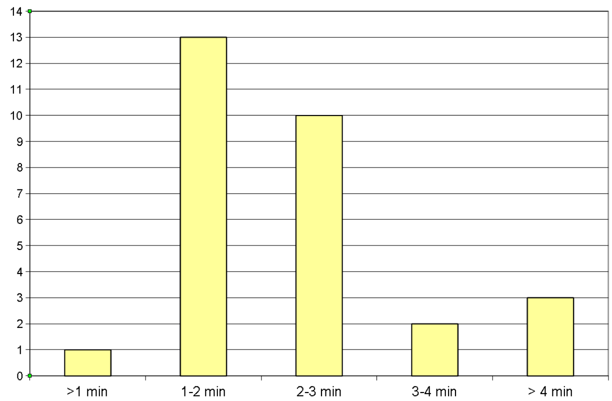


Figure 7.26: Number of users distributed over the time it took to define the spatial extent of the data-layer)

H2RQ2 Is there an identifiable connection between task completion time, the number of errors and the rate of interaction?

The finding of the RIV case-study about the correlation between rate of interaction and task completion time seems to apply to this case study as well. The five slowest users of the evaluation were among the six users who used between eight and 15 clicks using the navigation tools.

When we considered the errors that the users made during the evaluation we found two typical errors:

- users did not notice that they had to click on the shopping-basket in order to continue
- users did not select the appropriate number of zones. In four cases the users had selected too many zones (the task specified that the user needed to select three zones) and two users had only selected one or two zones.

In the analysis of the number of zones that users selected we detected an interesting problem. For each evaluation we compared the maximum number of zones that had been selected during the evaluation and the final number of zones that had been selected and "submitted". We discovered that nine users at some point during the evaluation had selected too many zones. Five out of these nine users noticed the error and corrected the problem (leaving four users who finally "ordered" too many zones). The interesting finding that we made from those users who had corrected the problem was that four out of these five users in fact used the spatial selection tool to select the zones (as shown in figure 7.21). We then analyzed the screen-shots videos of these users in order to find out why the users had selected too many zones. All four users in fact drew a rectangle to select the zones. The rectangle, however, selected all zones that were either entirely or partly within the rectangle, thereby selecting too many zones and the users had to remove the zones that were not required by the scenario.

Both problems that we detected (the shopping-basket and the selection of zones) resulted in an increased task-completion time and a higher rate of interaction.

H2RQ3 Which strategies result in better performance?

Previously when we addressed **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*) we found that 23 users had used the dialog-box tool to select zones; three users had used the spatial selection tools only and four users had used both selection tools. If we compare the task completion time for these three groups we can observe that the non-spatial dialog-box tool (145 seconds in average) to select the zones appears to be more efficient than the the spatial selection tools (246 seconds in average). Figure 7.27 visualizes the distribution of users according to their strategy and task completion time. The connection between task completion time and choice of tools is however more difficult to interpret due to the following reasons:

- One of the fastest users (third fastest) was using the spatial selection tools only; the use of spatial selection tools is thus not necessarily less efficient.
- The slowest user was using the dialog-box only
- As mentioned above one of the reasons why users, who were using the spatial selection tools, were slower was the fact that some had selected too many zones and were therefore required to delete several zones from the selection
- The spatial selection tool required the user to navigate the maps. As we have found in the discussion of **H2RQ2** (*Is there an identifiable connection between task completion time, the number of errors and the rate of interaction?*) more clicks resulted in increased interaction time.

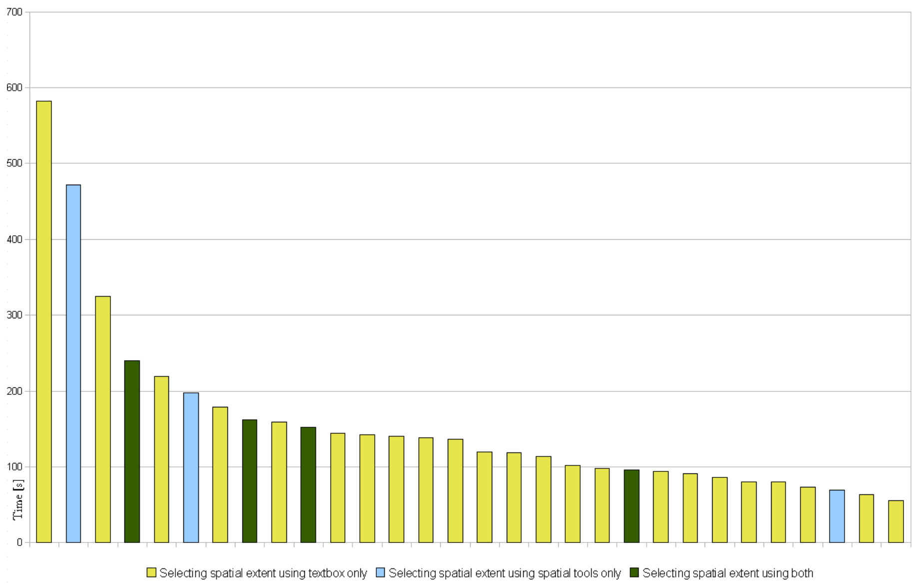


Figure 7.27: Number of users distributed according to the time to select the spatial extent and their selection strategy)

The non-spatial selection manner (using the dialog-box tool) however seems to be the safer method since fewer errors were made (selection of too many zones).

H3 User-related parameters have a significant influence on user performance, user strategies (spatial and non-spatial) and the perception of spatial features

H3RQ1 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their performance?

Due to the fact that all users were around 23 years old (+- 4 years) we did not consider our data sufficient for addressing the question of whether user's age could have an influence on the performance.

Concerning the parameters gender and task completion time (i.e. time to select the three zones) we found that the seven women were faster on average (95 seconds per user) than the male users (177 seconds per user). The difference between males and females was statistically significant with p=0.03. When we looked at the errors we noticed that three of the seven women did not select the correct number of zones (43% of the women did thus make an error). For men the error quota was 26%.

In the first questionnaire we asked the test-users how many hours per week they used a computer at home (0-2 hours, 2-4 hours, 4-6 hours, 6-10 hours, 10-12 hours, 12-14 hours or more than 14 hours). We then compared these answers to the task-completion time (assuming that users who are using their computers more during their free time would be faster), but we could not find a significant relationship.

H3RQ2 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their strategies?

In the first questionnaire, we asked the participants whether they had already used the following geospatial systems: Map Search[16], Map 24[17], Google Maps[18], Google Earth[19], Mappy[20], Geoplanet[21], Swissgeo[22] and SBB's mapping system[23] and if yes how frequently. The users could add other systems of the same type to the list and specify frequency of usage. Google Earth and Google Maps were the spatial systems that the test-users had used most. We then calculated an index based on the user's answers regarding these systems as follows:

- zero points if the user never had used the system
- one point if the user had used the system sometimes
- two points if the user had used the system often

[16] http://map.search.ch
[17] http://map.search.ch
[18] http://maps.google.com
[19] http://earth.google.com
[20] http://www.mappy.ch
[21] http://www.geoplanet.vd.ch
[22] http://www.swissgeo.ch
[23] http://www.sbb.ch

The addition of these points gave us an index of previous experience. Users who were frequent users of many systems thereby had a high index. This index was then compared with the strategies we had identified during the discussion of **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*). We found that users, who chose the dialog-box to select zones, on average had a geospatial systems index of 8.04, users who chose spatial tools had an index of 9 and users who were using both had an index of 9.25. However we cannot show a statistical significance of these differences since there were only three users in the group that used the spatial selecting tools and four users in the group that used both tools. Yet the result suggest that the previous experience of online geospatial systems has some influence on the user's interaction strategy. We therefore propose that the connection between these two parameters should be evaluated further.

H4 System-related parameters have an influence on user performance, user strategies (spatial and non-spatial) and perception of spatial features

H4RQ2 Is it possible to identify a connection between the system's graphical design, interaction design and map design, and user performance?

Concerning the system's graphical design and interaction design we used heuristics and guidelines (Nielsen's Ten usability heuristics (Nielsen, 1990) and Shneiderman's Eight Golden Rules of Interface Design (Shneiderman and Plaisant, 2009)) to identify a set of features that are likely to influence user performance:

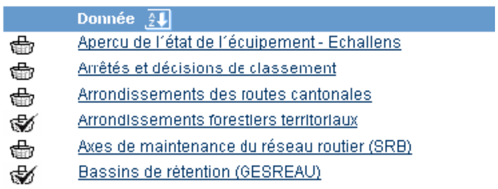
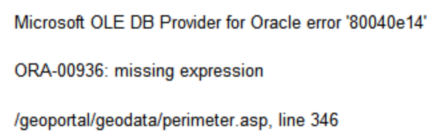


Figure 7.28: Selection of spatial data layers

Consistency: We analyzed the system according to its external consistency (i.e. towards other systems and standards) and internal consistency and found the following elements:

- Compared to other web-sites where users can order products or data, ASIT-VD's system uses graphical elements in a non-standard way. The HTML language for instance provides a set of standard graphical elements for making selections (e.g. checkboxes and radio-buttons). Instead, the ASIT-VD uses hyperlinks as elements for selecting the visualization of data-layer descriptions and meta-data in a new window (see figure 7.28 - the user clicks on a basket (to the left) in order to select a given data-layer. Selected data-layers are marked with a tick on the basket. A click on the data-layer's label (to the right) opens a new page displaying the description of the data-layer).

- The two components of the system's interface have different designs (both in terms of interaction design and graphical design). In the first component, where the user can choose the data-layer (see figure 7.17), the interface is conceived as a list that the user can modify, using different filters, and select the data layer. The second component of the interface, where the user selects the spatial extent of the data, is designed as a step-by step interface using tabs (see figure 7.18)
- In order to select a spatial extent the user needs to clicks twice: once on the tab that alerts the the user to define the spatial extent and once on an icon that actually opens the Java-applet that performs the selection.


Microsoft OLE DB Provider for Oracle error '80040e14'

ORA-00936: missing expression

/geoportal/geodata/perimeter.asp, line 346

Figure 7.29: Error message produced by the ordering system

System feedback and help: When we analyzed the error-handling in the system, we found error that some messages were not likely to help the user (e.g. figure 7.29). Moreover the system did not offer any complementary help (besides an instruction-manual for the Java-applet as a downloadable pdf-file).

These external consistency- and feedback-related issues are likely to influence performance due to the fact that the user may have difficulties finding the elements he is familiar with. Moreover, internal inconsistencies in the interface may have a disturbing effect on the user.

H4RQ3 Is it possible to identify a connection between the systems graphical design, interaction design and map design, and user interaction strategies (spatial and non-spatial)?

Although we found evidence that the user's previous experience with online geospatial systems might have influenced the strategy for selecting the three zones (using the dialog-box or the spatial selection tools), we argue that the choice of strategy could also be influenced by the system's graphical design and interaction design.

When the Java-applet, that is used to define the spatial extent, is loaded, the user sees (figure 7.19) the standard navigation tools on the upper left, the spatial selection tools (point, rectangle and polygon) in the upper middle, and a drop-down menu containing the data-layers, from which the user can choose a zone, in the upper right (e.g. municipalities). If the user chooses one of these data-layers, a message beneath the map alerts the user to choose a zone by clicking on the button "Add" (Ajouter in french) or by using the spatial selection tools. Clicking on the button "Add" leads the user to the dialog-box where the user can choose the zones. The fact that the option to use the dialog-box is mentioned first might have an influence on users' choice of strategy.

H5 User satisfaction depends on user-specific parameters

H5RQ1 Is there any evidence to suggest that users, depending on their age, gender, handedness, knowledge, skills and context are more or less satisfied?

In the second questionnaire, we asked users to rate the following elements on a scale from 1 (very unsatisfied) to 5 (very satisfied):

- Map design
- Map navigation
- The graphical design
- The design of the icons and buttons
- Relationship between the icons and buttons and the expected functionality of those elements
- Navigation in the system (excluding map-navigation)
- The manner in which the selection of spatial objects is implemented
- The logical design (the sequence of actions)
- System speed

When we calculated the average overall satisfaction rating for each user (by taking into account each element) we found that there is no significant relationship either between satisfaction and gender, or between satisfaction and previous experience with geospatial systems. Male users were on average slightly more satisfied (3.23) than female users (3.06), the difference was however not significant ($p=0.54$). Taking into account the index of previous experience of spatial systems, uwe found that sers having an index of ten and more (17 users) are on average less satisfied (3) than users having an index of less than ten (13 users, rating 3.44). The differences between the two groups were however not significant ($p=0.59$).

We compared the different measures of satisfaction to the different parameters specifying the user, but we did not find any evidence to suggest that specific groups of users are more or less satisfied.

H6 System-related parameters influence user satisfaction

H6RQ1 What is the connection between the systems' graphical design, interaction design, map design, the user's computer and user satisfaction?

When we analyzed the different measures of satisfaction, we were able to detect some differences (see figures 7.30 and 7.31):

- No user was very satisfied with the design of the buttons and icons and their expected functionality. Moreover five users commented on their rating of this feature, saying that the functionality behind the shopping-basket-icon did not meet their expectations.
- On the other hand the users seemed to be content with the graphical design of the system. This aspect of the system received the best rating.

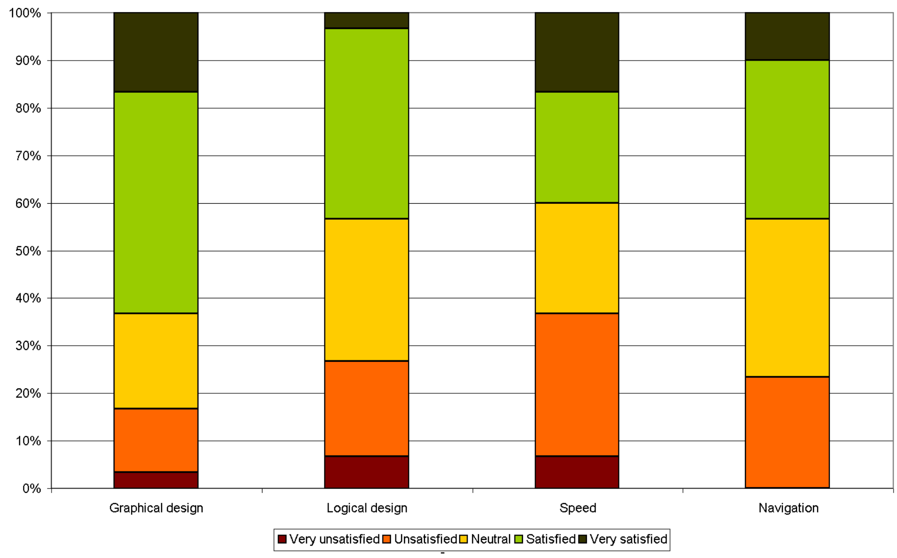


Figure 7.30: The user's satisfaction with specific elements

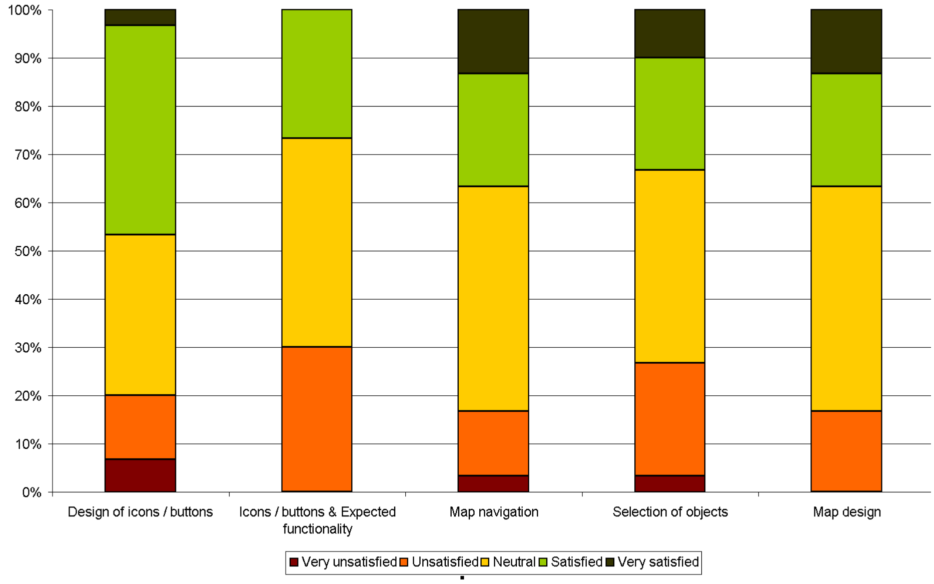


Figure 7.31: The user's satisfaction with general aspects

7.3.7 Summary of results

Considering our framework of parameters (see figure 4.2) we were able to find evidence for the following relations:

Parameter	Parameter influenced	Finding
Gender	Task-completion time	Female users were significantly faster than male users in selecting zones.
Knowledge and skills	Spatial interaction strategies	Contrary to the RIV case study, the "zoom-by marquee" tool did not cause any problems. The seven users who navigated the maps by zooming and panning did not encounter the same interaction problems as the participants of the RIV case study. We believe that this finding is correlated to the fact that the participants of this present case study were frequent users of desktop-GIS. In desktop-GIS the "zoom-by marquee" is a standard
Spatial interaction strategies	Errors Task-completion time	The manner in which users selected zones by drawing a rectangle caused errors. All zones that were either within the rectangle or intersecting with the rectangle were selected. As a consequence, the user had to remove unwanted zones. This problem resulted in an increased task-completion time
Rate of interaction	Task-completion time	We were able to find evidence that interaction rate and interaction time are related. This supports the findings of the RIV-case study where we found a similar correlation.
Interaction design	Spatial interaction interaction strategies Task completion strategies	There was little spatial interaction with the maps of the geospatial module. For the task to select spatial zones, the majority of participants preferred dialog-boxes over the spatial selection-tools. We believe that this preference is incited by the system's interaction design, especially by the order in which options were presented in the alert-message. In this message users were advised to either click on the button "Add" (which opens the dialog-box) or to use spatial selection tools. Another finding in this context is the interaction problem with a poorly designed icon symbolizing a shopping-basket. A majority of the users were not able to identify the icon's functionality, resulting in attempts to find alternate strategies to solve the tasks.
Interaction design	Satisfaction with the system's interaction design	The icon symbolizing a shopping basket was difficult to understand. This resulted in a decreased satisfaction with the system's interaction design.

Table 7.4: Summary of results. Evaluation of the spatial data ordering system

7.3.8 Conclusions

The evaluation of the spatial data ordering system provided some complementary findings to the RIV-case study. The participants who chose spatial interaction over dialog-boxes to select a zone did not encounter any difficulties in navigating the maps (contrary to the first case study). We conclude that the difference is strongly related to the fact that the participants of this second case study were used to spatial navigation and interaction.

Further, we have found that the gender-difference we detected (females were faster to complete the task) is consistent with the findings of Simon (2001) (described in chapter four, section 4.2.1) who claimed that males are better at spatial orientation tasks, whereas females are better at verbal or linguistic tasks. The option to select the zones through dialog-boxes (the option that most users chose) is not a task that requires spatial interaction but rather a linguistic task.

These two user-related findings demonstrate the importance of the user's profile in terms of knowledge and skills, but also demographic parameters, in determining the usability of online geospatial systems.

Regarding the method we used to evaluate the system, we have found that the tools, that we originally developed for verbal protocol evaluations of the RIV-system, can be extended to capture multiple (non-verbal) evaluations in parallel. One drawback of this extension is, however, that the work required to adapt the tool for a multi-evaluation setting is very time-consuming (development of the necessary tools to capture the interaction; preparation of the computers, data collection and data analysis). On the other hand the tools allowed for creating an evaluation environment which was at the same time non-intrusive to the user (e.g. no camera in front of the user), and allowed for collecting usable interaction-data.

7.4 Spatial interface for EPFL's online survey system

7.4.1 Context

At the Swiss Federal Institute of Technology in Lausanne (EPFL) online-surveys are frequently used to gather information about different topics that concern EPFL's staff and students. A recurring online survey is a survey about the staff's and student's mobility habits.

In order to facilitate the creation of such online-surveys, the school has developed a system called inForm[24]. The system allows its users to create new surveys, to send these surveys to the relevant target-group and finally to collect the responses. In principle, anybody can easily create a new questionnaire using the inForm system.

The inForm-system, however, has long lacked an important functionality that is frequently demanded by the administrators of online-surveys: in order to specify a location, users are required to write an address in a textbox. The addresses added by the users then have to be geo-localized manually by the administrators of such surveys before the data can be analyzed. The geo-localization task takes a considerable amount of time and effort. It was therefore proposed to develop a spatial module for the inForm-system. With this module, users would be enable to point out locations on a navigable map instead of providing addresses in a textbox. The locations would then be stored in a spatially enabled database.

7.4.2 System characteristics

After an analysis of the inForm's architecture we found that it was too difficult to develop the spatial module as an internal module of the system. We therefore decided to implement the module as a separate system that would be integrated in the questionnaire system as a pop-up fixed size window.

We implemented the system using the open-source frameworks MapServer, PostgreSQL/PostGIS, PhP and Javascript (also see section 3.3.3). The spatially enabled database PostgreSQL/PostGIS was used to store the coordinates of the locations the users had pointed out.

The interface (see figure 7.32) of the system was conceived in such a way that it offered several possibilities for navigation. Zooming in and out was possible through

- zoom buttons. (a single click zooms out/in, keeping the original center)
- the mouse wheel (moving the mouse wheel up or down zoomed in or out)
- fixed scales (nine choices indicated with blue bars; the actual scale was highlighted by a red color)

[24]http://inform-doc.epfl.ch

Figure 7.32: A screenshot of the mobility survey modules's interface

Panning was implemented as follows:

- a single click on the map pans it (setting the location as a new center)
- pan-buttons for panning were distributed around the map

The function of pointing out locations was implemented using the metaphor of “dropping a pin” on the map. A button named ”drop pin” invited the user to click on it. Once the user had clicked on the button, the mouse cursor transformed into a pin. After the user had clicked on the map, the pin stayed on the map and the mouse cursor changed back to its original appearance. At the same time a new button appeared at the bottom of the screen, requesting the user to confirm the location.

All elements (buttons, map, etc.) had tool-tips associated to them which appeared after one-two seconds of mouse-over, indicating what the user could do with the element.

The maps that our system displayed were topographical maps without any specific thematic overlay. The maps were obtained from the Swiss Federal Office of Topography, Swisstopo, and were originally based on the paper-maps at the scales 1:25’000, 1:100’000, 1:200’000, 1:500’000 and 1:1’000’000. The features that are shown on these maps can be categorized into:

- The terrain (with features such as mountains, waterbodies, rivers or forest; represented by areas of a certain color, lines of a certain color and place names)

- Inhabited places (e.g. villages or cities; represented by areas of a certain color and names)
- Infrastructure (for instance railways, roads; represented by lines and signatures of a certain color)

At the highest zoom level, the system displayed ortho images.

7.4.3 The test-users

The evaluation of the system was conducted as a remote online-evaluation. An email was sent out to 800 potential candidates using mailing lists (professors, students, assistants and EPFL staff). 331 persons responded by doing the evaluation and completing the questionnaires.

	<= 20 y.o.	21-30 y.o.	31-40 y.o.	41-50 y.o.	51-60 y.o.	Total
Male	82	140	5	0	1	228
Female	42	57	2	0	2	103
Total	124	197	7	0	3	331

Table 7.5: Distribution of users over age and gender

Out of these 331 users 228 were male and 103 female. 124 users were younger than 20 years old, 197 users between 21 and 30, 7 users between 31 and 40, and 3 users between 51 and 60 years (see table 7.5).

7.4.4 Evaluation setting

The users had the choice to do the evaluation in English, French or German. First the users were asked to complete a questionnaire with demographic questions (age, gender, etc) and questions about their computer skills and about their experience with similar web mapping systems such as Google Maps, Mappy or Map24.

After the questionnaire the users were required to point out two locations on the systems' map. The original map was centered on the city of Lausanne. The first location to point out was the EPFL (about 5 km outside Lausanne) and the second location was the train station in the city of Yverdon (about 40 km north of Lausanne). Figure 7.33 shows the locations of both targets.

After the evaluation, the users were asked to complete a second questionnaire with questions about their satisfaction concerning specific elements (e.g. the graphical design or the functionality). Users were required to rate different aspects according to their satisfaction.

7.4.5 Analytical methods

Before the system was integrated into the final questionnaire system, a major goal was to evaluate it with real-world users. This evaluation setting offered the

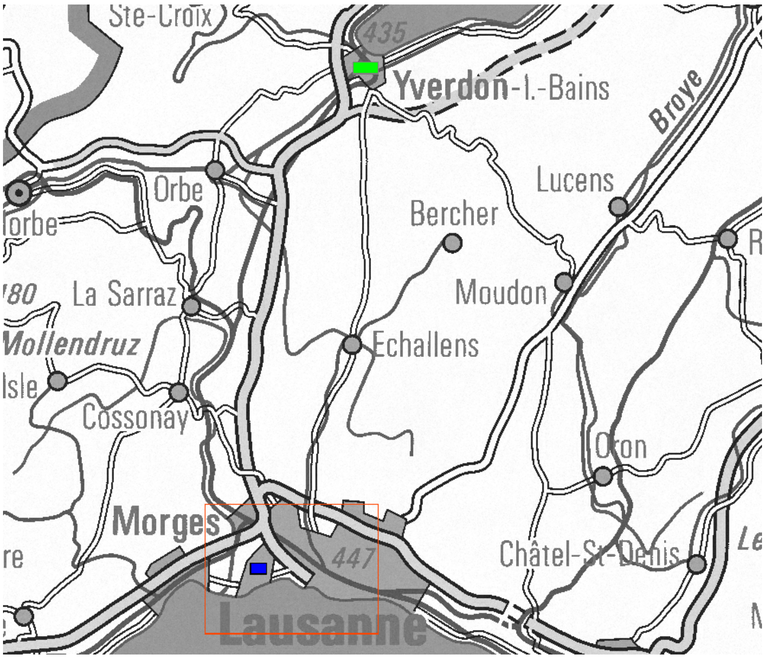


Figure 7.33: A map showing the initial region the system displayed (red frame), EPFL (blue square) and the station in Yverdon (green square)

possibility to not only test the system for its usability, but also to record and analyze the parameters described in our conceptual framework.

For the recording of the user interactions two tools were implemented:

- A tool that recorded the server's activity (the server that hosts the system)
- A tool that recorded the interaction with the client (the interface of the system loaded a web-browser)

The first tool was based on the log-file that was generated by the Apache web-server. In effect, the log-file contains all requests that the server receives, along with a time stamp.

To find out users' physical location at the time of the evaluation, we used IP to location databases (available freely on the Internet) and the host name to find this data. Users with fixed EPFL IP-addresses were classified as users with the highest bandwidth since they are directly connected to the hosting server (with speeds of 100mbit/s and more). Users with a Swiss ADSL or DSL connection were classified as users with a medium bandwidth. All other users (with a foreign Internet connection) were classified into a third category.

The second tool that records what the client is doing is a Javascript library that is loaded when the user accesses the online geospatial system. The tool

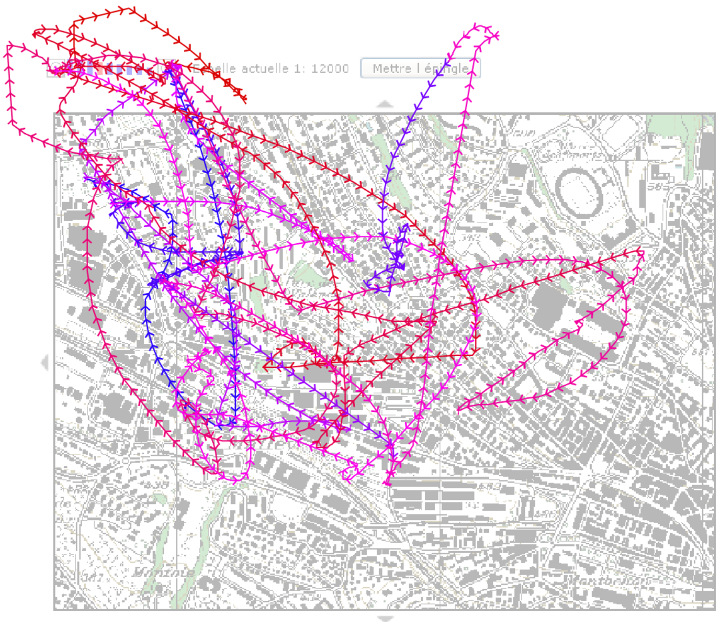


Figure 7.34: The cursor track of a user solving a task (higher speed = red color, lower speed = blue color)

samples the user's cursor position (in screen coordinates) and the pointing device's interactions (clicks and mouse-wheel movements) 40 times per second. The generated data is consecutively sent to a second server which stores it into a spatially enabled database.

When a user had finished their interaction with the online system, the data from the database was used to generate parameters such as the cursor speed, the cursor track length and the time spent on specific elements of the interface (e.g. the percentage of time spent on the map itself versus the time spent on the tools around)

With these two tools it was possible to re-generate the user's screen for any moment of interaction since the cursor position and clicks were recorded, and the map that the user was seeing could be re-created (all map-generating queries were recorded in the log-file). A sample of the data is given in Figure 7.34.

The data however required a certain amount of post-processing due to the following reasons: the data generated by the client included the time stamp from the user's computer system. The Apache web server however used the server's time stamp. In order to compare these two sets of data, the timestamps had to be compared and normalized. Another problem was that the screen coordinates recorded in Microsofts Internet Explorer (versions 6 and 7) were misaligned compared to all other browsers (about 5-10 pixels in both axes).

Therefore all sessions recorded with Microsofts Internet Explorer had to be post-processed separately (the browser type was recorded in the Apache-log-file) and re-aligned according to the other browsers.

7.4.6 Parameters collected

The different tools and questionnaires mentioned above enabled us to collect the following parameters relevant for our framework of parameters (see figure 4.2)

User characteristics: The first questionnaire enabled us to collect the following parameters:

- Gender
- Age
- Handedness
- Knowledge and skills (especially previous experience with similar systems, experience with geospatial information and computer use)

The log-file parsing tool was moreover used to detect factors that are related to the user's context:

- The user's physical location at the time of evaluation
- The language that the user utilized to fill in the questionnaires (English, French or German)

System characteristics: In addition to the general description of the system regarding the architecture, technologies, interaction design, functionalities and available maps (described in subsection 7.4.2), our log-file parsing tool enabled us to detect the following parameters related to the user's computer:

- Internet connection type (e.g. ADSL, DSL or EPFL direct connection)
- Operating system (e.g. Windows, Linux, Mac OS, etc.)
- Browser type (e.g. Mozilla Firefox, Safari, etc.)

Moreover in the first questionnaire we asked the user what pointing device type (e.g. wheel mouse, touchpad, etc.) was connected to their computer.

Interaction characteristics: Our log-file parsing tool enabled us to capture the following parameters for each user:

- The task completion time
- The rate of interaction
- What errors the user made during the evaluation (e.g. if the location that he pointed out was not the location specified in the task)

- Spatial interaction strategies (e.g. which navigation tools the user was using)

Furthermore the Javascript-library that recorded the users's cursor position, clicking and mouse-wheel interaction, was used to calculate measures such as the cursors' speed (in pixels per second). Moreover we used this tool to address the parameter "Interest in spatial features".

Satisfaction characteristics: In the second questionnaire users were asked about their

- Satisfaction with the system's graphical design
- Satisfaction with the system's interaction design (especially the logical design, and spatial navigation)
- Satisfaction with the access (especially system speed)
- general satisfaction

7.4.7 Results

First we tried to determine if user-specific parameters (such as gender, left-right handedness, etc) and the user's background have a significant influence on interaction performance and interaction behavior. Thereafter we analyzed if the system (especially parameters that are specific for the user's computer system) have an influence on the interaction. Then we analyzed if the user's background & demographic features and the system (especially parameters specific for the user's computer system) have an influence on satisfaction. Since many studies claim that there is no connection between user performance and user satisfaction we finally investigated if there is evidence to support this claim in our data.

For the comparison of different parameters we used two different statistical tests:

- The Wilcoxon rank sum test was utilized for the comparison of two measurement series classified according to a nominal parameter (e.g. task-completion time classified according to the gender). We chose this test since it is robust for comparing samples where there is no hypothesis on the distribution. The null hypothesis to be tested is that two populations are identical with respect to their medians. A p-value smaller than 0.05 rejects the null hypothesis at a significance level of 5% (Gibbons, 1985), meaning that the difference between the groups is significant.
- The χ^2-test was used for the comparison of two nominal parameters (e.g. the satisfaction according to gender). The null hypothesis states that there is no significant difference between the expected and observed values. If the p-value is smaller than 0.05 we reject the null hypothesis at a significance level of 5% and infer that the groups are significantly different. (Toutenburg, 2000)

H1 Users show different strategies during the interaction with a system

H1RQ1 Is it possible to distinguish different kinds of spatial interaction strategies?

There are two main kinds of spatial interaction manners implemented in our system: spatial navigation and digitization of points (pointing out locations). As mentioned above, the system offered a variety of tools to zoom and to pan the map. In order to answer the first research question we thus analyzed which navigation tools the users utilized during the two tasks. For this analysis we had generated interaction-diagrams (see chapter six, figure 6.5) for each of the participants (two examples can be found in appendix A, figures A.1 and A.2). These diagrams helped us to get an impression of the participants' strategies.

First we considered the use of tools to change the scale of the maps. Depending on the pointing device (e.g. a wheel mouse or a touchpad) there were two or three choices to zoom in or zoom out: the zoom buttons, the choice of fixed scales, and zoom using the mouse wheel. During both tasks we counted each click on each of the navigation tools and each mouse-wheel movement. The analysis of the data gave the following result:

- Most users (80% in task 1 and 76% in task 2) used just one set of tools to change the scale (e.g. just the zoom buttons - see table 7.6)
- The zoom buttons were the preferred (i.e. most frequently used) set of tools to change the scale for about half of the users (51% in task 1 and 50% in task 2 - see table 7.7) - followed by the mouse wheel and the scale choice list.
- 256 users (77%) had exactly the same preference for changing the scale in task 2 as they had in task 1.

	Task one		Task two	
	# of users	% of all users	# of users	% of all users
One set of tools	264	80%	250	76%
Two sets of tools	60	18%	79	24%
Three sets of tools	7	2%	2	1%

Table 7.6: Number of sets of tools used to change scale; both tasks

	Task one		Task two	
	# of users	% of all users	# of users	% of all users
Zoom buttons	169	51%	167	50%
Mouse wheel	88	27%	59	18%
Scale-choice	61	18%	93	28%
Neither	13	4%	12	4%

Table 7.7: Preference for a manner to change scale for both tasks

For the determination of a user's preference for a set of tools (such as zoom buttons) we counted the number of clicks that the user made using this tool. We were able to see that most users (80% in task one and 76% in task two) used just one set of tools. For all other users, however, we need to make the following observations about the tools:

- The different tools for changing the scale do not have exactly the same effect. A click on the scale-choice for instance can change the scale of the map from a very small scale to a very large scale with only a single interaction. The same change in scale, when made with zoom buttons, can demand several more clicks, depending on the current scale and the desired target scale. As a result, the determination of a user's preference for a tool by counting clicks can be biased if the user frequently used both the scale-choice and the zoom buttons.
- As already mentioned, some users did not have a wheel-mouse at hand, which means that even if a user would have preferred to use the mouse wheel to change the scale, he could not choose this option.

In terms of tools for moving the map, the system implemented two possibilities: either by clicking directly on the map and thereby making that point the new center, or by clicking on the four pan-buttons (north, west, east, south) around the map. When we analyzed the usage of the two tools we found that:

- 219 users (or 66% of all users) used just one tool to move the map in task one. In task two, 112 users (or 34% of all users) used both possibilities to move the map (the pan-buttons and clicking on the map).
- 264 users (or 80% of all users) preferred clicking on the map in task one, but in task 2 only 179 users (or 54% of all users) had this preference for moving the map.
- 202 users (or 61% of all users) had the same preference for moving the map in task one and two. 129 users (or 39% of all users) changed their preference between the tasks.

If we now compare the combined use of tools for changing the map scale and moving the map (see tables 7.8 and 7.9)we can state that:

- The zoom buttons and clicking on the map was the preferred combination of tools to navigate the maps
- In task one the mouse-wheel combined with clicks on the map was preferred by every fifth user. In task two about the same number of the users preferred the combination zoom buttons and pan-buttons.

At this point we need to make a similar remark that we made concerning the tools that are used to change the scale of the map: the different tools to move the map do not have the same effect. A click on the map (and thus re-centering it) has not necessarily the same effect as clicking on the pan-buttons around the map. With the pan-buttons, the map can be moved in four directions

	Pan buttons	Recenter	Neither
Zoom buttons	22 (7%)	141 (43%)	6 (2%)
Mouse wheel	10 (3%)	67 (20%)	6 (2%)
Scale-choice	9 (3%)	46 (14%)	11 (3%)
Neither	2 (1%)	10 (3%)	1 (0%)

Table 7.8: Preferences for combinations of tools in task 1 (number of users; % of all 331 users)

	Pan buttons	Recenter	Neither
Zoom buttons	65 (20%)	91 (27%)	11 (3%)
Mouse wheel	20 (6%)	32 (10%)	7 (2%)
Scale-choice	35 (11%)	49 (15%)	9 (3%)
Neither	4 (1%)	7 (2%)	1 (0%)

Table 7.9: Preferences for combinations of tools in task 2 (number of users; % of all 331 users)

only (north-east-west-south). If a user wants to move the map diagonally, for instance towards north-east, he needs to do it with two clicks on the pan buttons. Moreover a click on the pan-buttons always moves the map a fixed amount of pixels. A click using the recenter tool can move the map a variable amount of pixels.

H1RQ2 Is there any evidence to suggest that the user's perception of spatial features influences spatial interaction strategies.

As described in chapter six, section 6.4.4, any action the user takes (such as moving the map or changing the scale) depends on the spatial features the user perceives on the map. From a cognitive point of view, the user utilizes these spatial features to orientate himself and to get a sense for the scale of the map.

Our research question thus relies on the hypothesis that if the information displayed by an online geospatial geospatial system does not have a relation to the real world, the interaction with the system is different than if the information does relate to the real world. Since the geospatial information displayed by the system is derived from the real world, also the navigation on a geospatial system's maps must have a relation to the perception of geospatial features.

In order to discover which spatial features were perceived by the user (which in turn may have led to the decision to navigate in a certain direction or at a certain scale) we base our analysis on the assumption that a user's eyes follow the pointing devices' cursor. As a justification we use the results of several researchers (such as Cooke (2006) and Chen *et al.* (2001)) that have found that the correlation between these two movements is about 69% - 75%.

With our pointing-device capturing tool (described in section 7.4.5) we were able to sample the user's cursor in screen coordinates (at a rate of about 15

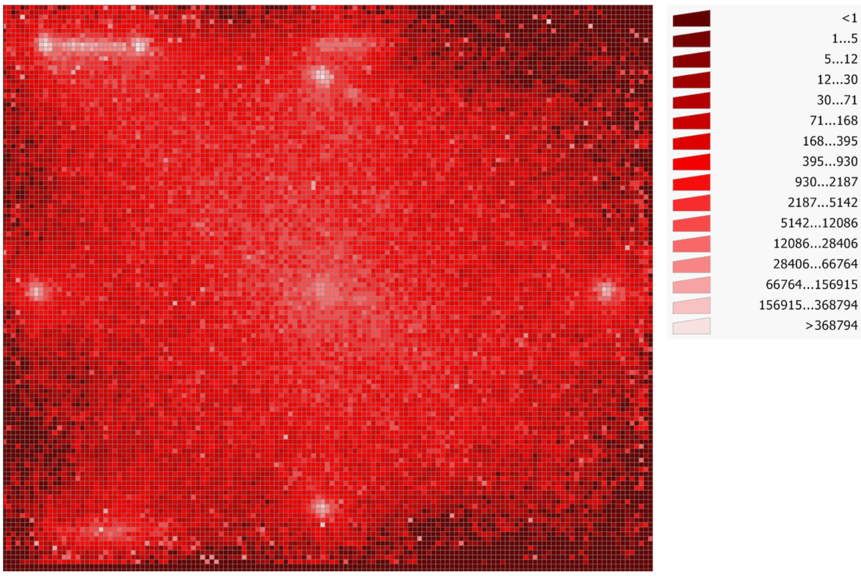


Figure 7.35: The density of points captured by the pointing-device capturing tool for all users for a grid of 5x5 pixels per cell; task two

samples a second). For each unit of time in each of the two tasks we were thus able to quantify on which of the interface features (the map or the buttons and icons around the map) the user had placed the cursor of their pointing device. Figure 7.35 shows the regions in which users spent most time. The different navigation tools stand out clearly.

To address the perception of spatial features, we introduce a measure that we use as an indicator of interest of particular spatial features: the percentage of the total task time a user spent with his cursor on the map (and not on the tools around the map). The choice is based on the following assumptions:

- if a user spends a relatively high amount of time on the map he focuses more on the map and its contents.
- if a user spends a relatively high amount of time on the map he interacts more with the map (e.g. clicking on the map)

Here we need to mention that a user's cursor is not necessarily moving over the map the whole time; as figure 7.34 shows, the cursor alternates between the map and navigation tools.

For the computation of this relative time we counted the milliseconds users spent with their cursors on the map and outside the map. For each user and task we then calculated the percentages. Table 7.10 shows the number of users having spent a certain percentage of their interaction-time on the map.

An explanation for the high percentage of time spent on the map can be found in a phenomenon that we discovered for a random selection of users: Users seem to slow down their cursors while moving towards the map (e.g. after having clicked on one of the interface features such as the pan-buttons, the zoom buttons, the scale choice list or the button to put the pin). On the other hand users tend to be quicker in moving the mouse cursor away from the map when planning to click on the tools. Figure 7.34 shows an example of this behavior.

Percentage of task time on the map	# of users task 1	# of users task 2
0% -19.9%	0 (0%)	3 (1%)
20%-39.9%	3 (1%)	4 (1%)
40%-59.9%	16 (5%)	29 (9%)
60%-79.9%	105 (32%)	117 (35%)
80%-100%	207 (63%)	178 (54%)

Table 7.10: Distribution of users over percentages of interaction time spent with the cursor on the map; both tasks (percentages of all users in brackets)

A first approach for answering **H1RQ2** was thus the comparison of the two parameters "preference for a combination of tools" and "percentage of the interaction on the map". Tables B.1 and B.2 in appendix B show the results of this comparison for both tasks. It becomes evident that users who used the pan-buttons to move the map spent less time with their cursors on the map then users who clicked on the map to recenter it. The χ^2 test for both comparisons was significant with p=1.40E-007 for the first task and p=5.47E-008 for the second task.

The fact that a user spent a certain amount of time with his cursor on the map is however not a proof for the perception of specific spatial features - the measure of % cursor-time on the map can (to a certain degree) only be used as an indicator of how much users interact with the spatial information.

In order to find evidence for the fact that specific spatial features lead to certain navigational decisions, we tried to find out which geospatial features the user focused on while navigating the map. Since we also recorded the spatial extent (in the Swiss coordinate system) of the map the user was viewing at any given time (at a precision of one second using our log-file analyzing tool, described in section 7.4.5) we were able to translate the user's cursor position from screen coordinates into the Swiss map coordinate system. By doing this we were able to see over which regions (in the real world) each of the 331 users was moving his pointing device cursor.

Figure 7.36 shows the users' cursors remapped into real coordinates for the first task. The density of points is very high in the target area compared to the density in the surroundings.

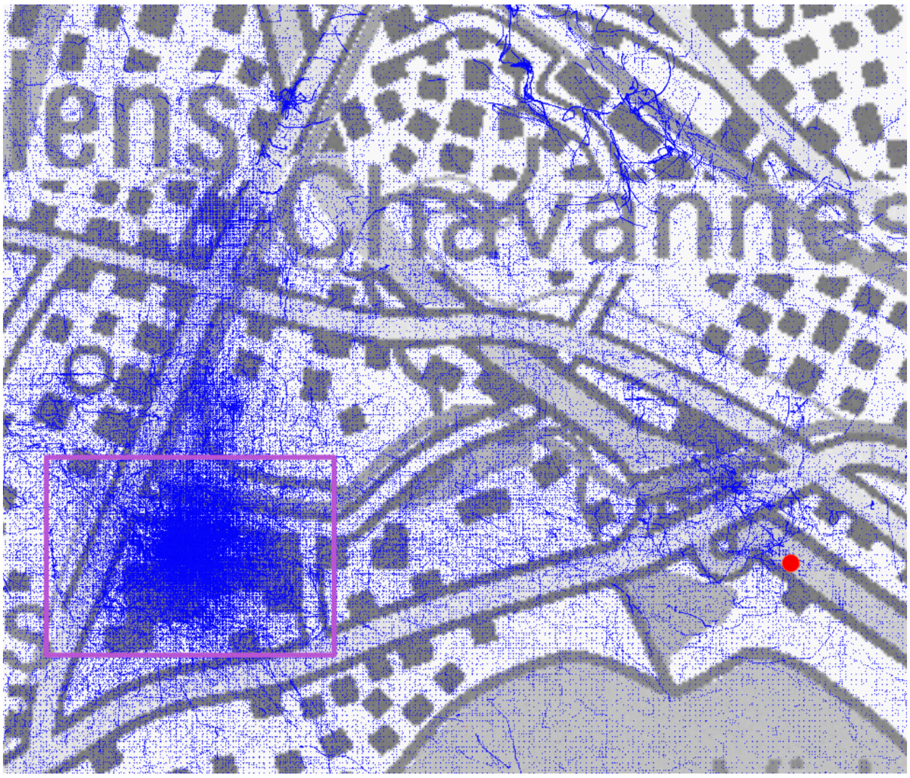


Figure 7.36: The users' cursors translated into real coordinates (task 1). The purple square is the target area (EPFL); the red point is the center of the initial map that all users view at the beginning of the task.

We were able to identify at least five users who followed infrastructures such as roads or tramway lines to navigate on the map. Figure 7.37 shows an example of a user who follows the tramway line from the closest train station in Renens to EPFL. More examples are found in appendix A (Figures A.3, A.4, A.5 and A.6).

Figure 7.36 visualizes the users' cursors remapped into real coordinates for the second task. Also here we can clearly see that the density of points is very high in the target area compared to the surroundings. Another interesting finding is that most users seem to first focus their navigation on north and then east when navigating towards Yverdon (Yverdon is north-east of Lausanne). This is the same way the major infrastructure (railroad and motorway) are built between Lausanne and Yverdon (first north, then east). For figure 7.39 we calculated the density of points captured by our tools and remapped into Swiss map coordinates in the Swiss projection system per square kilometer.

In the captured data we found evidence to suggest that the way users navigate the maps is influenced by spatial features. We were able to identify at least five users who seem to follow the infrastructure (such as roads or tramway

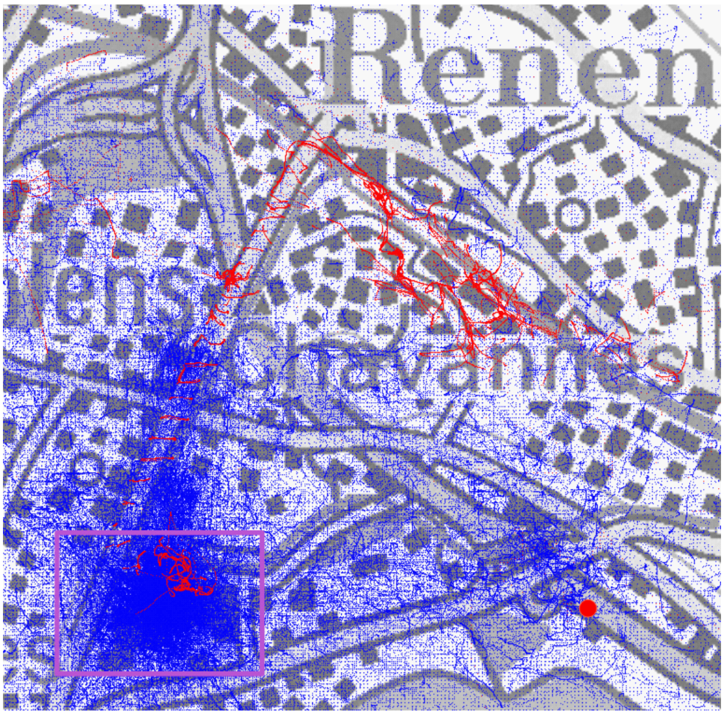


Figure 7.37: A user's cursor positions in task 1 highlighted in red color (example 1).

lines) to reach the target. This evidence also suggests that their spatial navigation strategies (the decisions to move the map towards a certain direction or to change the scale) highly depend on the perception of the spatial features displayed.

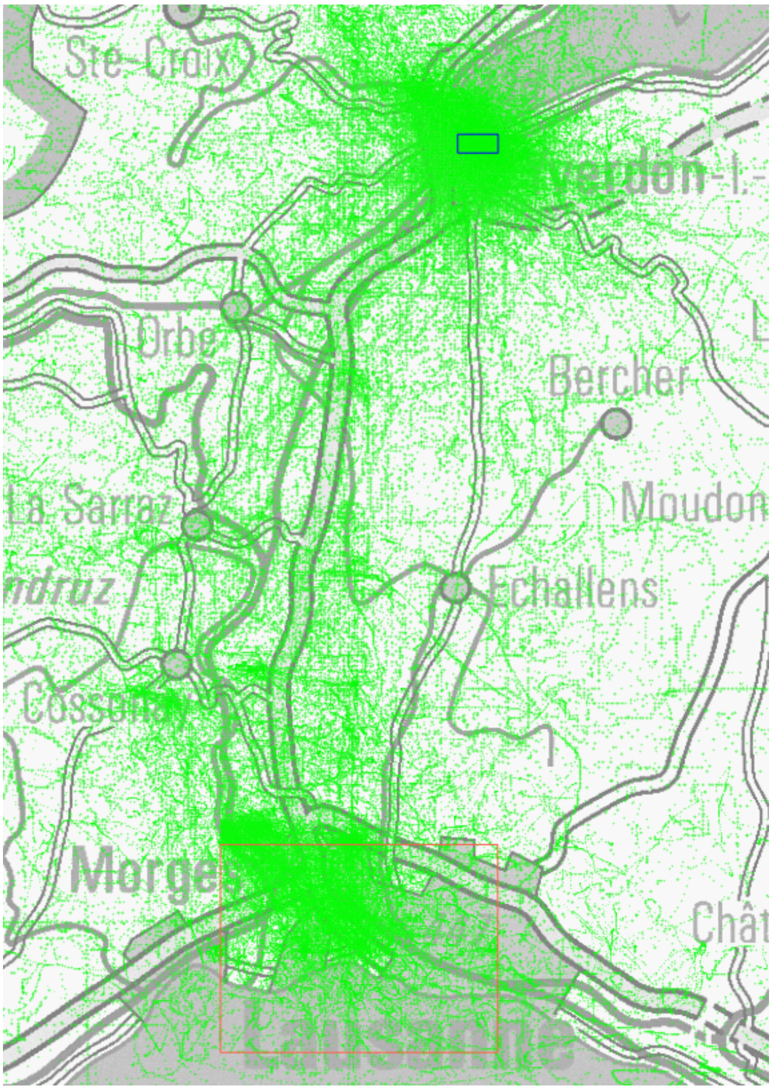


Figure 7.38: The users' cursors translated into real coordinates (task 2). The blue square is the target area (the train station in Yverdon); the red square is the bounding-box of the initial map that all users viewed at the beginning of the task.

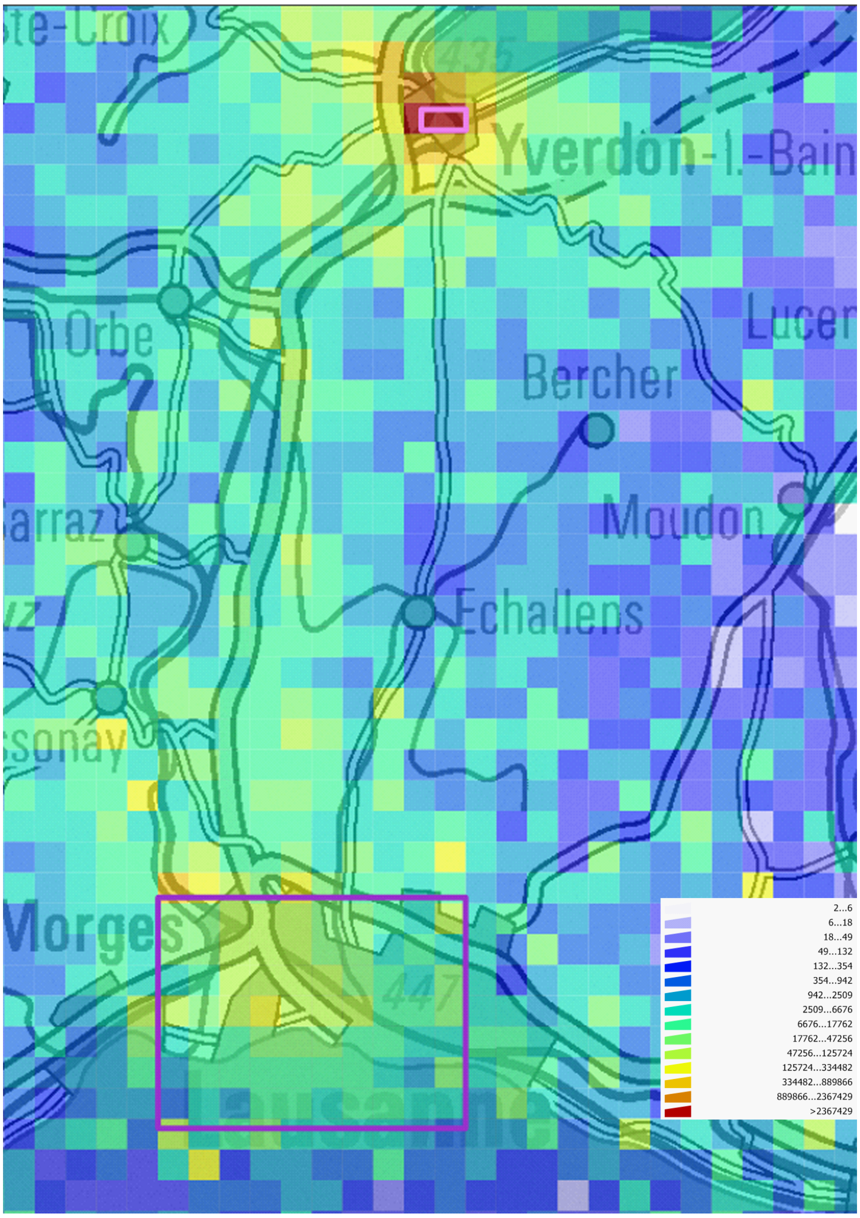


Figure 7.39: The density of cursor points per square kilometer. The pink square is the target area (the train station in Yverdon); the purple square is the bounding-box of the initial map that all users viewed at the beginning of the task.

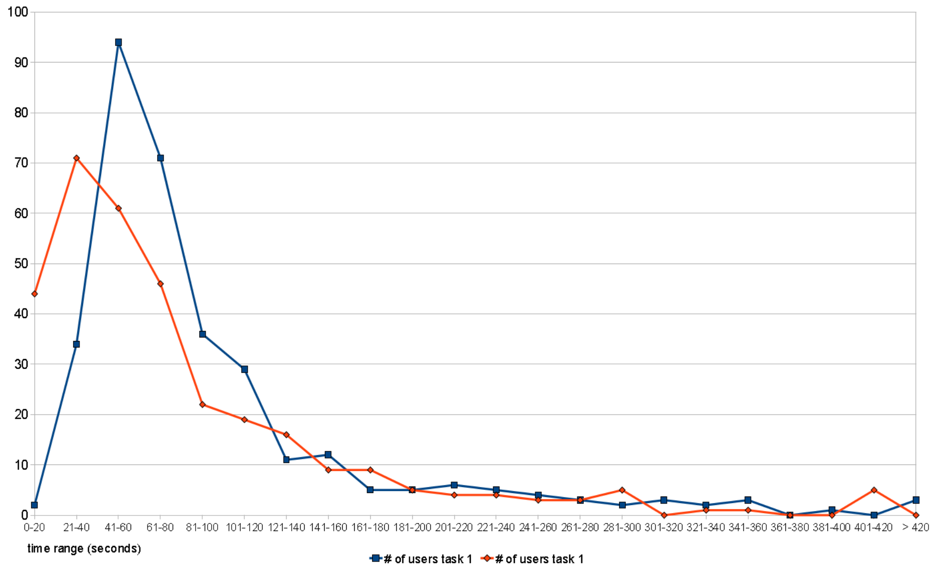


Figure 7.40: Distribution of users over task completion time (task 1 and 2)

H2 Users perform differently when interacting with a system

H2RQ1 Are there differences in task completion time, rate of interaction and rate of errors?

We have categorized the users according the time it took to complete task 1 and task 2. As shown in figure 7.40 it took between 21 and 40 seconds for the majority of users to complete task 1 and between 41 and 60 seconds to complete task 2. The average time for task 1 was 98.95 seconds. Although task 2 required the users to navigate much farther than task 1, the average time for task 2 was 103.63 seconds. It is also noteworthy that 13 % of the participants managed to complete task 2 in less than 21 seconds. The largest groups of users needed between 21 and 60 seconds (40% of all users).

Concerning the number of interactions (clicks on the interface or mouse-wheel movements) it took to complete the first task we found that 46% of all users used 5-9 interactions; the other two large groups were users who used less than four interactions and users who used between ten and fourteen interactions (see figure 7.41). The average number of interactions for the first task was 10.69.

110 users or 33% of all users used between ten and fourteen interactions to solve the second task. The other large groups of users were those with between five and nine interactions and those between 15 and 19 interactions. Due to the larger distance to the target (compared to task 1), the average number of interactions was 16.34.

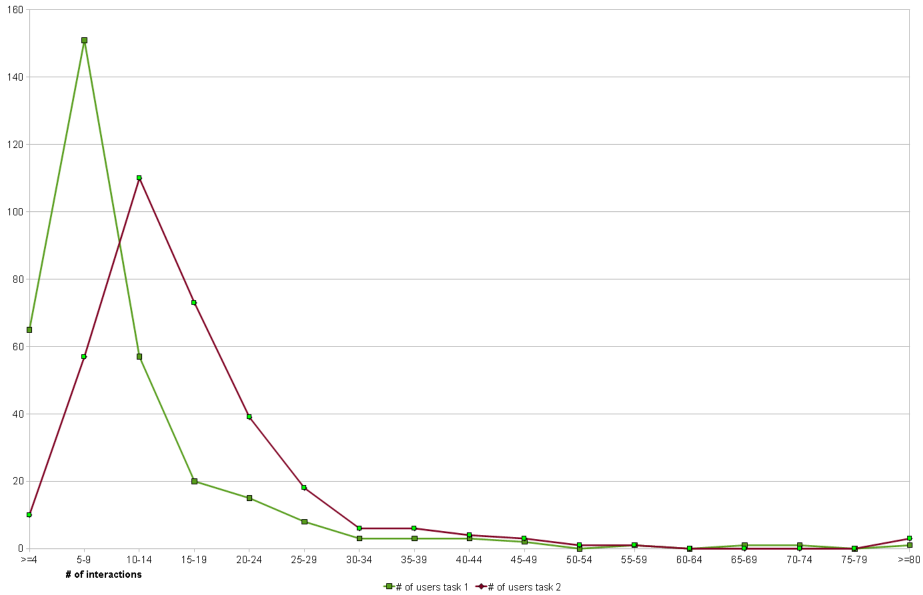


Figure 7.41: Number of users distributed over the number of interactions made to complete task 1 and 2

Regarding errors we counted how many users correctly pointed out the targets in task 1 and 2. In task 1 there were 37 users (or 11% of all users) who failed to point out the EPFL (only the last location pointed out by the user was taken into account). In task 2, 30 users (or 9% of all users) failed to point out the train station in Yverdon. Figures 7.42 and 7.43 show all locations pointed out by the users during the first and the second task.

H2RQ2 Is there an identifiable connection between task completion time, the number of errors and the rate of interaction?

First we compared the number of interactions with the task completion time. For both tasks the correspondence was significantly high ($p \leq 2.33$ E-105 for the first task and $p \leq 3.83$ E-102 for the second task). This high significance is (as we also discovered in the previous two case studies) highly related to the fact that each click or mouse-wheel movement results in a new map. The processing of a map in the spatial interface for EPFL's online survey system takes about 0.5 - 1 seconds. Moreover the user needs to interpret the new map and update the strategy to solve the task.

We compared the interaction time of the 37 users (11% of all users) who failed to point out EPFL during the first task and the 30 users (9% of all users) who did not manage to locate the train station in Yverdon in the second task. Table B.5 in appendix B shows this categorization and the percentages of users who failed among all users within the same category.

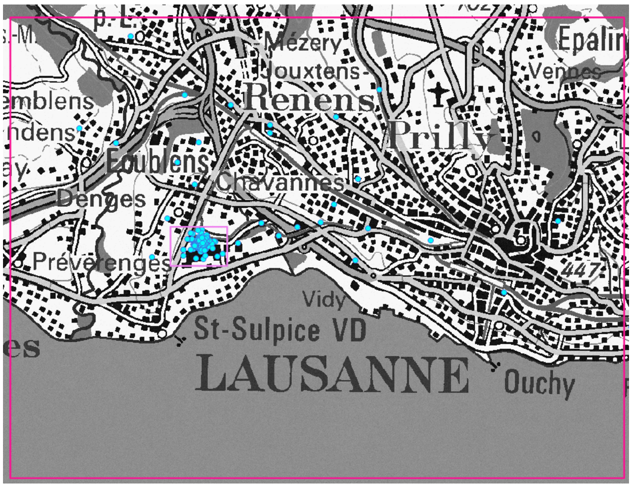


Figure 7.42: Locations pointed out as EPFL (task 1)

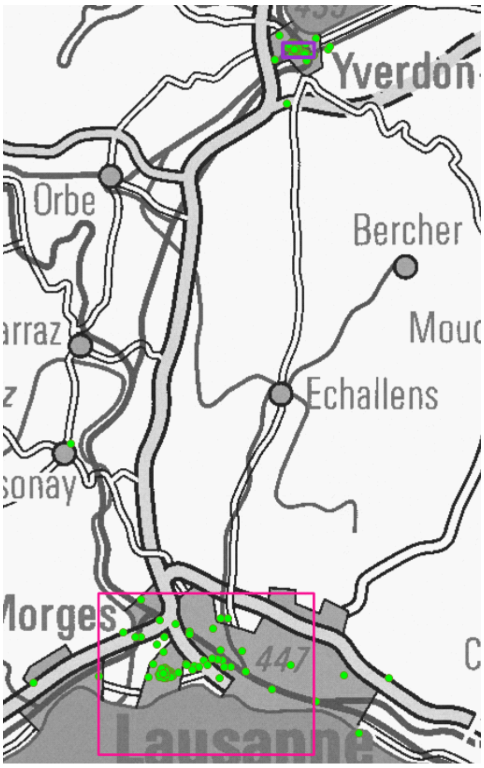


Figure 7.43: Locations pointed out as the train station in Yverdon (task 2)

- Users with a long interaction time (more than 160 seconds per task) were more inclined to fail the task than users with a shorter interaction time (less than 160 seconds per task). The percentages of "slow" users who failed are in all categories higher than 20%.

- The high number of users who had a very short interaction time (up to 40 seconds) and failed on task 2 indicate that many users gave up the task at an early stage and pointed out a random location.

H2RQ3 Which strategies result in better performance?

Previously when addressing **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*) we established a set of user categories according to users' preference for combining tools for zooming and moving the map. To answer the current research question, we thus compared these categories to the time it took to complete task 1 and 2. Table 7.11 shows the results of this comparison. We found that users who preferred the pan-buttons around the map were slower than users who either preferred the recenter tool or who had no preference for a tool. We compared the statistical significance (see table B.3) for the relationship between task-completion time and the preference for tools in both tasks (only users with clear preferences were taken into account). For the first task the relationship was not significant, but for the second tasks certain comparisons were significant. For task 2 we can thus say that:

- Users who preferred the combination of zoom buttons to change the scale, and click on the map to move, were significantly faster than users who used the combination of zoom buttons and pan-buttons.

- Users who preferred the combination of scale-choice to change the scale, and click on the map to move, were significantly faster than users who used the combination of zoom buttons and pan-buttons.

- Users who preferred the combination of mouse-wheel to change the scale, and click on the map to move, were significantly faster than users who used the combination of zoom buttons and pan-buttons.

- Users who preferred the combination of zoom buttons to change the scale, and click on the map to move, were significantly faster than users who used the combination of mouse-wheel and pan-buttons.

- Users who preferred the combination of scale-choice to change the scale, and click on the map to move, were significantly faster than users who used the combination of mouse-wheel and pan-buttons.

- Users who preferred the combination of mouse-wheel to change the scale, and click on the map to move, were significantly faster than users who used the combination of mouse-wheel and pan-buttons.

	Time				Rate			
Preference	**#U**	**Task1**	**#U**	**Task2**	**#U**	**Task1**	**#U**	**Task2**
ZB and P	22	103.27 s	65	143.2 s	22	12.45	65	19.51
ZB and R	141	100.43 s	91	82.98 s	141	10.04	91	14.79
ZB and NP	6	65.17 s	11	66.55 s	6	6.83	11	11.09
SC and P	9	106.22 s	35	112.77 s	9	15.56	35	19.74
SC and R	46	96.41 s	49	90.33 s	46	9	49	14.67
SC and NP	6	111.67 s	9	82.56 s	6	9.83	9	9.44
MW and P	10	126.5 s	20	144.6 s	10	16.6	20	20.6
MW and R	67	104 s	32	93.53 s	67	12.72	32	17.31
MW and NP	11	55.64 s	7	36.14 s	11	7.73	7	8.71
NZ and P	2	91 s	4	253.75 s	2	11.5	4	19.25
NZ and R	10	81.1 s	7	54.14 s	10	6.9	7	9.14
NZ and NP	1	31 s	1	62 s	1	0	1	8

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table 7.11: Preference for zooming and moving the map in relation to task-completion time and rate of interaction (task 1 and 2)

The reason why the comparisons did not yield any significant results for the first task can be found in the fact that the task required relatively few interactions. On the other hand it appears that the strategy to move the map using pan-buttons (regardless of preference for tool to change the scale) results in longer interaction-time than strategies not involving pan-buttons. This result is consistent with the findings of You *et al.* (2007) who point out that pan-buttons that are distributed around the map require the user to move the mouse pointer more than for instance pan-buttons that are grouped in one place.

After the comparison of interaction strategies and task completion time we compared interaction strategies with the rate of interaction. As table 7.11 shows the results are very similar to the results of the previous comparison between interaction strategies and task completion time. However there is one interesting difference: Users who used the mouse-wheel to zoom in and out made significantly more interactions than other groups (especially the group that preferred mouse-wheel and pan-buttons). Yet this result can be explained by the fact that each latching of the mouse-wheel is registered as an interaction by our Javascript-library.

Out of these two comparisons we draw the conclusion that

- clicking on the pan-buttons results in more interactions and a longer interaction time. This result is consistent with the observation that we made for **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*) where we found that the different tools' effect is not the same (e.g. moving the map towards the direction North-East requires two clicks on the pan-buttons, but only one click on the map).
- using the mouse-wheel to zoom in or out results in more interactions reg-

istered by system, but not necessarily in a shorter task-completion time.

When addressing **H1RQ2** (*Is there any evidence to suggest that the user's perception of spatial features influences spatial interaction strategies?*) we have found that users spent different percentages of time with their cursors on the map. To answer the current research question, we thus analyzed if this behavior could influence the task completion time. The results in table 7.12 suggest that the task-completion time decreases with an increasing percentage of time spent on the map (especially in the second task). An analysis of statistical significance showed that the differences between groups in task 1 were not significant. For the second task (see table B.3) the comparisons between the groups showed that the 29 users (9% of all users) having spent between 40% and 59.9% of the task-time with their cursors on the maps were significantly faster than the three users (1% of all users) having spent between 0% and 19.9% on the maps, but significantly slower than the 117 users (35% of all users) who spent 60%-79.9% of their time on the map, and the 178 users (54% of all users) who spent 80% - 100%.

For these 29 users we also analyzed whether they preferred specific sets of tools to navigate the map. The theory was that the choice of tools could have influenced users to spend less time on the map. Yet we were not able to identify any relationship between the choice of tools and time spent on the map (e.g. 13 out of these 29 users preferred to click on the map to recenter it).

The percentage of time that users spent on the map using their cursors was also compared to the number of interactions. The result of this comparison was very similar to the previous one concerning task-completion time. For the first task we did not find any statistically significant relationship; for the second task we found that interaction rate decreases with an increasing percentage of time spent on the map (see table B.4). This result however is not surprising since the task-completion time is highly related to the number of interactions (see section about **H2RQ2** (*Is there an identifiable connection between task completion time, the number of errors and the rate of interaction?*)).

	Time				**Rate**			
Percentage	**#U**	**Task1**	**#U**	**Task2**	**#U**	**Task1**	**#U**	**Task2**
0%-19.99%	0	0 s	3	270 s	0	0	3	14
20%-39.99%	3	138 s	4	140.75 s	3	15.67	4	13
40%-59.99%	16	103.44 s	29	126.83 s	16	8.13	29	19.21
60%-79.99%	105	96.55 s	117	110.08 s	105	11.6	117	18.34
80%-100%	207	99.26 s	178	91.97 s	207	10.36	178	14.66

Table 7.12: Average task-completion time and rate of interaction per user in relation to time spent on the maps with mouse cursor (task 1 and 2)

H3 User-related parameters have a significant influence on user performance, user strategies (spatial and non-spatial) and the perception of spatial features

H3RQ1 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their performance?

In order to answer **H3RQ1** we first compared our parameters for user performance (task completion time, rate of interaction and errors) with the demographic parameters age, gender and handedness. Table 7.13 shows the results of these comparisons and table B.6 the statistical significance of these comparisons. For the parameter "errors" we did not find any statistically significant differences between the groups.

		Time		Rate		Errors	
Parameter	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
Male	228 (69%)	86.75 s	89.69 s	10.07	14.32	0.11	0.09
Female	103 (31%)	125.96 s	134.49 s	12.06	20.8	0.1	0.09
Lefthanded	38 (11%)	98.92 s	112.21 s	13.16	17.32	0.18	0.08
Righthanded	293 (89%)	98.96 s	102.52 s	10.37	16.21	10.37	16.21
≤ 20 y.o.	124 (37%)	119.23 s	125.08 s	12.21	17.48	0.08	0.14
21 - 30 y.o.	197 (60%)	86.88 s	92.73 s	9.85	15.97	0.12	0.07
31 - 40 y.o.	7 (2%)	67.71 s	48.43 s	6	9	0.14	0
41 - 50 y.o.	0 (0%)	0 s	0 s	0	0	0	0
51 - 60 y.o.	3 (1%)	126.67 s	61.67 s	14	10.33	1	0
≥ 61 y.o.	0 (0%)	0 s	0 s	0	0	0	0

Table 7.13: Demographic parameters and user performance (task-completion time, rate of interaction and errors) (task 1 and 2)

Interestingly the 124 youngest users (younger than 20 years) were the slowest users to complete task 2, and second slowest to complete task 1 (only the three users between 51 and 60 years were slower). The difference to the the group 21-30 years was significant for both tasks (see table B.6 in appendix B). A very similar result can be found for the parameter rate of interaction. The fact that the youngest users were the slowest group of users might be related to the fact that they have less experience with similar systems and applications. We will investigate this question further later in this section.

A significant difference was noticed between the parameters task completion time, rate of interaction and gender of participant. The 228 male users spent an average of 86.75 seconds on task 1 and 89.69 seconds on task 2. Female users (103 users) however had an average of 125.96 seconds for the first task and 134.49 seconds for the second task. This difference stands in contrast with the result we obtained in the second case study. In that case study female users were faster than male users.

The parameter right- and left-handedness did not have any statistically significant influence on task completion time, rate of interaction and errors.

After the analysis of demographic parameters we wanted to find out whether the user's skills and knowledge had an influence on performance-parameters.

In the previous two case-studies we found that the user's experience with similar systems has an influence on the way users interact with a system they had never used before. In the current case study we therefore asked participants about their previous experience with geospatial systems and geospatial information:

- If they use paper maps (never, rarely, sometimes, often or very often)
- If they have used GPS (global positioning system)-based navigation systems
- If they have used a geographical information system (GIS)
- If they have used one of the following systems, and if yes, how many times (sometimes or often): Map24[25], MapSearch[26], Google Maps[27], Google Earth[28], Mappy[29], Swissgeo[30], GeoPlanet[31] or two other systems of this kind that the user could add to the list.

Moreover we asked the users how they would estimate their computer skills (very bad, bad, fair, good, very good).

The first parameter that we compared to user performance was the user's paper map usage. Only 14 users answered that they had "never" used them. The majority of users (155 users) answered "sometimes" (see table 7.14). The comparison with our performance parameters "task completion time", "rate of interaction" and "errors" showed no clear evidence that frequency of paper map usage is connected with performance (see table B.7 in appendix B). The statistically significant differences that we did detect were that

- users who use paper maps often are faster than users who use paper maps very rarely
- users who use paper maps very often make fewer interactions than users who never use paper maps
- users who use paper maps rarely make fewer interactions than users who use paper maps often

Regarding errors we did not find any statistically significant differences between the groups.

[25] http://www.map24.com
[26] http://map.search.ch
[27] http://maps.google.com
[28] http://earth.google.com
[29] http://www.mappy.com
[30] http://www.swissgeo.ch
[31] http://www.geoplanet.vd.ch

		Time		Rate		Errors	
Estimation	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
Never	14 (4%)	89.86	98	12.07	15.21	0.14	0
Very rarely	48 (15%)	124.65	143.25	13.27	17.65	0.08	0.1
Sometimes	155 (47%)	97.54	101.09	10.74	16.72	0.13	0.12
Often	95 (29%)	87.83	87.03	9.61	14.92	0.09	0.06
Very often	19 (6%)	107.95	111.37	8.16	17.84	0.11	0.05

Table 7.14: User-estimated map usage and user performance (task-completion time, rate of interaction and errors) (task 1 and 2)

Next we analyzed whether users' previous usage of similar systems had a significant influence on performance. Although the systems for which the users had to specify their experience were different in terms of their functionality, interaction design and available data, we decided to create a previous-experience-index that reflects the overall usage of these systems. We therefore translated the answers that participants gave into a three point scale:

- 0 points if the user never has used the system
- 1 point if the user has used the system sometimes
- 2 points if the user has used the system often

The index for each participant was thus the sum of these points. The system that received the highest amount of points was Google Maps (on average 1.37), followed by Google Earth (1.19) and MapSearch (0.96). Figure 7.44 shows the average points for all systems.

The highest possible number of points for each user was thus 18 (if the participant was a frequent user of all systems). We grouped the users in five groups:

- $I \in [0, 2]$: Users who have very rarely used similar systems (9% of the users)
- $I \in [3, 5]$: Users who have rarely used similar systems (50% of the users)
- $I \in [6, 8]$: Users who have sometimes used similar systems (31% of the users)
- $I \in [9, 11]$: Users who have often used similar systems (8% of the users)
- $I \in [12, 14]$: Users who have very often used similar systems (1% of the users)

These five groups of users were then compared in terms of task-completion time, rate of interaction and rate of errors for each task.

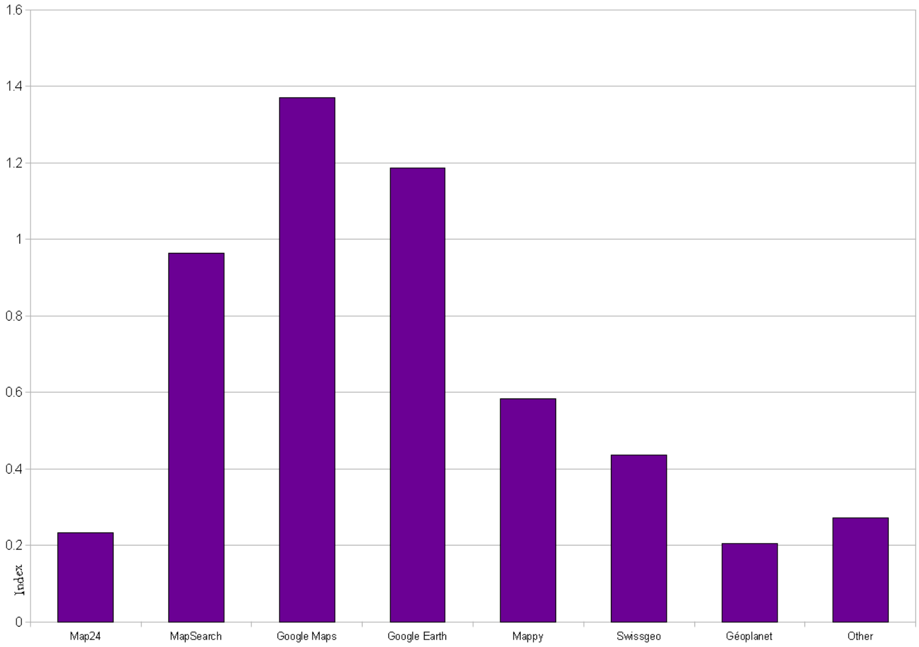


Figure 7.44: Experience with similar systems (average across all users

Table 7.15 shows the results of this comparison. It appears that the task completion time decreases with an increasing experience with similar systems (the group of fastest users was the group with the highest previous-experience-indexes). Yet a statistical comparison between the groups showed that many of the differences were not statistically significant. The highest significances were detected for the group $I \in [3, 5]$ compared to other groups (see table B.8 in appendix B). This result can be explained by the fact that the youngest group of users were the slowest (compared to the other groups; see above). The rate of interaction in relation to the previous-experience-index follows the same pattern: interaction-rate decreases with an increasing experience with similar systems. The most statistically significant differences between the index, task completion time and rate of interaction were found for the first task.

Based on the above findings, we argue that previous experience with similar systems has a certain influence on the parameters task-completion time and rate of interaction, especially if the user has never used the system before. This influence however decreases over time (which explains that fewer statistically significant differences were detected for task 2).

Regarding errors, we found that frequent and very frequent users of similar systems ($I \in [9, 11]$ and $I \in [12, 14]$) made on average less errors than users with little experience ($I \in [0, 2]$) (see table 7.15). For the first task these differences were not statistically significant (see table B.8 in appendix B), but two comparisons for the second task showed that the differences between the groups

		Time		Rate		Errors	
Index	#Users	Task1	Task2	Task1	Task2	Task1	Task2
$I \in [0,2]$	30 (9%)	107.97 s	103 s	13.43	15	0.20	0.20
$I \in [3,5]$	166 (50%)	109.46 s	113.5 s	11.34	17.33	0.09	0.12
$I \in [6,8]$	103 (31%)	81.09 s	97.76 s	9.87	15.89	0.14	0.03
$I \in [9,11]$	28 (8%)	100.14 s	74.14 s	7.57	14.04	0.07	0.04
$I \in [12,14]$	4 (1%)	47.25 s	56.25 s	6.25	12.5	0	0

Table 7.15: Experience of similar systems in relation to user performance (task completion time, rate of interaction, errors)

($I \in [0,2]$ and $I \in [6,8]$) and ($I \in [3,5]$ and $I \in [9,11]$) were significant. This result offers a feasible explanation for why some users did not manage to point out the train station in Yverdon: the experience with similar systems increased the user's knowledge both about the use of the system and the geospatial information in the system (i.e. where and how to find the target).

Besides the usage of paper maps and similar systems we also asked users whether they had ever used a GPS-based navigation system or geographical information systems (GIS). GPS-technology is today used in a variety of different devices; from cellular phones to car-navigation systems. It helps the user to navigate to specific points in space. GIS on the other hand are systems that are mostly used by experts and offer a variety of different possibilities to analyze and modify geospatial information.

We categorized users into four groups according to the two different parameters

- Users who have already used GPS-based navigation systems (65% of the users)
- Users who have never used GPS-based navigation systems (35% of the users)
- Users who have already used a GIS (23% of the users)
- Users who have never used a GIS (77% of the users)

		Time		Rate		Errors	
Parameter	#Users	Task1	Task2	Task1	Task2	Task1	Task2
Has used a GPS	216 (65%)	98.21 s	106.25 s	10.71	16.47	0.08	0.09
Has never used a GPS	115 (35%)	100.35 s	98.7 s	10.66	16.08	0.17	0
Has used a GIS	75 (23%)	87.89 s	95.13 s	9.25	14.45	0.15	0.05
Has never used a GIS	256 (77%)	102.2 s	106.12 s	11.11	16.89	0.1	0.1

Table 7.16: User performance (task-completion time, rate of interaction and errors) in relation to GPS-based navigation systems' and GIS usage

The comparison of these groups with our performance-measures gave an unexpected result:

- Users of GPS-based navigation systems had a significantly greater difficulty in finding the train station in Yverdon than other participants of the evaluation. (All users who had never used a GPS-based navigation system before pointed out the location correctly.)
- The usage of a GPS had no significant influence on the task completion time and the rate of interaction
- GIS users on the other hand were significantly faster in the second task and had a significantly lower rate of interaction in both tasks than participants who had never utilized a GIS.
- The usage of GIS had no significant influence on the rate of errors.

Next we compared user's self-estimated computer skills with user performance. None of the 331 participants judged that they had a very low level of computer skills. The other four groups were thus:

- Users with bad computer skills (6% of the users)
- Users with fair computer skills (37% of the users)
- Users with good computer skills (42% of the users)
- Users with very good computer skills (15% of the users)

The comparison of these groups of users showed some significant differences (for statistical tests, see table B.10 in appendix B):

		Time		**Rate**		**Errors**	
Estimation	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
Very bad	0 (0%)	-	-	-	-	-	-
Bad	19 (6%)	129.05 s	147.63 s	15.47	19.26	0.26	0.21
Fair	122 (37%)	98.52 s	106.3 s	10.93	15.75	0.11	0.12
Good	140 (42%)	105.39 s	101.24 s	10.73	17.06	0.11	0.06
Very good	50 (15%)	70.56 s	87.08 s	8.2	14.62	0.08	0.04

Table 7.17: Estimated computer skills and user performance (task-completion time, rate of interaction and errors)

- Users with good and very good computer skills were significantly faster in both tasks than users with bad computer skills
- Users with very good computer skills were significantly faster in task 1 than users with good and fair computer skills
- Users with very good computer skills needed significantly fewer interactions than users with bad computer skills
- Users with very good computer skills made significantly less errors than users with bad computer skills

It appears that especially the 50 users with very good computer skills stood out from the other groups (bad, fair and good computer skills) in terms of task completion time, rate of interaction and errors.

Regarding the user's context we did not ask users about their specific cultural background in the questionnaires, yet we were able to collect some parameters related to the context:

- The language that the user chose for the questionnaires and the system (English, French or German)
- The user's physical location at the time of the evaluation

Our assumption was that the users, when given the choice to use the system in a specific language, would prefer their mother tongue. However, considering that EPFL is an international institute of technology within a French-speaking region, within a country with four different languages, it is possible that users with a mother tongue other than English, French or German would choose English or French. Yet since English is not one of Switzerland's official languages it is probable that English-language users originated from many different cultural regions other than England-speaking countries.

We were able to detect the user's choice of language using our log-file parsing tool. The distribution was thus:

- 7% of participants used the system in English
- 85% of participants used the system in French
- 8% of participants used the system in German

Regarding the participants's physical location at the time of evaluation, we used the participants IP address and IPLocationTools'[32] freely available database to retrieve this parameter. Figures 7.45 and 7.46 show the user's location at the time of evaluation and the languages they used.

The distribution of users according to their location was:

- 297 users (90% of all users) were in Switzerland at the time of evaluation (65 (20% of all users) at EPFL, 232 (70% of all users) not at EPFL)
- 21 users (6% of all users) were in France
- Three users (1% of all users) were in Canada (the French-speaking part)
- Two users were in Luxembourg
- Two users were in Germany
- One user each was found in the United Kingdom, Belgium, Italy, Sweden, China and Armenia.

[32]http://www.iplocationtools.com

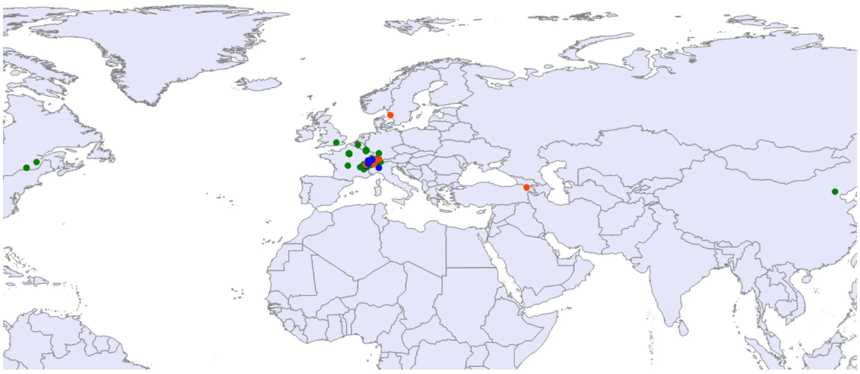


Figure 7.45: The physical location of the participants in the world at the time of the evaluation. Blue dots: users using the system in English; green dots: users using the system in French; orange dots: users using the system in German

The comparison of users based on language and user performance is shown in table 7.18. Connection were found between the following parameters (for statistical tests, see table B.11 in appendix B):

- English language users were significantly faster and made significantly fewer interactions than French language users in task 1.
- English language users had a significantly greater difficulty to locate the train station in Yverdon than French language users.
- German language users made significantly fewer interactions than French-language users in task 2.

A possible reason for why English language users had a greater difficulty to find Yverdon and the train station is that these participants originated from another cultural context than Switzerland and thus simply did not know Yverdon.

		Time		Rate		Errors	
Language	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
English	23 (7%)	69.09 s	122.09 s	8.04	21	0.13	0.22
French	282 (85%)	102.2 s	104.83 s	11.08	16.32	0.12	0.08
German	26 (8%)	90.23 s	74.23 s	8.85	12.42	0	0.08

Table 7.18: Choice of language and user performance (task-completion time, rate of interaction and errors)

The question whether the user's spatial location (at the time of evaluation) might have influenced user performance will be analyzed later in the section about **H4RQ4** (*Is there any evidence to suggest that parameters related to*

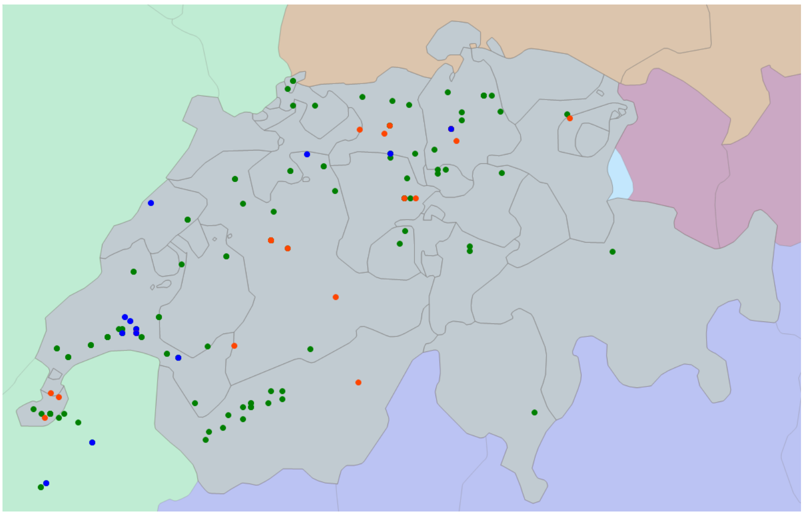


Figure 7.46: The location of the participants in Switzerland at the time of evaluation. Blue dots: users using the system in English; green dots: users using the system in French; orange dots: users using the system in German

the user's computer have a significant influence on user performance and user strategies?. The physical location is relevant for determining the Internet connection speed (e.g. a fast connection at EPFL or a slower ADSL connection) which also might influence the performance.

H3RQ2 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their strategies?

In order to determine whether user-related parameters influence the way users interact with the system, we consider the categories of tool preference that we established to answer **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*) and the percentage of time that users spent with their pointing-device on the map. We compared user-related parameters (e.g. female users) with categories of tool preference (e.g. users who preferred the zoom-buttons to zoom in and out and the pan-buttons to move the map) and the time users spent with their cursors on the map (e.g. 80-100%). The statistical tests of these comparisons can be found in appendix B:

- Tool preference and user's age (tables B.12 and B.13), handedness and gender (tables B.14 and B.15), experience with similar systems (experience index) (tables B.16 and B.17), GPS usage (tables B.18 and B.19), GIS usage (tables B.20 and B.21), user-estimated computer skills (tables B.22 and B.23), paper-map usage (tables B.24 and B.25) and languages (tables B.26 and B.27)

- Percentage of time spent on the map with the cursor and user's age (tables B.28 and B.29), gender (tables B.30 and B.31), handedness (tables B.32 and B.33), experience with similar systems (experience index) (tables B.34

and B.35), GPS usage (tables B.36 and B.37), GIS usage (tables B.38 and B.39), user-estimated computer skills (tables B.40 and B.41), map usage (tables B.42 and B.43) and languages (tables B.44 and B.45)

For each comparison we ran the χ^2 test in order to find out if there were differences between the groups. For the parameter "tool preference" we found (see table 7.19) that:

- experience with similar systems has an influence on users' preference for a given combination of tools to navigate the system. For instance, in task 1, only 15% of users with experience index ($I \in [3, 5]$) used the mouse wheel for scaling and click on the map for moving; on the other hand 36 % of users with a higher experience index ($I \in [6, 8]$) used this combination (see table B.16)

- cultural context may have an influence on user's preference for navigation tools. Almost all users (20 of 23 users) who used the system in English preferred to click on the map in order to move it in task 1 (see table B.26). Since we consider the click on the map as a more efficient way of moving the map than pan-buttons, this finding explains why English-language users were significantly faster in task 1.

- previous experience of GPS-based navigation tools has an influence on user's preference for navigation tools. For example in task 2, users who had not used GPS-technology before tended to prefer the combination of zoom buttons and pan-buttons more than users who had used GPS technology B.19.

	Task 1		**Task 2**	
Parameter	**H**	**p**	**H**	**p**
Age	0	0.98	0	0.47
Gender	0	0.95	0	0.33
Handedness	0	0.51	0	0.43
Experience index	1	0.001	0	0.4
GPS usage	0	0.76	1	0.02
GIS usage	0	0.58	0	0.3
Computer skills	0	0.29	0	0.55
Map usage	0	0.72	0	0.99
Language	1	0.04	0	0.46

Table 7.19: Statistical significance of comparison between user-related parameters and preference for navigation tools

Regarding the percentage of time spent on the map with the cursor we found a significant difference (table 7.20) between male and female users in the second task (see table B.31):

- 49% of the female participants spent between 60 and 79.9% of the time with the cursor on the map; only 29% of the male users spent this amount of time on the map.

- 61% of the male users spent between 80 and 100% of the task-completion time with the cursors on the map; for female users the percentage was 37%.

Male users thus tend to spend more time with the cursor on the map than female users.

Another interesting difference was found with regard to paper map usage. Users who use paper maps often or very often in other situations spend more time on the map with their cursor than users who very rarely or never use paper maps.

	Task one		**Task two**	
Parameter	**H**	**p**	**H**	**p**
Age	0	0.09	0	0.73
Gender	0	0.06	1	0.0003
Handedness	0	0.82	0	0.54
Experience index	0	0.47	0	0.27
GPS usage	0	0.81	0	0.62
GIS usage	0	0.38	0	0.89
Computer skills	0	0.33	0	0.08
Map usage	1	0.01	0	0.27
Language	0	0.6	0	0.27

Table 7.20: Statistical significance for the comparison between user-related parameters and time spent on the map with the cursor

H3RQ3 Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their perception of spatial features?

Previously, when addressing **H1RQ2** we identified five users whose pointing device cursor appeared to follow infrastructural features on the map. These users' cursors are shown in figures 7.37, A.3, A.4, A.5 and A.6). It was difficult to identify groups of users that followed given navigation patterns with their cursor only through the visualization of their cursor tracks in space due to the fact that there were 331 cursor tracks and two tasks, and that it is sometimes difficult to judge whether a cursor track really follows a structure. We therefore decided to focus on the five users that followed infrastructural features on the map, and investigated whether they had some common elements in terms of user-related parameters.

We found the following common elements:

- Four out of these five users (80%) were male
- Three out of these five users (60%) were between 21 and 30 years old
- All users were righthanded

- Four out of these five users (80%) had little or very little experience with similar systems (all four users had an experience index of 3 or less)
- Three users (60%) had good computer skills, two users (40%) had fair computer skills.
- Three users (60%) had used a GPS
- Four users (80%) had not used a GIS
- Although all five users were located in Switzerland, three of them were not in the proximity of regions described in the two tasks (one user was in Geneva, one in Zurich and one in Bern)

It thus appears that users who have (very) little experience with similar systems tend to follow the infrastructure displayed on the maps (high ways and railways) in order to navigate to the desired location. This theory is however difficult to prove and to validate. Moreover, it is likely that the user's context has a certain influence on the interest in spatial features. Figure 7.37 for instance shows a person whose cursor follows the light-rail from the nearest train station (in Renens) to EPFL. At the time this specific user was completing the task he was located in Montreux, a city with direct train connection to Renens. It is thus possible that the path that the user made with the cursor from Renens to EPFL is also the physical way this user commutes to EPFL.

H4 System-related parameters have an influence on user performance, user strategies (spatial and non-spatial) and perception of spatial features

H4RQ1 Is there any evidence that some interface features cause higher cognitive load?

Compared to the previous two case studies, the present case study was conducted with a much simpler interface containing few interactive elements (the navigation tools and a tool to point out a location). In the first case study for instance we had identified some users who changed their interaction strategy after having encountered problems related to interface features.

In order to address **H4RQ1** we will therefore analyze whether the users changed their interaction strategy from the first task to the second task. In the earlier section where we addressed **H1RQ1** (*Is it possible to distinguish different kinds of spatial interaction strategies?*) we identified certain preferences for combination of navigation tools in the two tasks. As a follow-up, to answer the present research question, we therefore compared these preferences and identified users who changed their preference for a tool between the two tasks.

Table 7.21 shows the number of users who changed their preference from task 1 to task 2. 25% of the users changed preference from the recenter option (click on the map) to pan-buttons. This change is unexpected due to the fact that

Change	Number of users	% of all users
Changed from pan-buttons to recenter	0	0 %
Changed from recenter to pan-buttons	82	25 %
Changed from zoom buttons to scale choice	13	4 %
Changed from scale choice to zoom buttons	2	1 %
Changed from zoom buttons to mouse wheel	2	1 %
Changed from mouse wheel to zoom buttons	13	4 %
Changed from scale choice to mouse wheel	3	1 %
Changed from mouse wheel to scale choice	19	6 %

Table 7.21: Distribution of users over their change of preference for spatial navigation tools between task 1 and task 2 (only users with a clear preference for a tool were considered

we consider clicking on the map a more efficient way to move the map than the pan-buttons.

An examination of the comments, that users gave in the second questionnaire, about map navigation and the system in general, revealed that 42 users (13% of all users) strongly disapproved of the recenter option (click on the map) to move the map. Instead they preferred to move the map with a dragging tool (like it is implemented in systems such as Open Street Map[33] or Google Maps[34]).

The reason why a quarter of all users changed their strategy for moving the map is thus to be found in the fact that they were used to other interaction manners (from previous experience with similar systems) or that they did not understand the recenter tool. Due to the problems they experienced with moving the map with the recenter click, users were inclined to find alternative strategies for moving the maps, and thus changed to the pan-buttons around the map.

H4RQ2 Is it possible to identify a connection between the system's graphical design, interaction design and map design, and user performance?

The finding we made for **H4RQ1** (*Is there any evidence that some interface features cause higher cognitive load?*) that users changed their strategy also had an influence on user performance. Due to the fact that users changed their preference for a set of tools (from the click on the map to pan-buttons), they chose a less efficient way of navigating (see table 7.11 where we analyzed tool preference, task-completion time and rate of interaction).

On the other hand 32 users (10% of all users) changed their preference either from zoom buttons or from mouse wheel to the scale choice. 15 user changed from the mouse wheel or the scale choice to the zoom buttons, and 5 users changed from the zoom buttons to the scale choice; see table 7.21). THis distribution could be explained by the fact that the scale-choice (physically located

[33]http://www.openstreetmap.org
[34]http://maps.google.com

between the zoom buttons on the interface) also provides information about the current scale of the map (short bars indicate a high zoom level, long bars a low zoom level) and could be understood as a non-clickable graphical element. If this was indeed how users perceived it, they naturally chose mouse wheel or zoom buttons for zooming, and only later when they discovered that the scale-bar was clickable, were they be able to choose this third tool for zooming.

Based on the above reasoning we claim that the interaction design of this case study's system had an influence on interaction strategies (which also answers **H4RQ3** (*Is it possible to identify a connection between the systems graphical design, interaction design and map design, and user interaction strategies (spatial and non-spatial)?*)) and thereby on user performance.

H4RQ4 Is there any evidence to suggest that parameters related to the user's computer have a significant influence on user performance and user strategies?

We consider the user's computer as the part of the overall system that a system developer has no influence over. As mentioned in chapter four, the user's computer can be any device connected to the Internet and equipped with a web browser.

Within this case study we were able to collect the following parameters that we consider relevant for the characterization of the user's computer:

- The type of pointing device attached to the user's computer. As discussed in chapter four different pointing devices are likely to influence user performance. Moreover the type of pointing device can give some indication of which kind of computer the user was using (e.g. touchpad, pointing stick and touchscreen represent users who are more likely to use a mobile computer)
- The type of connection the user's computer has to the Internet. The connection type gives indications about the speed of connection and is thus likely to influence the performance of the system.
- The kind of operating system that is installed on the user's computer. The kind of operating system can give indications of the kind of computer the users were using. Apples operating system OS X is for instance more likely to be found on an Apple MacIntosh computer. Windows and Linux on the other hand run on other kinds of computers. Linux usually requires the user to install it manually since most personal computers today are delivered with either Microsoft's or Apples operating systems.

The first parameter, the type of pointing device, was collected in the first questionnaire. The distribution of users according to their pointing device was:

- Mouse without a wheel: 16 users (5% of all users)
- Mouse with a wheel: 216 users (65% of all users)
- Touchpad users: 91 (27% of all users)

- Pointing stick users: 4 (1% of all users)
- One track ball user
- Two touchscreen users
- One user who used a different pointing device (the user was using a PlayStation, a video game console)

The second parameter, the Internet connection type, was identified using the IP-address and IPLocationTool[35]. We divided the users into three categories:

- 65 users (20% of all users) at EPFL: these users had the fastest connection to the server where the system was hosted
- 232 users (70% of all users) with a Swiss ADSL or cable modem connection
- 34 users (10% of all users) with an Internet connection in a foreign country

The type of operating system that users had on their computers was the third parameter we collected using our log-file parsing tool:

- 56 users (17% of all users) used a computer with the operating system OS X
- 254 users (77% of all users) used Microsoft Windows
- 20 users (6% of all users) used Linux
- one user used a different operating system (the PlayStation operating system)

With these parameters we thus divided the participants of our case study and compared whether these groups showed differences in terms of interaction strategies and performance.

The divisions of users according to the preference of navigation tools and the parameters related to the user's computer can be found in appendix B (tables B.46, B.47, B.48 and B.49). The divisions of users according to the time they spent on the map with their pointing devices and the three parameters describing the user's computer are listed in appendix B (tables B.52, B.53, B.54, B.55, B.56 and B.57)

On each of these tables we ran the χ^2-test (see tables B.58 and B.59 in appendix B). The only statistically significant difference was found for the parameter "pointing device" and "preference for a navigation tool" in task 1.

[35]http://www.iplocationtools.com

This difference however is not surprising due to the fact that the input devices offer different possibilities for spatial navigation (a trackball for instance cannot offer a mouse-wheel). Yet it was surprising that for eight users who claimed to have a touchpad, mouse-wheel movements were recorded. After a short investigation we came to the conclusion that some touchpads were able to simulate mouse-wheel movements (e.g. multitouch touchpads through sliding the fingers up or down). Moreover the users could theoretically have several pointing devices attached to their computers (a touchpad and a mouse with a wheel).

Next we investigated the relationship between the user's computer and user performance.

Regarding the three parameters "pointing device", "connection type" and "operating system" we found the following differences:

- Users with a wheel equipped mouse were significantly faster than touchpad users for the completion of task 2
- Users who used the system at EPFL (thus with a direct connection to the server) were significantly faster than users with a Swiss ADSL / cable modem connection and users with a foreign Internet connection.
- Users with a foreign Internet connection had a significantly greater difficulty to find the train station in Yverdon than users at EPFL
- Users who were physically at EPFL at the time of evaluation needed significantly fewer interactions to navigate to EPFL in the first task
- OS X users were significantly faster in the first task than Windows users

The first finding is consistent with the results of MacKenzie *et al.* (2001) study: the mouse is more accurate and faster than the touchpad. The explanation for the second finding is also obvious: due to the fact that the users at EPFL had a much faster connection to the system's server, the maps loaded faster and the users were able to find the targets in a shorter interval of time.

The finding that users with a foreign Internet connection had significantly more problems finding Yverdon is probably related to the user's context and was previously discussed in **H3RQ1** (Is is possible to identify a connection between the user's age, gender, handedness, knowledge, skills and context, and their performance?). The fact that the 34 users were not physically in Switzerland, but in different countries, implies that some of these users had a stronger cultural relationship with their foreign location than with Switzerland. Therefore these users did not know the location of Yverdon and thus were not able to point out the correct location.

H5 User satisfaction depends on user-specific parameters

H5RQ1 Is there any evidence to suggest that users, depending on their age, gender, handedness, knowledge, skills and context are more or less satisfied?

User satisfaction is a very subjective measure that each user decides independently. When answering **H5RQ1** we presuppose that the answers that users give to questions about satisfaction depend on their demographic parameters, knowledge and skills and context.

In our case study we asked four questions about specific elements that each participant could answer with either "no", "rather no", "indifferent", "rather yes" or "yes":

- Does the system give enough instructions?
- What is happening is understandable?
- Is the system too loaded (with buttons, icons, etc)?
- Are there needless elements?

Moreover we asked the participants about their satisfaction with the following elements: (possible answers were "very bad", "bad", "ok", "good", "very good")

- The systems' graphical design
- The logical design (sequence of actions)
- The relationship between the design of the icons/buttons and the functionality that is behind
- Map navigation
- The systems' speed
- The system in general

Figures 7.47 and 7.48 show the results of these questions for all users. Map navigation and the graphical design were the points that received more negative ratings (bad and very bad). On the other hand the design of the buttons/icons and the logical design received fewer negative ratings. The design of the buttons/icons and the system's speed were rated more positively (good and very good). The reasons why certain elements received more positive or negative critique is further discussed in **H6RQ1** (*What is the connection between the systems' graphical design, interaction design, map design, the user's computer and user satisfaction?*).

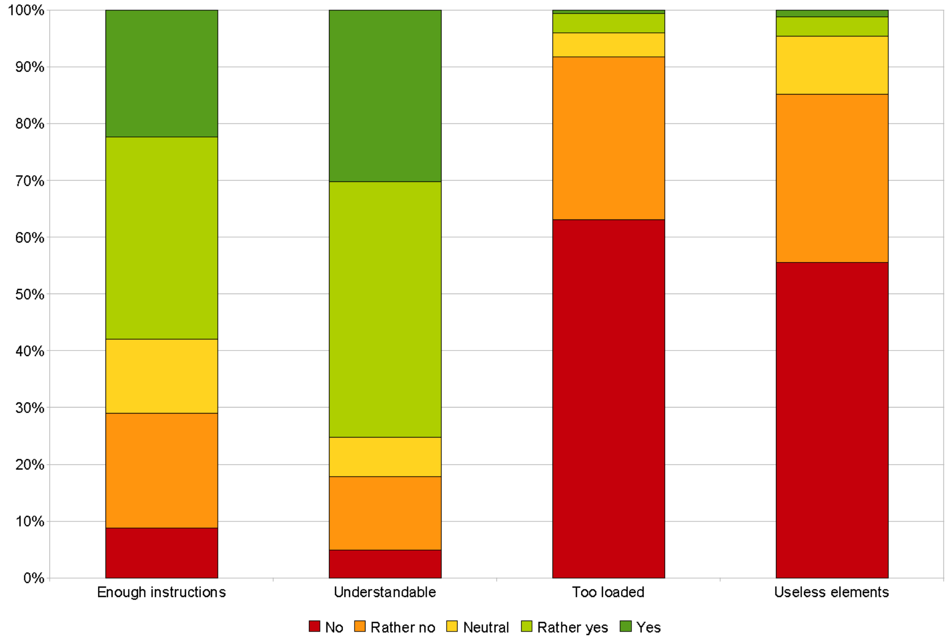


Figure 7.47: Answers to the questions “Does the system give enough instructions?”, “What is happening is understandable””, Is the system too loaded (with buttons, icons, etc)?”, “Are there needless elements?”

To determine whether user-related parameters influenced the participants' subjective judgment of the different elements of the system, we categorized participants according to the following parameters:

- Age
- Gender
- Handedness
- Experience with similar systems
- GPS and GIS usage
- The participants self-estimated level of computer skills
- The usage of paper maps
- The language chosen for the evaluation (English, French or German)

We then compared the groups with each other (e.g. females vs. males) and verified using the χ^2-test which of the user-related parameters had a significant influence on the satisfaction. The results of these comparisons can be found in appendix B, tables B.66 and B.67.

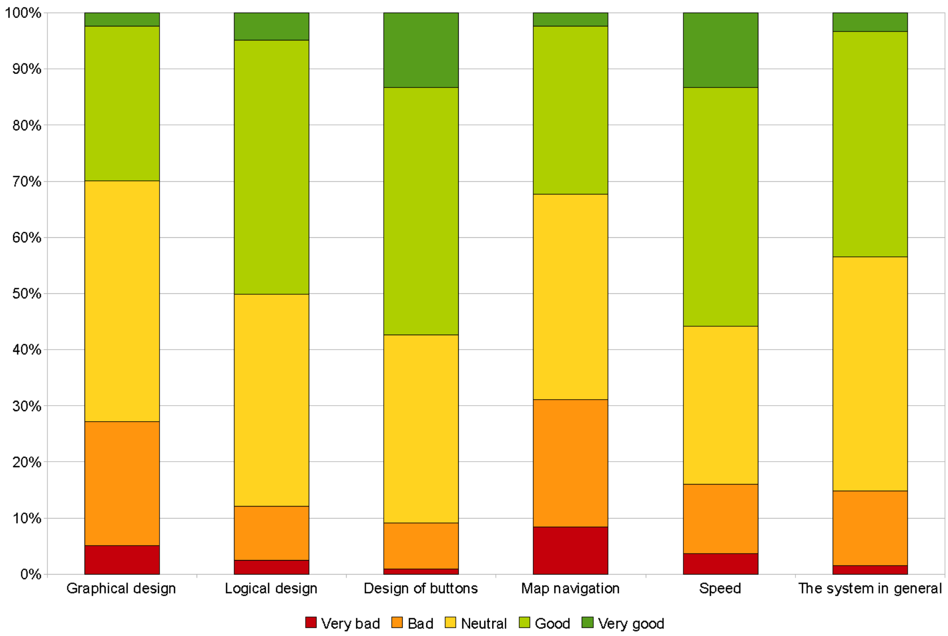


Figure 7.48: The user's satisfaction with the graphical design, the logical design, the relationship between the design of the icons/buttons and the functionality that is behind, map navigation, the systems' speed, and the system in general

The parameters that showed significant differences between users and different elements of satisfaction were:

- Age: Depending on the user's age, they gave different answers to the question "the system is too loaded". The three users between 51 and 60 years answered that the system is too loaded. For all the other groups, the majority of the users (more than 60%) clearly answered "no" to this question. The comparison can be found in appendix B, figure B.1.

- Handedness: Depending on the participants handedness, there were significant differences concerning the satisfaction with map navigation. More than 35% of the 38 left-handed participants were either very unsatisfied or unsatisfied with map navigation; for right-handed participants the percentage of unsatisfied and very unsatisfied participants was 28%. The comparison can be found in appendix B, figure B.2.

- Experience: Depending on the users' experience with similar systems, we found significant differences in the answers to the questions about the instructions given by the system, the graphical design and the design of buttons/icons. The experience-index that we calculated yielded most significant ($p \leq 0.05$) differences between the users. Especially the questions about the graphical design and the design of buttons/icons showed a distinctive pattern: If not considering the four users with the highest index ($I \in [12, 14]$), users with very little experience ($I \in [0, 2]$) and users with

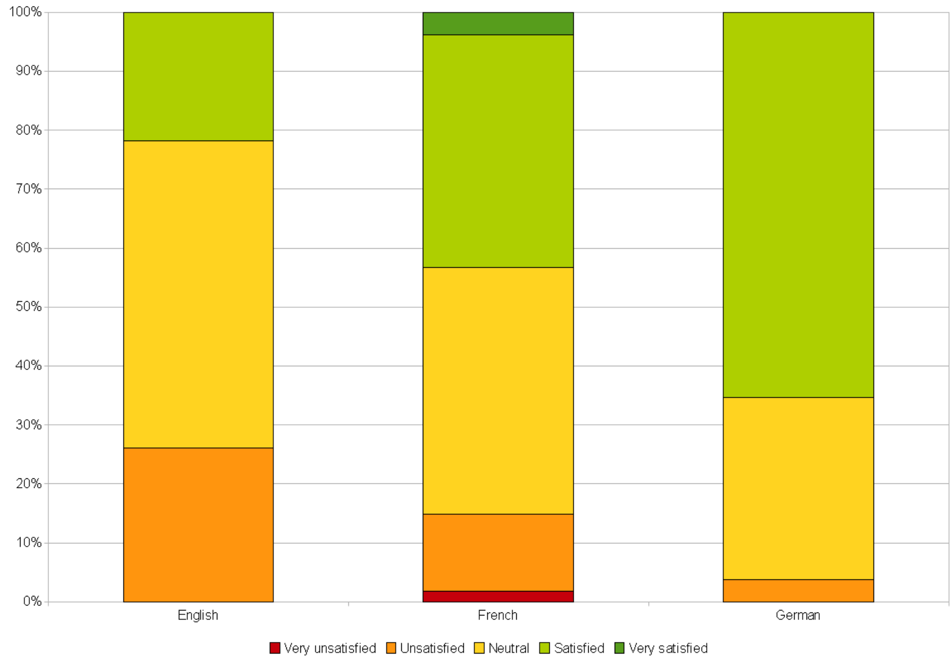


Figure 7.49: Satisfaction with the system in general according to language used in the evaluation

much experience ($I \in [9, 11]$) are more satisfied than users with a fair experience ($I \in [3, 5]$). The comparisons can be found in appendix B, figures B.3, B.4 and B.5.

- Computer skills: Depending on the user's self-estimated level of computer skills we detected significant differences regarding the participants satisfaction with the logical design of the system. Users with bad and very good skills were more satisfied than users with fair and good computer skills. The results of the comparisons can be found in appendix B, figure B.6.

- Origin of user: Depending on the language the participants used, there were significant differences concerning the satisfaction with the logical design of the system. German language users were significantly more satisfied than French language users. English language users were least satisfied. Language was also the parameter which produced the lowest p-values (compared to all the other user-related parameters). Concerning general satisfaction with the system we noticed the same correlation between language user and satisfaction (although the comparison was less significant (p=0.063)). Figure 7.49 shows the users' satisfaction with the system in general according to the language used. The comparison between the parameters "language" and "logical design" can be found in appendix B, figure B.7.

H6 System-related parameters influence user satisfaction

H6RQ1 What is the connection between the systems' graphical design, interaction design, map design, the user's computer and user satisfaction?

In our conceptual framework in chapter 4 we defined the online geospatial system system as a conglomerate of different components that include both soft- and hardware. All of these components are interconnected and influence each other mutually. If we thus discuss user satisfaction with for instance the system's speed, we must take into account that the system's speed depends on the system's architecture and the Internet connection speed.

In our framework of parameters (see figure 4.2) we defined the following categories of satisfaction:

- Satisfaction with maps
- Satisfaction with the access
- Satisfaction with the graphical design
- Satisfaction with the system's consistency
- Satisfaction with the system's functionality
- Satisfaction with the system's interaction design

Satisfaction with maps: In this case study we did not specifically ask how satisfied the participants were with the maps displayed. However the participants did give comments about the map's contents and presentation:

Map contents:

- Four users requested to have a legend that explains the map's contents
- Three users requested to have street names displayed on the maps
- Three users requested to have public buildings (such as train stations) pointed out on the map
- Three users would have liked the system to display a scale-bar (with distance indications)

All four comments were related to information that the participants were missing. Especially street names and particular buildings are features that are helpful for navigating at larger scales. Our system's maps were based on scanned paper maps (at smaller scales) and aerial images (at large scale). The aerial images however did not contain any additional information which may have caused greater difficulty in navigation.

The fact that four users were missing a legend and a scale-bar indicates that these users had difficulties interpreting the contents of the maps.

Map presentation:

- Five users found that the maps were too blurry at larger scales
- Three users did not like the change of maps from scale to scale (e.g. the fact that the system changed to aerial images at large scale)
- Two users found that the colors were either strange or aggressive

The comments made by the users about the presentation of maps might indicate that the users disliked the fact that scanned paper maps were used. These paper maps were initially not meant to be used in online geospatial systems and are thus not optimized for this usage.

Satisfaction with the access: Regarding the access, users were asked to rate the system's speed. Compared to other satisfaction-ratings of specific elements (graphical design, etc. see 7.48), more than 50% of the users were either "very satisfied" or "satisfied" with the access speed; on the other hand 16% of the users were either "unsatisfied" or "very unsatisfied". Due to the fact that the Internet connection speed can influence the speed of the system as a whole, we divided users into three different groups (users with a direct connection at EPFL, Swiss ADSL cable modem users and users with an Internet connection outside Switzerland). The χ^2-test showed that the three groups were significantly different (p=0.0001) in terms of satisfcation with the system's speed (see figure B.8). More than 65% of the users at EPFL were thus either satisfied or very satisfied. 55% of the Swiss ADSL / cable modem users were either satisfied or very satisfied and only 41% of the users with a foreign connection were satisfied or very satisfied with the system's speed.

Satisfaction with the graphical design: Compared to the ratings of other features (such as the system's speed), the graphical design was not rated very high (see figure 7.48). Only 30% of the users were either satisfied or very satisfied while 27% were unsatisfied or very unsatisfied. One key factor in this rating is the satisfaction with maps. Since we did not not ask the users specifically about their satisfaction with maps, many users might have based their rating both on the maps and the graphical design. In fact the 24 comments that users made about the graphical design were mostly negative comments about the design of maps.

On the other hand more than 90% of the users answered the question "Is the system too loaded (with buttons, icons, etc)?" with "no" or "rather no". Moreover 57% of the users were satisfied or very satisfied with the design of the buttons and icons. (see figure 7.48)

Satisfaction with the system's consistency: As discussed in the second case study a system's consistency can be considered from different angles such as the external consistency (compared to other similar systems) and the internal consistency of the system.

External consistency: One important issue that was pointed out by several participants was that the system's map navigation tools did not follow the same principles as many standard map navigation systems. Especially Google Maps was given as a reference by seven participants. This might also be the reason why 42 users pointed out (see the discussion of **H4RQ1** (*Is there any evidence that some interface features cause higher cognitive load?*) that they would have preferred a map-dragging tool instead of the recenter-click on the map.

Internal consistency: One issue that can be related to the internal consistency of the system is the change of map presentation. The map presentation changed from topographical maps to aerial images depending on the scale. Moreover the topographical maps displayed at different scales did not show exactly the same color palettes and symbologies as they had been conceived as paper maps by different map designers.

Satisfaction with the system's functionality: Due to the simplicity of the system's functionality (navigation and "dropping" a pin) we did not address the satisfaction with the system's functionality through the questionnaire. The only functionality that four different participants were missing was a search-field were users could type the name of the place to go to instead of navigate to the place.

Satisfaction with the system's interaction design: In our questionnaires we asked users to rate the logical design (the sequel of actions) and map navigation. Concerning the logical design 50% of the users gave the ratings "good" or "very good" while only 12% answered with "bad" or "very bad", but as already mentioned map navigation was one of the categories that received poor ratings. Yet map navigation was also judged differntly depending on the pointing device used (the p-value of the χ^2-test was significant with p=0.0003). If we consider the three categories of pointing devices that were used by most users (mouse without wheel (5% of all users), wheelmouse (65% of all users) and touchpad (27% of all users)) we can state touchpad-users were significantly more satisfied than wheel-mouse users who in turn were more satisfied than users with a mouse without a wheel (see B.9. An explanation to this difference in satisfaction can be found in the interaction-design of the different input devices: a critique that was given by many users concerning map-navigation was that they preferred to move the map by dragging it. Dragging objects using a mouse (with or without a wheel) is a very simple and customary task, since the user only needs to hold the mouse-button pressed while moving the mouse. If the same task is done with a touchpad it requires a physically more demanding interaction: the user needs to hold down a button with one finger while moving the object with another finger. We thus presume that the reason why touchpad users were significantly more satisfied with map navigation is either that they did not miss the dragging function in our system (due to the fact that they do not use this feature in other systems either) or else that they were positively surprised by the fact that the map could be moved by simply clicking on it (and thus demanded less complicated physical interaction). The reason why wheel-mouse users were more satisfied than users with a wheel-less mouse might simply lie in the fact that wheel-mouse users had more choices for changing the scale of the map.

7.4.8 Summary of results

To give an overview of all important findings of this case study we give a summary of the results that confirm the relationships between the parameters of our conceptual framework (see figure 4.2). Table 7.22 summarizes the relationships of interaction-related parameters. Tables 7.23, 7.24, and 7.25 give an overview of the influence of user-related parameters on the interaction and satisfaction and tables 7.26 and 7.27 describe the influence of system-related parameters.

Parameter	**Parameter influenced**	**Finding**
Rate of interaction	Task completion time	Each interaction leads to a new map. The user needs more time to solve the task if he makes more interactions
Errors	Task completion time	Users try to correct errors and therefore need more time
Errors	Rate of interaction	Users try to correct errors and therefore make more interactions
Spatial interaction strategies	Task completion time	Users who preferred to move the map by clicking on it were significantly faster than users who used the pan-buttons located around the map

Table 7.22: Influence of interaction-related parameters on other interaction-related parameters

Parameter	**Parameter influenced**	**Finding**
Age	Task completion time	The youngest users were the slowest users
Age	Rate of interaction	The youngest users made most interactions
Age	Satisfaction with the graphical design	The oldest users (between 51 and 60 years) found the interface to be too loaded
Handedness	Satisfaction with the interaction design	Left-handed participants were less satisfied with the map navigation
Gender	Task completion time	Males are significantly faster than females
Gender	Rate of interaction	Males make less interactions than females
Gender	Spatial interaction strategies	Males spend significantly more time with their pointing device cursor on the map than females

Table 7.23: Influence of demographic parameters on the interaction and satisfaction

Parameter	Parameter influenced	Finding
Paper maps usage	Task completion time	Frequent users of paper maps are faster than users who use paper maps very rarely
Paper maps usage	Rate of interaction	Frequent users of paper maps make less interactions than users who use paper maps very rarely
Online geospatial systems experience	Task completion time	Experience of similar systems influences task completion time when users use the system for the first time
Online geospatial systems experience	Rate of interaction	Experience of similar systems influences the rate of interaction if users use the system for the first time
Online geospatial systems experience	Tool preference	Previous experience of spatial navigation tools has a significant influence on the preference of navigation tools, if users use the system for the first time
Online geospatial systems experience	Satisfaction with the graphical design	Extremes (much and little experience) have a positive effect on satisfaction with the graphical design
GPS-based navigation systems usage	Rate of errors	Users who have experience of GPS-based navigation systems have more difficulty pointing out locations on a map than users who have never used GPS systems
GIS usage	Task completion time	Users who have experience of GIS are faster than users who have no experience
GIS usage	Rate of interaction	Users who have used GIS made fewer interactions than users who had not
Estimated computer skills level	Task completion time	Extreme computer skills (e.g very good vs bad) influence task-completion time significantly
Estimated computer skills level	Rate of interaction	Extreme computer skills (e.g very good vs bad) influence rate of interaction significantly
Estimated computer skills level	Rate of errors	Extreme computer skills (e.g very good vs bad) influence rate of errors
Estimated computer skills level	Satisfaction with the interaction design	Users with poor computer skills are less satisfied with the logical design of the system

Table 7.24: Influence of the user's knowledge and skills on the interaction and satisfaction

Parameter	Parameter influenced	Finding
Language	Rate of interaction	German language users make significantly fewer interactions than French language users
Language	Rate of errors	English language users have more difficulty pointing out specific location in the Lausanne area
Language	Satisfaction (interaction design + general s.)	German language users are more satisfied than French language users who are more satisfied than English language users
User's location	Rate of errors	Users who are located in a foreign country have more difficulty pointing out specific locations in the Lausanne area

Table 7.25: Influence of the user's context on the interaction and satisfaction

Parameter	Parameter influenced	Finding
Map design	Satisfaction with maps	The lack of certain information in the map (e.g. street names or a legend) result in negative satisfaction. Moreover users do not like the change of map presentation from one scale to another (e.g. from topographical to ortho-images)
Interaction design	Satisfaction with system's consistency	Users prefer the system to have a map-dragging tool for moving the map which is more consistent with other online geospatial systems
Interaction design	Satisfaction with the system's functionality	Users wish to have a text-input-field that enabled them to navigate to a specific location without spatial navigation tools

Table 7.26: Influence of the system's design on the satisfaction

Parameter	Parameter influenced	Finding
Pointing device	Task completion time	Wheel-mouse users are faster than touchpad users
Pointing device	Satisfaction with the interaction design	Touchpad users are more satisfied with the map-navigation than wheel-mouse users who in turn are more satisfied than users with a wheel-less mouse
Internet connection speed	Task completion time	Users with a higher bandwidth are faster
Internet connection speed	Satisfaction with the access	Users with a higher bandwidth are more satisfied with the system's speed

Table 7.27: Influence of the user's computer on the interaction and satisfaction

7.4.9 Conclusions

The evaluation of the spatial interface for the online survey system has confirmed that many parameters influence users' interaction and satisfaction with an online geospatial system. The fact that this study was conducted outside a laboratory environment had two great advantages. First, it allowed the user to evaluate the system remotely from their private computer, which enabled us to collect important parameters about the user's computer (such as the type of input device). Second, due to the fact that the system was accessible online, we were able to get a large number of participants (331) to evaluate the system.

The quantity and diversity of the collected parameters however made the analysis very complex: the collected data had to be post-processed in order to normalize both time-specific data (e.g. timestamps collected from the system's server and the client's computer) and screen-coordinates (collected from different web-browsers of which some had shifted the screen-coordinates a few pixels).

Contrary to the two previous case-studies where the users represented a specific group of users (winegrowers and students with a background in geomatics engineering), the participants of this case study were a heterogeneous group. This group however can not be seen as an approximation of the "grand public" since the context of EPFL as an institute of technology already imposes certain requirements on its students and staff in terms of technological competence and interest. Moreover, considering the age of the participants (37% of the participants were at most 20 years old and 60% were between 21 and 30 years), we can conclude that the vast majority of the participants were either undergraduate students or PhD students.

We were able to identify users who navigated maps by using the pointing device cursor to follow infrastructural features depicted on the system's maps (roads, railway tracks). This finding suggests that the user's eyes followed these spatial features, which confirms the results of previous research about the relationship between direction of gaze and pointing device movement (e.g. Chen *et al.* (2001) or Cooke (2006)). On the other hand, the fact that users followed certain paths on the map with their mouse cursor also helps in understanding the user's decisions when navigating maps. For both tasks where the participants were required to navigate to a specific location, the movements of their pointing devices suggest that the way they move in the real world from point A to B also influences the way they spatially navigate in an online geospatial system.

Concerning the evaluation method we conclude that the remote testing yields a considerable amount of quantitative data. Although in this case-study there was no evaluation expert physically present during the evaluations, we were able to obtain deep insight about how users interact with this type of system.

7.5 Summary

In this chapter we presented three case studies that were conducted in order to validate our conceptual framework of usability-related parameters. In each case study we evaluated a specific online geospatial system with real-world users. The first system, called “RIV”, was created for professionals involved in wine-growing in the Swiss canton of Vaud. The second system called “Géocommande” allows for ordering spatial data on-line, and the third system was a spatial module for an online survey system with the principal functionality to point out locations on an online map.

The case studies differed in terms of available participants (the number of participants, but also the kind of participants), method used for the evaluation (e.g. laboratory-based experiment using verbal protocols and remote-evaluation using online-questionnaires and specific interaction-capturing tools) and system functionalities that were tested in each system.

For each case study we developed the necessary tools to gather relevant information for the characterization of the user, the system, the interaction and the satisfaction in the evaluation. The most important tools we developed were scripts that parse web-server log files and capture network traffic into human-readable interaction protocols and automatically generate statistics and diagrams. Moreover we used and modified a Javascript library for capturing the user’s pointing device interactions (e.g moving and pointing activity).

The gathered data enabled us to analyze the hypothetical connections between the parameters of our conceptual framework. These connections are discussed in the following chapter.

8 Discussion

8.1 Introduction

In the previous chapter we evaluated three different systems with diverse participants. In each of the case studies we discussed research questions that were associated to hypotheses about the connections between different user-system- interaction- and satisfaction related parameters. Due to the fact that each evaluation addressed a different system, but also due to the characteristics of the participants in each evaluation, we were not able to discuss all research question in each case study. In this chapter we therefore summarize our overall findings and discuss each hypothesis separately.

Further, based on the hypotheses that we were able prove or partially support with our data, we elaborate on how they can be translated into recommendations regarding the design and development of online geospatial systems. These recommendations are the concrete output of our work and are intended for people who intend to conceive and develop future online geospatial systems for different types of users and for different ranges of application.

8.2 The hypotheses

8.2.1 The interaction

H1 Users show different strategies during interaction with a system

The first hypothesis is confirmed by all our three case-studies which show that the participants did use different strategies to solve a given tasks. We identified preferences for specific sets of tools and specific interaction sequences to solve spatial tasks. Moreover we found evidence that the user's perception of spatial features influences spatial interaction strategies.

In the third case study we found evidence suggesting that users (given a variety of spatial navigation tools) prefer using only one set of spatial navigation tools (an example are zoom buttons and pan-buttons). In our case study the preferred choice for zooming and un-zooming were the zoom buttons (instead of zooming with the mouse-wheel or a direct scale-choice). Another finding was that direct interaction with the map (clicking on the map in order to re-center, instead of using pan-buttons) is the preferred choice for panning (although participants would have used a dragging-tool instead if it was available). In the second case study we found that users preferred dialog-boxes over spatial navigation and spatial selection tools to select spatial areas.

It appears that decisions about spatial navigation strategies in terms of zooming and panning are highly influenced by the user's perception of infrastructure displayed on the map (roads, railway tracks), but also by the user's cognitive map of the space.

H2 Users perform differently when interacting with a system

This hypothesis is supported by an important finding that was discovered in all three case studies about the direct influence of rate of interaction on task completion time. When users made errors (and when they discovered them), they were required to correct them in order to complete the task. This resulted in an increased rate of interaction and thereby also interaction time. Furthermore we found that the performance (in terms of rate of interaction, task-completion time and errors) of users is highly dependent on the strategy they use to solve the task and whether these strategies lead to errors or not. In the first case study we found that users who prefer one set of spatial navigation tools are faster than users who use several tools and that users who prefer to move the map by using pan buttons around the map are slower than users who choose a direct interaction (clicking on the map). This finding is related to Fitts' law Fitts (1954) as claimed by You *et al.* (2007): it takes more time to navigate with the mouse to the pan-buttons than clicking directly on the map.

Since users spend a considerable time of their interaction perceiving the map and the geospatial features displayed, spatial navigation seems to be a conglomerate of different processes influencing user strategies and thereby performance. We conclude that the iterative model for interaction proposed by Dix *et al.* (2004) (see figure 6.1) applies to the process of spatial navigation: the user perceives the map and the interface, then decides for a strategy to navigate (e.g. to pan the map), then applies the chosen strategy which results in the system displaying a modified map. Consequently, user performance for spatial navigation tasks does not only rely on interaction-clicks, but also on the perception of geospatial features. As a result user performance can only be optimized by optimizing the interface and the geospatial content.

8.2.2 The user and the interaction

H3 User-related parameters have a significant influence on user performance, user strategies (spatial and non-spatial) and the perception of spatial features

To prove this hypothesis, we have found evidence that demographic parameters, parameters related to the users' knowledge and skills and the user's context have a significant influence on interaction strategies and thereby also on performance. Regarding demographic parameters we found certain gender-specific differences: females are faster than males in non-spatial interaction (e.g. selection of object in dialog-boxes) but slower than males at spatial navigation. This finding is consistent with Simon (2001). Although the participant's age in case study three was shown to have an influence on both the rate of interaction and task-completion time, we argue that this parameter cannot be considered in isolation but is highly connected to the user's knowledge and skills: very young users have less experience with geographical information and technologies and therefore do not use the most efficient strategy. Older users (older than 50 years) do not have an extensive training in using these technologies, due to the fact that these technologies are rather recent and have only become available for a larger public in recent years. Concerning the parameter "handedness" we found that the left-handed user digitized a polygon counter-clockwise, whereas the right-handed users digitized clockwise. This finding is related to the way a subject draws an object (a circle or a polygon) using a pen on a paper: A right-handed subject begins at the top of the object and continues rightwards (so that his hand does not cover the line). On the other hand a left-handed subject does the opposite and begins leftwards.

The user's knowledge and skills in terms of previous contact with similar systems and spatial information was found to influence spatial interaction strategies and performance substantially. In our three case studies we found several examples.

Concerning spatial navigation we found in our first case study that participants did not know how the "zoom by marquee" tool was utilized. We conclude that the reason is that they had not been in contact with systems that implemented this tool. In the second case study where the participants were experienced users of GI-technology, the "zoom by marquee" did not represent any difficulty. Moreover in the third case study we found evidence that users with a higher level of experience were faster at learning to use the new interface (although in the second task the influence diminished).

The experience with similar systems helps users to understand a new interface, but after a while (depending on the complexity of the system's functionality) users learn how to use it regardless of previous experience. In our third case study users with much experience of similar systems performed significantly better in the first task, than users with less experience. During the second task this difference diminished.

The kind of the geospatial technologies and information users have been in contact with before has a substantial influence on both user strategies and user performance. In our third case study users who had been in contact with GIS (i.e. geospatial systems for experts) were significantly faster than users who had not used GIS. On the other hand users who had used a GPS-based navigation system before the evaluation had significantly more difficulty in finding the correct location than users who had never used this kind of technology.

Digitizing a polygon was found to be difficult for non-expert users, since the notion of polygon is very specific to the data-structure of a polygon. In a study conducted by Kalbermatten (2010) it was found that the 15 participants who were required to digitize a landslide (given the three data types "point", "line" and "polygon") rarely chose the "polygon"- option unless they wereexperts in GI-technologies. The fact that non-expert users find it difficult to digitize polygons supports the claim by Traynor and Williams (1995) that *GIS' interfaces reflect the system architecture view, rather than the view of the user's work and require a sufficient level of knowledge in geography, cartography, database management and computer skills.*.

Concerning the user's cultural context we found evidence in the third case study that users who used the interface in the German language made significantly fewer interactions than French-language users. Another difference was the fact that English-language users and users who were abroad at the time of evaluation had a greater difficulty finding the locations specified in the task. This finding can be explained by the fact that these participants did not have previous knowledge about the two locations in the task (since they did not grow up in the region).

8.2.3 The system and the interaction

H4 System-related parameters have an influence on user performance, user strategies (spatial and non-spatial) and perception of spatial features

This hypothesis is related to classical usability studies (e.g. Haklay and Tobon (2003); Skarlatidou and Haklay (2006); Nivala *et al.* (2007); Wachowicz *et al.* (2008); Cöltekin *et al.* (2008)) where so-called usability problems are detected in different systems. In our three case studies we identified such problems as well. The problems were mainly related to the system's consistency (e.g. the inconsistent graphical and logical design in the second case study) or to the interaction design (e.g. tools for digitizing a parcel).

However, in the scope of system-related parameters, we have included not only aspects of the system's software but also the user's computer. In case study three we found that the type of the input device (mouse, touchpad, trackpad, etc.) has a significant influence on spatial navigation strategies (e.g. that the mousewheel is the preferred tool for zooming) and on the task-completion time (e.g. that wheel-mouse users were faster than touchpad-users). Moreover the Internet connection speed has a significant influence on the overall speed of the system.

8.2.4 The user and satisfaction

H5 User satisfaction depends on user-specific parameters

This hypothesis is supported by several results showing the influence of user's demographic parameters on specific ratings of satisfaction (e.g. age on graphical design or handedness on map navigation). Especially the user's knowledge and skills have a strong influence on the satisfaction: Our third case study showed that experience with similar systems has a significant influence on the satisfaction with graphical design, whereas computer skills influence the satisfaction with the system's logical design. Yet we argue that the user's knowledge and skills have both positive and negative consequences on satisfaction: Users who have less knowledge of geographical information and systems (and thus perform worse in terms of error rate, task-completion and rate of interaction) tend to be positive about the many possibilities of using the system and are thus more satisfied. On the other hand users with more experience (and thus a better performance) tend to expect more or different functionality than they have seen so far and are thus less satisfied.

8.2.5 The system and satisfaction

H6 System-related parameters influence user satisfaction

The three case studies confirm this hypothesis by providing several examples where usability-problems had a very negative effect on the satisfaction. For instance, in the second case study where the meaning of an icon was not evident to the participants, the users declared a strong dissatisfaction with the design of the icons. Furthermore, parameters related to the user's computer were also shown to have an influence on satisfaction: In the third case study, touchpad users were significantly more satisfied with map-navigation than wheel-mouse users. Also the Internet-connection speed had an influence on the user's appreciation of the system's speed. The user himself may not necessarily know that an online geospatial system's speed is highly dependent on the Internet connection speed.

8.3 Connections between parameters

In summary, we claim that the three case studies provide sufficient evidence to support each of our hypotheses. They also prove that the connections between the parameters of our conceptual framework exist. The framework however includes not only parameters that are measurable on nominal and ordinal scales, but also parameters that cannot be expressed with numbers. It is therefore difficult to say if an ordinal parameter has a greater influence on another ordinal parameter than an interface feature's interaction design on a parameter such as satisfaction. In this study we were hence only able to detect that a given connection between two parameters existed, but not to determine the weight of the connection.

Since our main interest lies in the interaction-related parameters of the framework, we addressed the connectedness of the parameters within this field with two hypotheses (H1 and H2). We proved that a user's strategy (e.g. a preference for a tool) has a significant influence on the rate of interaction which in turn is significantly connected to the task-completion time. Regarding the other three fields of parameters in our framework (the user, the system and the satisfaction) we anticipate similar degrees of connectedness.

By comparing user-related parameters among each other, we found that there is a significant connection between the user's age and his knowledge and skills (e.g. users' age was shown to have a correlation with experience of online geospatial systems. Age was also shown to have a correlation with the estimated level of computer skills. On the other hand, we found only a weak relationship between the user's gender and the user's knowledge and skills. Male and female users have similar experience of online geospatial systems. On the other hand male users have a higher self-estimated level of computer skills than female users.

8.4 Tools for analyzing user interaction with online geospatial systems

In chapter seven we have discussed several tools that enabled us to capture, visualize and analyze user interaction with online geospatial systems. Two of these tools (the log-file parsing tool, used in the first and third case study and the tool that captures the data traffic between the client and the server, used in the second case study) were built with the idea in mind that an online geospatial system only visualizes a piece of the available data at once. We thereby took advantage of the systems' architecture in order to retrace what exactly the users were doing while interacting with the systems.

We suggest that the idea to retrace user interaction by analyzing the requests that are sent between the client and the server could be re-utilized for the testing of almost any online geospatial system. Researchers, who are for instance interested in analyzing the usability of online geospatial systems could use such tools not only for the analysis of parameters suchlike the task-completion time or interaction strategies, but also for the detection of usability problems.

The javascript-library that captures and stores the interactions of the user's pointing device (used in the third case-study, see chapter seven) has been a reliable tool for the analysis of user's interaction strategies. Moreover it has enabled us to find evidence that suggest that spatial navigation strongly depends on the user's perception of geospatial data and that this perception is scale-dependent. These findings were rooted in the consideration that there is a high correlation between the user's pointing device movements and the user's eyes.

This tool could be re-utilized in the context of other online geospatial systems as well. However we need to mention that this tool only functions with specific system architectures (e.g. systems that are not based on plugins such as java-applets) and that its usage requires a slight modification (i.e. the inclusion of the library) of the system.

8.5 Recommendations

Based on the above findings, and the general experience acquired by conducting evaluations of three online geospatial systems, we propose a set of recommendations to help future designers and developers of online geospatial systems.

Recommendations for the design of interfaces:

1. **Implement several sets of spatial navigation tools.** Both the users' input device (mouse, touchpad, etc) and the users' previous experience have a significant influence on how users learn to interact with a new system. If the users are a heterogeneous group it is advisable to implement multiple tools for navigation (zoom tools, mouse-wheel zoom, a pan tool and pan-buttons).

2. **Optimize the system's architecture for low bandwidth consumption and map-processing.** We were able to prove that both bandwidth and map-processing substantially influence the system's speed and hence interaction time. Users are less satisfied when the system responds slowly to interactions.

3. **Optimize maps**. The design of the maps should not change from zoom level to zoom level, e.g. maps should not switch between satellite images and topographical maps. The infrastructure (roads, railway lines) should be made easily recognizable on the map since these features help the user to orientate and navigate. Street signatures are important.

4. **Implement navigation shortcuts**. Spatial navigation requires a considerable cognitive effort. The user needs to perceive the spatial information displayed, understand the interface, think of a strategy to navigate and apply the strategy. Shortcuts (e.g. a dialog-box where the user can enter the desired location, or drop-down menus) help users to find specific locations. A "locate-me" tool provides addition orientation help and can be easily implemented using databases or web-services that translate the IP-address to geospatial coordinates.

Recommendations for the development of online geospatial systems:

1. **Identify the user** and his previous experience of online geospatial systems ad well as his computer skills. Our case studies showed that especially extreme differences in knowledge and skills (e.g. experts vs novice users) have a significant influence on the way users interact with an online geospatial system. Below we explain how interfaces for experienced and less-experienced users should be designed.

2. **Conduct usability tests with real-world users** Many usability problems can be easily revealed with only a few test-users (depending on the complexity of the system and the number of functions implemented), but select the test-users with care since the user's gender, and knowledge and skills, have significant influence on the way they interact with a web-based geospatial system.

3. **Use the user-centered system development approach (UCD)** as the preferable model for the development process. The user-centered system development approach is a concept which already includes the two recommendations above. It includes four different stages: 1. the identification of the user, 2. the specification of user requirements, 3. the development of prototypes and finally 4. the validation of the prototypes

by the users. The philosophy behind this approach is to involve the user at all stages of the development process. We have successfully used this approach for the development of the RIV-system (see chapter seven) and we were able to conceive a successful system that was adapted to the user's needs.

Interfaces for less-experienced users: spatial navigation interfaces for less experienced users should contain navigation tools with a more direct interaction design that follows the interaction-design of standard (non-spatial) web-pages. For instance, one click on the interface should result in one immediate action. Navigation tools adapted to non-expert users are: clearly visible zoom in and zoom out, scale-choice tools, and pan-buttons around the map. Furthermore users with less experience of geospatial information and online geospatial information systems do not know geospatial data types (polygons, lines and points). For digitization tasks or tasks that require interaction with these data types users need to be guided (e.g. by giving explanations or through contextual help).

Interfaces for experienced users: experienced users are aware of the fact that an online geospatial system is not a simple web-page. These users are used to less implicit navigation tools such as the "zoom by marquee" tool or the mouse-wheel zoom. The system should therefore be optimized for performance (quick spatial interaction).

9 Conclusions and future work

9.1 User interaction with online geospatial systems

In recent years online geospatial systems have become a very diverse group of geospatial systems, available for a broad range of users. This fact has led to a gap between developers and users: the developing community still knows very little about the actual users of such systems; who they are, what their needs are and how they perceive and interact with geospatial technology and information. Moreover no clear guidelines or recommendations exist about how these systems should be developed and designed in a way that takes into account the user's context and background. Some researchers have conducted usability evaluations of existing systems and detected a variety of usability issues. These studies stress the importance of usability as a factor in development and evaluation of such systems, yet it is difficult to formulate general recommendations about the design of online geospatial systems purely based on these studies since few usability measures were collected in each study (e.g. only the end-user satisfaction or only the rate of errors), and the participants were often poorly characterized. It is not known if user-related factors influenced the results of the usability tests. Moreover, the systems that were evaluated were of a kind that change very rapidly, which means that the usability problems associated with them also may have changed.

In this work we chose a different approach to address user interaction with online geospatial systems. We established a conceptual framework of usability which includes all variables susceptible to influence both the interaction with online geospatial systems and the satisfaction of utilizing such systems. Most importantly, we have characterized users according to their demographic parameters, skills and knowledge of geospatial information and geospatial information technologies, and the user's physical and cultural context. Another aspect that is very important in the evaluation of online geospatial systems is the characterization of the user's computer in terms of input device (mouse, touchpad, touchscreen) and Internet connection speed.

In three different case studies we analyzed and explained the interaction of users with online geospatial systems with reference to the conceptual framework of usability-related parameters. We found that the user's knowledge and skills about geospatial technologies and information have a significant influence on both the interaction and the satisfaction with these systems. One of the results supporting this finding is that users who have used GPS-based navigation systems in the past, have a significantly greater difficulty to find specific locations on a map. This result can be explained by the fact that users who rely on GPS-technology to navigate in real life often have difficulties with orientation in general. It is also possible that the usage of GPS-technology make users pay less attention to their surroundings and therefore less capable of recognizing these surroundings on a map. Further we have detected a relationship between gender and task completion time. For tasks requiring less spatial interaction female subjects were faster, whereas male participants were faster in tasks requiring spatial navigation.

Regarding the impact of the user's computer on the usability of an online geospatial system, we found that some input devices are more adapted to certain spatial navigation tasks. Wheel-mouse for instance provides the option to zoom in and out by moving the wheel. Touchpad is difficult to use for map-dragging interaction. The pointing device hence has a significant effect on the way users interact with web-based geospatial systems.

The choice of interaction strategies can be further explained by the cognitive processes involved in using an online geospatial system. Spatial navigation in online geospatial systems is an iterative process between the user and the system. For every action that a use makes, the system displays a new map which is then perceived by the user. This perception and orientation activity represents a considerable mental effort which in turn has an influence on the way users choose the subsequent actions. We claim that interaction with geospatial systems differs in important ways from interaction with other non-geospatial systems: in geospatial systems the content represented has a strong relation to the real world. Therefore the perception, cognition and interaction with geospatial systems are influenced by the cognitive map a user has in mind of the real world.

Assessing the usefulness of the methods used for our three evaluations we conclude that the use of verbal protocols is particularly useful for understanding the cognitive processes involved in the interaction with online geospatial systems. The insights obtained from the first case study helped us to refine our evaluation method and to focus on the important elements of the interaction and satisfaction in the subsequent case-studies. With a supervised and a remote-testing approach we then gathered interaction- and satisfaction-related data along with relevant user- and system-characterizations.

The remote-testing of online geospatial systems has the advantage that it enables the evaluator to collect a considerable amount of usable data which yields statistically significant results. Moreover remote-testing does not influence the users in the same way a laboratory-based test does, and users get the opportunity to evaluate a system under more natural conditions. On the other hand the evaluation-expert does not have the same degree of control on the evaluation (e.g. if a user encounters a problem, the evaluation expert is not there to assess the problem). This lack of control however can also result in a more accurate assessment of user satisfaction. In a controlled laboratory-environment the satisfaction can be influenced by the contact with the evaluator. On the other hand in a remote-testing experiment new variables and constraints need to be considered (such as different computer features, browser types or network properties). One drawback of remotely conducted evaluations is that data analysis takes much time and that the data needs to be normalized (e.g. due to different variables such as the browser type).

Regarding the tools we implemented to collect interaction-related data, a great advantage is that the tested systems only download small amounts of data for each user-interaction, which is sufficient to retrace and analyze the user's interaction. We propose that these tools can be extended to evaluate nearly any online geospatial system, since most systems are divided into one or several data-servers providing the spatial data and a client that accesses only small pieces of this data at a time. The two main drawbacks with these data-capturing tools are that it is technically demanding to implement a solution to retrace data-exchanges and that profound knowledge of a system's architecture and technologies is required.

9.2 Limits of this study

Due to the limited functionality of the evaluated systems we had to focus on more general aspects of spatial interaction such as spatial navigation and digitization. Yet there are other important functions implemented in a variety of todays web-based geospatial systems such as layer management options, spatial analytical functions, three-dimensional spatial navigation, spatial data exchange and geospatial statistics. We go as far as to claim that, theoretically, any functionality implemented in desktop-systems can be implemented in online geospatial systems as well, for instance using the capabilities of geospatial databases and more advanced interfaces. Such systems could benefit from being evaluated with our methods and tools as well.

Another limitation of this work was imposed by the characteristics of our participants who were primarily students at technical universities. We presume that these participants already had a certain level of technical skills, experience and interest regarding technology. A more diverse group of users would possibly yield even more significant research results.

Concerning the different aspects of usability we need to remark that we neglected the aspect of learnability to a certain amount. In two case studies users were asked to perform almost the same task two times, yet we tested the three different systems with first-time users. Since one important finding of our study is that the interaction with similar systems generates knowledge and skills (which in turn help users to utilize a new system), a natural consequence is that the accumulated knowledge and skills change the way a user utilizes a system over time. The change of utilization of systems over time has been addressed by several researchers in the past and is an important aspect of the Activity Theory.

9.3 Future work

We have seen that online geospatial systems evolve very rapidly and new interaction manners and functions are being implemented. Spatial navigation for instance has seen recent developments. An increasing number of systems today offer navigation in three dimensions (e.g. the Google Earth plugin, porting 3D-capabilities to web-browsers). New input devices have reached the market (such as Logitech's 3-D Spatial Navigator device), and new ways for spatial navigation are being implemented (e.g. using the gestures "pinching" and "unpinching" for zooming in Apple's Iphone device). In order to keep up with these recent trends we stress that new evaluations are necessary to validate both the usage and the usability of these technologies.

The method that we have used to address user interaction with online geospatial systems presumably needs to be adapted to accommodate recent trends, but we suggest that the general idea of capturing the interaction of real-world users with geospatial systems yields reliable results and generates generalizable recommendations. We therefore propose that future evaluations of online geospatial systems help refining, adapting and validating the recommendations derived from this work. We can also imagine that these recommendations can be generalized to integrate other geospatial systems, yet we stress that the technical specificities of geospatial systems has a substantial effect on the interaction (for instance the web-context of online geospatial systems).

Another interesting track for future work is the perception of geospatial data and features in geospatial systems. It would be interesting to validate our findings by analyzing the correlation between the user's eye-movements and the moves of the pointing-device for the specific case of geospatial systems. It is possible that the perception of geospatial features is both scale- and perspective-dependent and therefore substantially influences the user's interaction with such systems. It is also possible that the type of input device has a significant influence on this correlation.

The pointing-device tracking tool could be useful for future evaluations (both remotely conducted and laboratory-based) where both the interface and the content that is displayed are evaluated. In our study we predominantly used the pointing-device's movements to assess the perception of geospatial features and user strategies, yet the tool also captures all actions with a high accuracy (clicks, mouse-wheel movements) and could be used to gather measures such as task-completion time or the rate of interaction.

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A
Diagrams and figures - case study three

Interaction diagrams

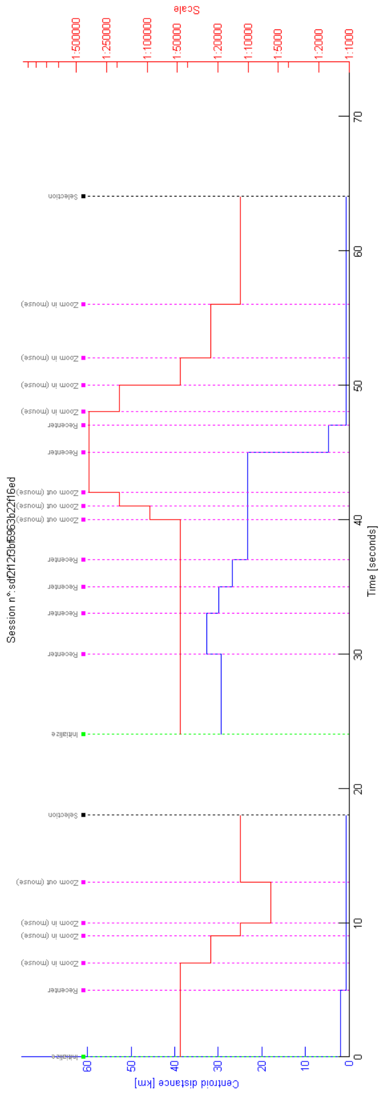

Figure A.1: An example of an interaction-diagram showing a test-user using the mouse-wheel for zooming and clicking on the map for panning

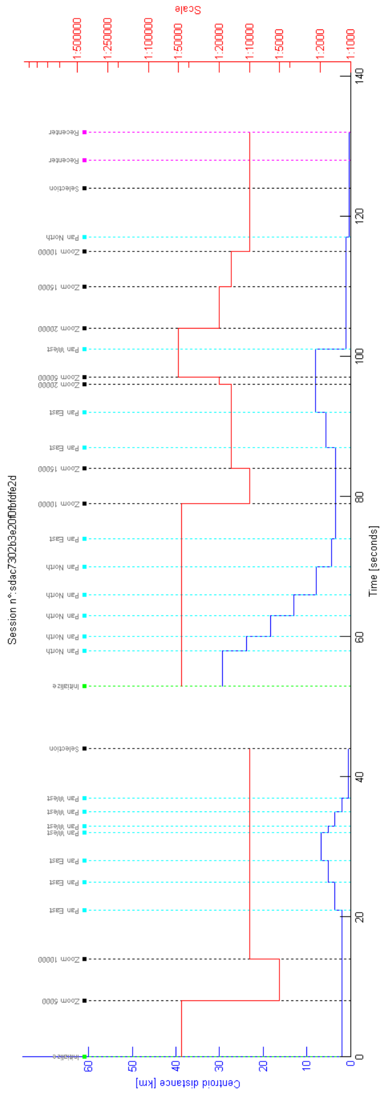

Figure A.2: An example of an interaction-diagram showing a test-user using zoom buttons for zooming and pan-buttons for panning

Perception of spatial features

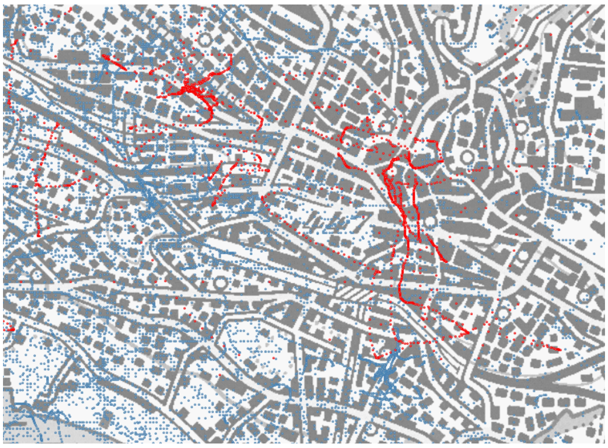

Figure A.3: A user's cursor positions in task 1 highlighted in red color, example 2.

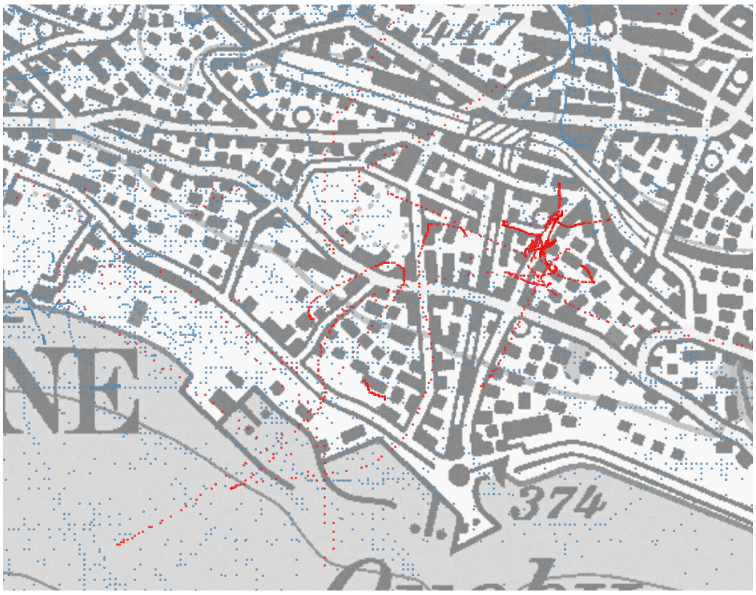

Figure A.4: A user's cursor positions in task 1 highlighted in red color, example 3.

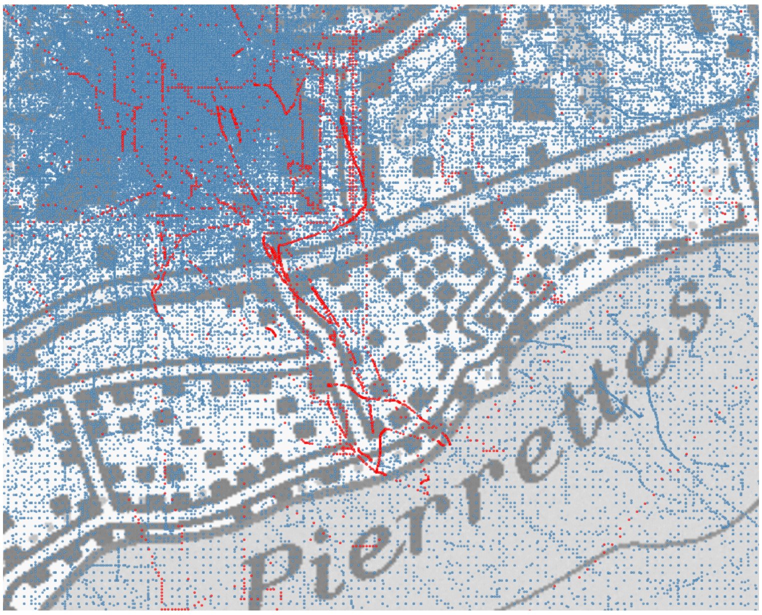

Figure A.5: A user's cursor positions in task 1 highlighted in red color, example 4.

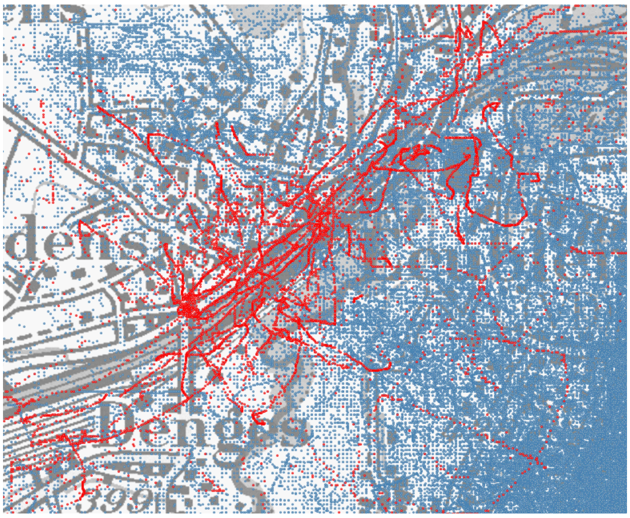

Figure A.6: A user's cursor positions in task 1 highlighted in red color, example 5.

B

Statistical data - case study three

Comparison interaction strategies

	0% - 19.9%		20%-39.9%		40%-59.9%		60%-79.9%		80%-100%	
Preference	#U	%U	#U	%U	#U	%U	#U	%U	#U	%U
ZB+P	0	0%	0	0%	5	31%	15	14%	2	4%
ZB+R	0	0%	1	33%	4	25%	47	45%	89	43%
ZB+NP	0	0%	0	0%	0	0%	4	4%	2	1%
SC+P	0	0%	0	0%	1	6%	3	3%	5	2%
SC+R	0	0%	0	0%	1	6%	2	2%	43	21%
SC+NP	0	0%	0	0%	0	0%	2	2%	4	2%
MW+P	0	0%	0	0%	0	0%	8	8%	2	1%
MW+R	0	0%	1	33%	3	19%	17	16%	46	22%
MW+NP	0	0%	0	0%	0	0%	5	5%	6	3%
NZ+P	0	0%	0	0%	1	6%	0	0%	1	0%
NZ+R	0	0%	1	33%	1	6%	2	2%	6	3%
NZ+NP	0	0%	0	0%	0	0%	0	0%	1	0%
Total	0		3		16		105		207	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.1: Categories of preference for zoom choice and moving the map compared to the time users spent on the map (in percent); task one

	0% - 19.9%		20%-39.9%		40%-59.9%		60%-79.9%		80%-100%	
Preference	#U	%U	#U	%U	#U	%U	#U	%U	#U	%U
ZB+P	1	33%	0	0%	11	38%	38	32%	15	8%
ZB+R	0	0%	2	50%	8	28%	45	38%	36	20%
ZB+NP	0	0%	0	0%	3	10%	5	4%	3	2%
SC+P	1	33%	0	0%	1	3%	6	5%	27	15%
SC+R	0	0%	1	25%	2	7%	0	0%	46	26%
SC+NP	0	0%	0	0%	0	0%	0	0%	9	5%
MW+P	1	33%	1	25%	1	3%	8	7%	9	5%
MW+R	0	0%	0	0%	3	10%	10	9%	19	11%
MW+NP	0	0%	0	0%	0	0%	2	2%	5	3%
NZ+P	0	0%	0	0%	0	0%	2	2%	2	1%
NZ+R	0	0%	0	0%	0	0%	0	0%	7	4%
NZ+NP	0	0%	0	0%	0	0%	1	1%	0	0%
Total	3		4		29		117	0	178	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.2: Categories of preference for zoom choice and moving the map compared to the time users spent on the map (in percent); task two

Comparison user performance and user strategies

	Time				Rate			
	Task one		Task two		Task one		Task two	
Comparison	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
ZB + P vs ZB + R	0	0.1254	1	0.0001	0	0.6105	1	0.0005
ZB + P vs SC + P	0	0.7113	0	0.3401	0	1.0000	0	0.4670
ZB + P vs SC + R	0	0.3352	1	0.0005	0	0.2689	1	0.0000
ZB + P vs MW + P	0	0.3352	0	0.4072	0	0.3811	0	0.3776
ZB + P vs MW + R	0	0.7681	1	0.0465	0	0.4627	0	0.5852
ZB + R vs SC + P	0	0.5501	0	0.0535	0	0.5225	0	0.1109
ZB + R vs SC + R	0	0.6696	0	0.5221	0	0.2550	1	0.0084
ZB + R vs MW + P	0	0.1101	1	0.0012	0	0.1350	1	0.0018
ZB + R vs MW + R	0	0.0800	0	0.1392	1	0.0184	1	0.0081
SC + P vs SC + R	0	0.7500	0	0.0532	0	0.4097	1	0.0067
SC + P vs MW + P	0	0.4967	0	0.1301	0	0.6744	0	0.3054
SC + P vs MW + R	0	0.8281	0	0.6155	0	0.7716	0	0.7773
SC + R vs MW + P	0	0.1811	1	0.0029	0	0.0678	1	0.0004
SC + R vs MW + R	0	0.3482	0	0.0908	1	0.0098	1	0.0005
MW + P vs MW + R	0	0.3592	1	0.0403	0	0.5535	0	0.2312

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel
P: Pan-buttons, R: Recenter by clicking on the map

Table B.3: Statistical significance for the relation between interaction strategies and task completion time and between interaction strategies and rate of interaction; both tasks

	Time				Rate			
	Task one		Task two		Task one		Task two	
Comparison	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
0%-19.9% vs 20%-39.9%	-	-	0	0.2286	-	-	0	0.8571
0%-19.9% vs 40%-59.9%	-	-	1	0.0279	-	-	1	0.0377
0%-19.9% vs 60%-79.9%	-	-	1	0.0138	-	-	1	0.0325
0%-19.9% vs 80%-100%	-	-	1	0.0098	-	-	0	0.1273
20%-39.9% vs 40%-59.9%	0	0.3509	0	0.9341	0	0.59	0	0.2336
20%-39.9% vs 60%-79.9%	0	0.1608	0	0.7224	0	0.96	0	0.2761
20%-39.9% vs 80%-100%	0	0.1154	0	0.4369	0	0.72	0	0.9082
40%-59.9% vs 60%-79.9%	0	0.8814	1	0.0081	0	0.28	0	0.4347
40%-59.9% vs 80%-100%	0	0.6728	1	0.0003	0	0.42	1	0.0040
60%-79.9% vs 80%-100%	0	0.1740	0	0.0583	0	0.32	1	0.0002

Table B.4: Statistical significance for the comparisons between groups of users having spent a certain percentage on the map with their cursors, task-completion time and rate of interaction; both tasks

Comparison user performance

	Task one		Task two	
Time	**# of users**	**% of users in cat.**	**# of users**	**% of users in cat.**
0-20 s	0	0%	3	7%
21-40 s	1	3%	7	10%
41-60 s	4	4%	5	8%
61-80 s	9	13%	3	7%
81-100 s	5	14%	0	0%
101-120 s	5	17%	3	16%
121-140 s	2	18%	0	0%
141-160 s	2	17%	0	0%
161-180 s	2	40%	0	0%
181-200 s	2	40%	3	60%
201-220 s	0	0%	3	75%
221-240 s	1	20%	0	0%
241-260 s	1	25%	1	33%
261-280 s	0	0%	1	33%
281-300 s	0	0%	0	0%
301-320 s	1	33%	1	0%
321-340 s	0	0%	0	0%
341-360 s	1	33%	0	0%
361-380 s	0	0%	0	0%
381-400 s	0	0%	0	0%
401-420 s	0	0%	0	0%
$\geq$ **420 s**	1	33%	0	0%
Total	37		30	

Table B.5: Number of users having failed to complete task one and two according to their task-completion time

Comparison user-related parameters and user performance

	Time				Rate			
	Task one		Task two		Task one		Task two	
Comparison	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Male vs female	1	0.0000256	1	0.0000001	1	0.006022	1	0.000002
Left- vs righthanded	0	0.7820918	0	0.2242296	0	0.720162	0	0.414797
≤20y.o. vs 21-30y.o.	1	0.0001275	1	0.0001974	1	0.020739	1	0.008113
≤20y.o. vs 31-40y.o.	0	0.1901771	1	0.0035942	1	0.047589	1	0.002073
≤20y.o. vs 51-60y.o.	0	0.2874593	0	0.1623873	0	0.308162	0	0.137230
21-30y.o. vs 31-40y.o.	0	0.8705947	1	0.0444128	0	0.173408	1	0.013606
21-30y.o. vs 51-60y.o.	0	0.0743821	0	0.4661533	0	0.145406	0	0.285767
31-40y.o. vs 51-60y.o.	0	0.0833333	0	0.9666667	0	0.116667	0	0.966667

Table B.6: Statistical significance of the comparison between demographic parameters, task-completion time and rate of interaction; both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Never vs v rarely	0	0.47	0	0.11	0	0.69	0	0.28	0	0.52	0	0.22
Never vs sometimes	0	0.60	0	0.24	0	0.34	0	0.31	0	0.89	0	0.18
Never vs often	0	0.40	0	0.43	0	0.21	0	0.39	0	0.58	0	0.34
Never vs very often	0	0.51	0	0.91	1	0.04	0	0.73	0	0.77	0	0.43
V rarely vs sometimes	0	0.08	0	0.15	0	0.38	0	0.72	0	0.69	0	0.82
V rarely vs often	1	0.02	1	0.02	0	0.20	0	0.51	0	0.83	0	0.39
V rarely vs v often	0	0.27	0	0.11	1	0.02	0	0.16	0	1.00	0	0.52
Sometimes vs often	0	0.31	0	0.17	0	0.05	0	0.76	0	0.41	0	0.17
Sometimes vs v often	0	0.83	0	0.28	0	0.43	0	0.14	0	0.77	0	0.41
Often vs v often	0	0.85	0	0.67	0	0.19	0	0.20	0	0.89	0	0.87

Table B.7: Statistical significance for the comparison map usage and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
$I \in [0,2]$ vs $I \in [3,5]$	0	0.861	0	0.911	0	0.352	0	0.777	0	0.075	0	0.240
$I \in [0,2]$ vs $I \in [6,8]$	0	0.172	0	0.324	0	0.051	0	0.817	0	0.392	1	0.001
$I \in [0,2]$ vs $I \in [9,11]$	0	0.056	0	0.107	1	0.032	0	0.469	0	0.163	0	0.059
$I \in [0,2]$ vs $I \in [12,14]$	0	0.115	0	0.219	0	0.114	0	0.574	0	0.352	0	0.352
$I \in [3,5]$ vs $I \in [6,8]$	1	0.003	0	0.101	1	0.047	0	0.460	0	0.243	0	0.909
$I \in [3,5]$ vs $I \in [9,11]$	1	0.005	1	0.022	1	0.033	0	0.214	0	0.747	1	0.009
$I \in [3,5]$ vs $I \in [12,14]$	1	0.026	0	0.135	0	0.187	0	0.474	0	0.537	0	0.184
$I \in [6,8]$ vs $I \in [9,11]$	0	0.188	0	0.202	0	0.409	0	0.397	0	0.360	0	0.467
$I \in [6,8]$ vs $I \in [12,14]$	0	0.192	0	0.224	0	0.488	0	0.521	0	0.439	0	0.752
$I \in [9,11]$ vs $I \in [12,14]$	0	0.648	0	0.608	0	0.797	0	0.797	0	0.634	0	0.777

Table B.8: Statistical significance for the comparison between groups having the same range of experience (represented by the index I) with similar systems) and user performance; both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
GPS vs no GPS	0	0.313	0	0.599	0	0.783	0	0.766	1	0.025	1	0.001
GIS vs no GIS	0	0.051	1	0.043	1	0.035	1	0.016	0	0.277	0	0.202

Table B.9: Statistical significance for the comparison GPS and GIS usage and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
Bad vs fair	0	0.0909	1	0.0251	0	0.4018	0	0.1338	0	0.0587	0	0.3025
Bad vs good	1	0.0190	1	0.0205	0	0.1095	0	0.1436	0	0.0557	1	0.0300
Bad vs v good	1	0.0006	1	0.0067	1	0.0424	0	0.1387	1	0.0464	1	0.0267
Fair vs good	0	0.1850	0	0.8432	0	0.1357	0	0.9550	0	0.9890	0	0.1016
Fair vs v good	1	0.0011	0	0.1405	1	0.0329	0	0.8846	0	0.5995	0	0.0995
Good vs v good	1	0.0191	0	0.1393	0	0.3299	0	0.9701	0	0.5859	0	0.5314

Table B.10: Statistical significance for the comparison computer skills and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
English vs French	1	0.03	0	0.93	1	0.05	0	0.89	0	0.89	1	0.03
English vs German	0	0.22	0	0.23	0	0.47	0	0.12	0	0.06	0	0.17
French vs German	0	0.55	0	0.12	0	0.36	1	0.04	0	0.06	0	0.94

Table B.11: Statistical significance for the comparison chosen language and user performance (task-completion time, rate of interaction and errors); both tasks

Comparison user-related parameters and interaction strategies

	All users		≤20y.o.		21-30 y.o.		31-40 y.o.		51-60 y.o.	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	22	7%	10	8%	10	5%	1	14%	1	33%
ZB and R	141	43%	49	40%	89	45%	2	29%	1	33%
ZB and NP	6	2%	1	1%	5	3%	0	0%	0	0%
SC and P	9	3%	2	2%	7	4%	0	0%	0	0%
SC and R	46	14%	19	15%	24	12%	2	29%	1	33%
SC and NP	6	2%	3	2%	3	2%	0	0%	0	0%
MW and P	10	3%	4	3%	6	3%	0	0%	0	0%
MW and R	67	20%	26	21%	40	20%	1	14%	0	0%
MW and NP	11	3%	4	3%	7	4%	0	0%	0	0%
NZ and P	2	1%	1	1%	1	1%	0	0%	0	0%
NZ and R	10	3%	5	4%	4	2%	1	14%	0	0%
NZ and NP	1	0%	0	0%	1	1%	0	0%	0	0%
Total # of U	331		124		197		7		3	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.12: Categories of preference for zoom choice and moving the map compared to the user's age; task one

	All users		≤20y.o.		21-30 y.o.		31-40 y.o.		51-60 y.o.	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	65	20%	24	19%	39	20%	1	14%	1	33%
ZB and R	91	27%	29	23%	60	30%	2	29%	0	0%
ZB and NP	11	3%	5	4%	6	3%	0	0%	0	0%
SC and P	35	11%	10	8%	24	12%	1	14%	0	0%
SC and R	49	15%	21	17%	25	13%	1	14%	2	67%
SC and NP	9	3%	5	4%	3	2%	1	14%	0	0%
MW and P	20	6%	13	10%	7	4%	0	0%	0	0%
MW and R	32	10%	11	9%	21	11%	0	0%	0	0%
MW and NP	7	2%	3	2%	4	2%	0	0%	0	0%
NZ and P	4	1%	1	1%	3	2%	0	0%	0	0%
NZ and R	7	2%	1	1%	5	3%	1	14%	0	0%
NZ and NP	1	0%	1	1%	0	0%	0	0%	0	0%
Total # of U	331		124		197		7		3	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.13: Categories of preference for zoom choice and moving the map compared to the user's age; task two

	All users		Female		Male		Lefthanded		Righthanded	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	22	6%	8	8%	14	6%	2	5%	20	7%
ZB and R	141	43%	44	43%	97	43%	21	55%	120	41%
ZB and NP	6	2%	3	3%	3	1%	2	5%	4	1%
SC and P	9	3%	2	2%	7	3%	2	5%	7	2%
SC and R	46	14%	12	12%	34	15%	4	11%	42	14%
SC and NP	6	2%	2	2%	4	2%	0	0%	6	2%
MW and P	10	3%	3	3%	7	3%	1	3%	9	3%
MW and R	67	20%	19	18%	48	21%	6	16%	61	21%
MW and NP	11	3%	5	5%	6	3%	0	0%	11	4%
NZ and P	2	1%	1	1%	1	0%	0	0%	2	1%
NZ and R	10	3%	4	4%	6	3%	0	0%	10	3%
NZ and NP	1	0%	0	0%	1	0%	0	0%	1	0%
Total # of U	331		103		228		38		293	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.14: Categories of preference for zoom choice and moving the map compared to the user's gender and handedness; task one

	All users		Female		Male		Lefthanded		Righthanded	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	65	20%	28	27%	37	16%	9	24%	56	19%
ZB and R	91	27%	24	23%	67	29%	8	21%	83	28%
ZB and NP	11	3%	4	4%	7	3%	4	11%	7	2%
SC and P	35	11%	13	13%	22	10%	6	16%	29	10%
SC and R	49	15%	13	13%	36	16%	4	11%	45	15%
SC and NP	9	3%	1	1%	8	4%	1	3%	8	3%
MW and P	20	6%	8	8%	12	5%	2	5%	18	6%
MW and R	32	10%	8	8%	24	11%	3	8%	29	10%
MW and NP	7	2%	1	1%	6	3%	0	0%	7	2%
NZ and P	4	1%	2	2%	2	1%	0	0%	4	1%
NZ and R	7	2%	1	1%	6	3%	1	3%	6	2%
NZ and NP	1	0%	0	0%	1	0%	0	0%	1	0%
Total # of U	331		103		228		38		293	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.15: Categories of preference for zoom choice and moving the map compared to the user's gender and handedness; task two

	$I \in [0,2]$		$I \in [3,5]$		$I \in [6,8]$		$I \in [9,10]$		$I \in [11,12]$	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	2	7%	11	7%	8	8%	1	4%	0	0%
ZB and R	13	43%	70	42%	48	47%	9	32%	1	25%
ZB and NP	0	0%	3	2%	3	3%	0	0%	0	0%
SC and P	0	0%	5	3%	2	2%	0	0%	2	50%
SC and R	1	3%	31	19%	10	10%	4	14%	0	0%
SC and NP	1	3%	4	2%	0	0%	1	4%	0	0%
MW and P	1	3%	6	4%	2	2%	1	4%	0	0%
MW and R	10	33%	25	15%	22	21%	10	36%	0	0%
MW and NP	0	0%	4	2%	4	4%	2	7%	1	25%
NZ and P	0	0%	2	1%	0	0%	0	0%	0	0%
NZ and R	1	3%	5	3%	4	4%	0	0%	0	0%
NZ and NP	1	3%	0	0%	0	0%	0	0%	0	0%
Total # of U	30		166		103		28		4	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.16: Categories of preference for zoom choice and moving the map compared to the experience index I; task one

	$I \in [0,2]$		$I \in [3,5]$		$I \in [6,8]$		$I \in [9,10]$		$I \in [11,12]$	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	7	23%	36	22%	19	18%	3	11%	0	0%
ZB and R	7	23%	42	25%	35	34%	6	21%	1	25%
ZB and NP	0	0%	9	5%	2	2%	0	0%	0	0%
SC and P	3	10%	13	8%	14	14%	4	14%	1	25%
SC and R	4	13%	32	19%	9	9%	3	11%	1	25%
SC and NP	1	3%	6	4%	1	1%	1	4%	0	0%
MW and P	4	13%	9	5%	4	4%	2	7%	1	25%
MW and R	3	10%	13	8%	9	9%	7	25%	0	0%
MW and NP	1	3%	2	1%	4	4%	0	0%	0	0%
NZ and P	0	0%	2	1%	2	2%	0	0%	0	0%
NZ and R	0	0%	2	1%	3	3%	2	7%	0	0%
NZ and NP	0	0%	0	0%	1	1%	0	0%	0	0%
Total # of U	30		166		103		28		4	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.17: Categories of preference for zoom choice and moving the map compared to the experience index I; task two

	Has used GPS		**Has not used GPS**	
Preference	**#U**	**% of U**	**#U**	**% of U**
ZB and P	12	6%	10	9%
ZB and R	97	45%	44	38%
ZB and NP	3	1%	3	3%
SC and P	5	2%	4	3%
SC and R	29	13%	17	15%
SC and NP	5	2%	1	1%
MW and P	6	3%	4	3%
MW and R	42	20%	25	22%
MW and NP	8	4%	3	3%
NZ and P	2	1%	0	0%
NZ and R	7	3%	3	3%
NZ and NP	0	0%	1	1%
Total # of U	216		115	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.18: Categories of preference for zoom choice and moving the map compared to the question if the user has used a GPS-based navigation system; task one

	Has used GPS		Has not used GPS	
Preference	**#U**	**% of U**	**#U**	**% of U**
ZB and P	34	16%	31	27 %
ZB and R	66	31%	25	22 %
ZB and NP	10	5 %	1	1 %
SC and P	27	13 %	8	7 %
SC and R	26	12 %	23	20 %
SC and NP	5	2 %	4	3 %
MW and P	11	5 %	9	8 %
MW and R	24	11 %	8	7 %
MW and NP	5	2 %	2	2 %
NZ and P	4	2 %	0	0 %
NZ and R	3	1 %	4	3 %
NZ and NP	1	0 %	0	0 %
Total # of U	216		115	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.19: Categories of preference for zoom choice and moving the map compared to the question if the user has used a GPS-based navigation system; task two

	Has used GIS		Has not used GIS	
Preference	**#U**	**% of U**	**#U**	**% of U**
ZB and P	3	4%	19	7%
ZB and R	27	36%	114	45%
ZB and NP	2	3%	4	2%
SC and P	4	5%	5	2%
SC and R	9	12%	37	15%
SC and NP	1	1%	5	2%
MW and P	2	3%	8	3%
MW and R	21	28%	46	18%
MW and NP	3	4%	8	3%
NZ and P	0	0%	2	1%
NZ and R	3	4%	7	3%
NZ and NP	0	0%	1	0%
Total # of U	75		256	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.20: Categories of preference for zoom choice and moving the map compared to the question if the user has used a GIS; task one

	Has used GIS		Has not used GIS	
Preference	**#U**	**% of U**	**#U**	**% of U**
ZB and P	11	15%	54	21%
ZB and R	19	25%	72	28%
ZB and NP	2	3%	9	4%
SC and P	12	16%	23	9%
SC and R	8	11%	41	16%
SC and NP	2	3%	7	3%
MW and P	4	5%	16	6%
MW and R	9	12%	23	9%
MW and NP	4	5%	3	1%
NZ and P	2	3%	2	1%
NZ and R	2	3%	5	2%
NZ and NP	0	0%	1	0%
Total # of U	75		256	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.21: Categories of preference for zoom choice and moving the map compared to the question if the user has used a GIS; task two

	Very bad		Bad		Fair		Good		Very good	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	0	0%	1	5%	8	7%	11	8%	2	4%
ZB and R	0	0%	10	53%	49	40%	52	37%	30	60%
ZB and NP	0	0%	1	5%	3	2%	2	1%	0	0%
SC and P	0	0%	1	5%	1	1%	5	4%	2	4%
SC and R	0	0%	1	5%	19	16%	18	13%	8	16%
SC and NP	0	0%	0	0%	4	3%	2	1%	0	0%
MW and P	0	0%	1	5%	7	6%	2	1%	0	0%
MW and R	0	0%	3	16%	26	21%	33	24%	5	10%
MW and NP	0	0%	1	5%	2	2%	8	6%	0	0%
NZ and P	0	0%	0	0%	1	1%	0	0%	1	2%
NZ and R	0	0%	0	0%	2	2%	6	4%	2	4%
NZ and NP	0	0%	0	0%	0	0%	1	1%	0	0%
Total # of U			19		122		140		50	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.22: Categories of preference for zoom choice and moving the map compared to the user-estimated level of computer skills; task one

	Very bad		Bad		Fair		Good		Very good	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
ZB and P	0	0%	7	37%	27	22%	22	16%	9	18%
ZB and R	0	0%	3	16%	33	27%	34	24%	21	42%
ZB and NP	0	0%	0	0%	4	3%	5	4%	2	4%
SC and P	0	0%	2	11%	11	9%	19	14%	3	6%
SC and R	0	0%	3	16%	22	18%	18	13%	6	12%
SC and NP	0	0%	0	0%	3	2%	5	4%	1	2%
MW and P	0	0%	1	5%	9	7%	9	6%	1	2%
MW and R	0	0%	3	16%	7	6%	18	13%	4	8%
MW and NP	0	0%	0	0%	3	2%	3	2%	1	2%
NZ and P	0	0%	0	0%	2	2%	2	1%	0	0%
NZ and R	0	0%	0	0%	1	1%	5	4%	1	2%
NZ and NP	0	0%	0	0%	0	0%	0	0%	1	2%
Total # of U			19		122		140		50	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.23: Categories of preference for zoom choice and moving the map compared to the user-estimated level of computer skills; task two

	Never		Very rarely		Sometimes		Often		Very often	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
ZB and P	0	0%	6	13%	8	5%	7	7%	1	5%
ZB and R	10	71%	18	38%	68	44%	39	41%	6	32%
ZB and NP	0	0%	1	2%	5	3%	0	0%	0	0%
SC and P	0	0%	2	4%	3	2%	2	2%	2	11%
SC and R	1	7%	7	15%	24	15%	10	11%	4	21%
SC and NP	1	7%	0	0%	2	1%	2	2%	1	5%
MW and P	0	0%	1	2%	5	3%	3	3%	1	5%
MW and R	2	14%	9	19%	28	18%	24	25%	4	21%
MW and NP	0	0%	0	0%	6	4%	5	5%	0	0%
NZ and P	0	0%	1	2%	0	0%	1	1%	0	0%
NZ and R	0	0%	3	6%	5	3%	2	2%	0	0%
NZ and NP	0	0%	0	0%	1	1%	0	0%	0	0%
Total # of U	14		48		155		95		19	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.24: Categories of preference for zoom choice and moving the map compared to the usage of paper maps; task one

	Never		Very rarely		Sometimes		Often		Very often	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	4	29%	12	25%	27	17%	18	19%	4	21%
ZB and R	4	29%	13	27%	44	28%	26	27%	4	21%
ZB and NP	1	7%	1	2%	8	5%	1	1%	0	0%
SC and P	1	7%	2	4%	20	13%	9	9%	3	16%
SC and R	2	14%	8	17%	22	14%	14	15%	3	16%
SC and NP	0	0%	1	2%	4	2%	3	3%	1	5%
MW and P	0	0%	5	10%	10	6%	5	5%	0	0%
MW and R	2	14%	4	8%	11	7%	12	13%	3	16%
MW and NP	0	0%	1	2%	4	3%	2	2%	0	0%
NZ and P	0	0%	0	0%	2	1%	2	2%	0	0%
NZ and R	0	0%	1	2%	2	1%	3	3%	1	5%
NZ and NP	0	0%	0	0%	1	1%	0	0%	0	0%
Total # of U	14		48		155		95		19	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.25: Categories of preference for zoom choice and moving the map compared to the usage of paper maps; task two

	English		French		German	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	2	9%	19	7%	1	4%
ZB and R	15	65%	118	42%	8	31%
ZB and NP	1	4%	3	1%	2	8%
SC and P	0	0%	8	3%	1	4%
SC and R	1	4%	39	14%	6	23%
SC and NP	0	0%	5	2%	1	4%
MW and P	0	0%	10	4%	0	0%
MW and R	3	13%	58	21%	6	23%
MW and NP	0	0%	11	4%	0	0%
NZ and P	0	0%	2	1%	0	0%
NZ and R	0	0%	9	3%	1	4%
NZ and NP	1	4%	0	0%	0	0%
Total # of U	23		282		26	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.26: Categories of preference for zoom choice and moving the map compared to the language chosen; task one

	English		French		German	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
ZB and P	8	35%	52	18%	5	19%
ZB and R	8	35%	76	27%	7	27%
ZB and NP	1	4%	10	4%	0	0%
SC and P	0	0%	35	12%	0	0%
SC and R	2	9%	40	14%	7	27%
SC and NP	2	9%	6	2%	1	4%
MW and P	1	4%	18	6%	1	4%
MW and R	1	4%	27	10%	4	15%
MW and NP	0	0%	6	2%	1	4%
NZ and P	0	0%	4	1%	0	0%
NZ and R	0	0%	7	2%	0	0%
NZ and NP	0	0%	1	0%	0	0%
Total # of U	23		282		26	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.27: Categories of preference for zoom choice and moving the map compared to the language chosen; task two

	≤20y.o.		21-30 y.o.		31-40 y.o.		51-60 y.o.	
Percentage	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	0	0%	0	0%	0	0 %	0	0%
20%-39.9%	2	2%	1	1%	0	0 %	0	0%
40%-59.9%	9	7%	5	3%	2	29%	0	0%
60%-79.9%	42	34%	61	31%	1	14%	1	33%
80%-100%	71	57%	130	66%	4	57%	2	67%
Total # of U	124		197		7		3	

Table B.28: Percentages the users spent on the map with their cursors during the task compared to the user's age; task one.

	≤20y.o.		21-30 y.o.		31-40 y.o.		51-60 y.o.	
Percentage	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	2	2%	1	1%	0	0%	0	0%
20%-39.9%	2	2%	2	1%	0	0%	0	0%
40%-59.9%	16	13%	12	6%	1	14%	0	0%
60%-79.9%	47	38%	67	34%	2	29%	1	33%
80%-100%	57	46%	115	58%	4	57%	2	67%
Total # of U	124		197		7		3	

Table B.29: Percentages the users spent on the map with their cursors during the task compared to the user's age; task two.

	Female		Male	
Percentage	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	0	0 %	0	0%
20%-39.9%	1	1 %	2	1%
40%-59.9%	8	8 %	8	2%
60%-79.9%	40	39%	65	29%
80%-100%	54	52%	153	67%
Total # of U	103		228	

Table B.30: Percentages the users spent on the map with their cursors during the task compared to the user's gender; task one.

	Female		Male	
Percentage	#U	% of U	#U	% of U
0%-19.9%	2	2%	1	0%
20%-39.9%	0	0%	4	2%
40%-59.9%	13	13%	16	7%
60%-79.9%	50	49%	67	29%
80%-100%	38	37%	140	61%
Total # of U	103		228	

Table B.31: Percentages the users spent on the map with their cursors during the task compared to the user's gender; task one.

	Lefthanded		Righthanded	
Percentage	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%
20%-39.9%	0	0%	3	1%
40%-59.9%	2	5%	14	5%
60%-79.9%	14	37%	91	31%
80%-100%	22	58%	185	63%
Total # of U	38		293	

Table B.32: Percentages the users spent on the map with their cursors during the task compared to the user's handedness; task one.

	Lefthanded		Righthanded	
Percentage	#U	% of U	#U	% of U
0%-19.9%	0	0 %	3	1%
20%-39.9%	1	3 %	3	1%
40%-59.9%	2	5 %	27	9%
60%-79.9%	17	45%	100	34%
80%-100%	18	47%	160	55%
Total # of U	38		293	

Table B.33: Percentages the users spent on the map with their cursors during the task compared to the user's handedness; task two.

	$I \in [0, 2]$		$I \in [3, 5]$		$I \in [6, 8]$		$I \in [9, 10]$		$I \in [12, 14]$	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%	0	0%	0	0%	0	0%
20%-39.9%	1	3%	2	1%	0	0%	0	0%	0	0%
40%-59.9%	1	3%	6	4%	5	5%	4	14%	0	0%
60%-79.9%	10	33%	49	30%	38	37%	7	25%	1	25%
80%-100%	18	60%	109	66%	60	58%	17	61%	3	75%
Total # of U	30		166		103		28		4	

Table B.34: Percentages the users spent on the map with their cursors during the task compared to the experience index I; task one.

	$I \in [0, 2]$		$I \in [3, 5]$		$I \in [6, 8]$		$I \in [9, 10]$		$I \in [12, 14]$	
Preference	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	0	0%	2	1%	1	1%	0	0%	0	0%
20%-39.9%	0	0%	3	2%	1	1%	0	0%	0	0%
40%-59.9%	5	17%	14	8%	8	8%	2	7%	0	0%
60%-79.9%	12	40%	64	39%	33	32%	8	29%	0	0%
80%-100%	13	43%	83	50%	60	58%	18	64%	4	100%
Total # of U	30		166		103		28		4	

Table B.35: Percentages the users spent on the map with their cursors during the task compared to the experience index I; task two.

	Has used a GPS		**Has not used a GPS**	
Percentage	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	0	0%	0	0%
20%-39.9%	2	1%	1	1%
40%-59.9%	11	5%	5	4%
60%-79.9%	72	33%	33	29%
80%-100%	131	61%	76	66%
Total # of U	216		115	

Table B.36: Percentages the users spent on the map with their cursors during the task compared to the question if the user has already used a GPS; task one.

	Has used a GPS		**Has not used a GPS**	
Percentage	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	1	0%	2	2%
20%-39.9%	3	1%	1	1%
40%-59.9%	17	8%	12	10%
60%-79.9%	80	37%	37	32%
80%-100%	115	53%	63	55%
Total # of U	216		115	

Table B.37: Percentages the users spent on the map with their cursors during the task compared to the question if the user has already used a GPS; task two.

	Has used a GIS		**Has not used a GIS**	
Percentage	**#U**	**% of U**	**#U**	**% of U**
0%-19.9%	0	0%	0	0%
20%-39.9%	0	0%	3	1%
40%-59.9%	6	8%	10	4%
60%-79.9%	22	29%	83	32%
80%-100%	47	63%	160	63%
Total # of U	75		256	

Table B.38: Percentages the users spent on the map with their cursors during the task compared to the question if the user has already used a GIS; task one.

	Has used a GIS		Has not used a GIS	
Percentage	#U	% of U	#U	% of U
0%-19.9%	0	0 %	3	1%
20%-39.9%	1	1%	3	1%
40%-59.9%	7	9 %	22	9%
60%-79.9%	25	33%	92	36%
80%-100%	42	56%	136	53%
Total # of U	75		256	

Table B.39: Percentages the users spent on the map with their cursors during the task compared to the question if the user has already used a GIS; task two.

	Very bad		Bad		Fair		Good		Very good	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%	0	0%	0	0%	0	0%
20%-39.9%	0	0%	1	5%	1	1%	0	0%	1	2%
40%-59.9%	0	0%	1	5%	4	3%	8	6%	3	6%
60%-79.9%	0	0%	5	26%	45	37%	44	31%	11	22%
80%-100%	0	0%	12	63%	72	59%	88	63%	35	70%
Total # of U	0		19		122		140		50	

Table B.40: Percentages the users spent on the map with their cursors during the task compared to the estimated level of computer skills; task one.

	Very bad		Bad		Fair		Good		Very good	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%	1	1%	2	1%	0	0%
20%-39.9%	0	0%	1	5%	1	1%	0	0%	2	4%
40%-59.9%	0	0%	5	26%	10	8%	11	8%	3	6%
60%-79.9%	0	0%	7	37%	45	37%	45	32%	20	40%
80%-100%	0	0%	6	32%	65	53%	82	59%	25	50%
Total # of U	0		19		122		140		50	

Table B.41: Percentages the users spent on the map with their cursors during the task compared to the estimated level of computer skills; task two.

	Never		Very rarely		Sometimes		Often		Very often	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%	0	0%	0	0%	0	0%
20%-39.9%	1	7%	2	4%	0	0%	0	0%	0	0%
40%-59.9%	0	0%	5	10%	2	1%	7	7%	2	11%
60%-79.9%	6	43%	15	31%	52	36%	28	30%	4	21%
80%-100%	7	50%	26	54%	101	65%	60	63%	13	68%
Total # of U	14		48		155		95		19	

Table B.42: Percentages the users spent on the map with their cursors during the task compared to the estimated usage of paper maps; task one.

	Never		Very rarely		Sometimes		Often		Very often	
Preference	#U	% of U	#U	% of U	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	1	2%	2	1%	0	0%	0	0%
20%-39.9%	0	0%	3	6%	1	1%	0	0%	0	0%
40%-59.9%	0	0%	3	6%	17	11%	8	8%	1	5%
60%-79.9%	6	43%	18	38%	56	36%	30	32%	7	37%
80%-100%	8	57%	23	48%	79	51%	57	60%	11	58%
Total # of U	14		48		155		95		19	

Table B.43: Percentages the users spent on the map with their cursors during the task compared to the estimated usage of paper maps; task two.

	English		French		German	
Preference	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0%	0	0%	0	0%
20%-39.9%	0	0%	3	1%	0	0%
40%-59.9%	0	0%	16	6%	0	0%
60%-79.9%	7	30%	87	31%	11	42%
80%-100%	16	70%	176	62%	15	58%
Total # of U	23		282		26	

Table B.44: Percentages the users spent on the map with their cursors during the task compared to the language chosen; task one.

	English		French		German	
Preference	#U	% of U	#U	% of U	#U	% of U
0%-19.9%	0	0 %	3	1%	0	0%
20%-39.9%	0	0 %	3	1%	1	4%
40%-59.9%	1	4 %	28	10%	0	0%
60%-79.9%	13	57%	94	33%	10	38%
80%-100%	9	39%	154	55%	15	58%
Total # of U	23		282		26	

Table B.45: Percentages the users spent on the map with their cursors during the task compared to the language chosen; task two.

Comparison user strategies and parameters related to the user's computer

	NW		WM		TP		ST		TB		TS		OT	
Pref.	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**
ZB+P	2	13%	14	6%	6	7%	0	0%	0	0%	0	0%	0	0%
ZB+R	10	63%	78	36%	46	51%	4	100%	0	0%	2	100%	1	100%
ZB+NP	1	6%	3	1%	2	2%	0	0%	0	0%	0	0%	0	0%
SC+P	0	0%	4	2%	4	4%	0	0%	1	100%	0	0%	0	0%
SC+R	1	6%	27	13%	18	20%	0	0%	0	0%	0	0%	0	0%
SC+NP	1	6%	3	1%	2	2%	0	0%	0	0%	0	0%	0	0%
MW+P	0	0%	7	3%	3	3%	0	0%	0	0%	0	0%	0	0%
MW+R	0	0%	62	29%	5	5%	0	0%	0	0%	0	0%	0	0%
MW+NP	0	0%	11	5%	0	0%	0	0%	0	0%	0	0%	0	0%
NZ+P	0	0%	1	0%	1	1%	0	0%	0	0%	0	0%	0	0%
NZ+R	1	6%	6	3%	3	3%	0	0%	0	0%	0	0%	0	0%
NZ+NP	0	0%	0	0%	1	1%	0	0%	0	0%	0	0%	0	0%
Total	16		216		91		4		1		2		1	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the maps; NW: Mouse without a wheel; WM: Mouse with a wheel; TP: Touchpad; ST: Pointing stick; TB: Track ball; TS: Touchscreen; OT: Other

Table B.46: Categories of preference for zoom choice and moving the map compared to the type of input device; task one

	NW		WM		TP		ST		TB		TS		OT	
Pref.	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**
ZB+P	4	25%	36	17%	22	24%	1	25%	0	0%	1	50%	1	100%
ZB+R	7	44%	56	26%	26	29%	1	25%	0	0%	1	50%	0	0%
ZB+NP	0	0%	6	3%	5	5%	0	0%	0	0%	0	0%	0	0%
SC+P	2	13%	21	10%	11	12%	0	0%	1	100%	0	0%	0	0%
SC+R	2	13%	32	15%	15	16%	0	0%	0	0%	0	0%	0	0%
SC+NP	1	6%	5	2%	3	3%	0	0%	0	0%	0	0%	0	0%
MW+P	0	0%	17	8%	3	3%	0	0%	0	0%	0	0%	0	0%
MW+R	0	0%	29	13%	3	3%	0	0%	0	0%	0	0%	0	0%
MW+NP	0	0%	7	3%	0	0%	0	0%	0	0%	0	0%	0	0%
NZ+P	0	0%	2	1%	1	1%	1	25%	0	0%	0	0%	0	0%
NZ+R	0	0%	4	2%	2	2%	1	25%	0	0%	0	0%	0	0%
NZ+NP	0	0%	1	0%	0	0%	0	0%	0	0%	0	0%	0	0%
Total	16		216		91		4		1		2		1	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the maps; NW: Mouse without a wheel; WM: Mouse with a wheel; TP: Touchpad; ST: Pointing stick; TB: Track ball; TS: Touchscreen; OT: Other

Table B.47: Categories of preference for zoom choice and moving the map compared to the type of input device; task two

	EPFL		Swiss ADSL		Foreign	
Preference	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**
ZB+P	9	14 %	11	5 %	2	6 %
ZB+R	30	46 %	101	44 %	10	29 %
ZB+NP	0	0 %	5	2 %	1	3 %
SC+P	1	2 %	7	3 %	1	3 %
SC+R	8	12 %	34	15 %	4	12 %
SC+NP	0	0 %	5	2 %	1	3 %
MW+P	1	2 %	8	3 %	1	3 %
MW+R	11	17 %	43	19 %	13	38 %
MW+NP	2	3 %	9	4 %	0	0 %
NZ+P	1	2 %	1	0 %	0	0 %
NZ+R	2	3 %	7	3 %	1	3 %
NZ+NP	0	0 %	1	0 %	0	0 %
Total	65		232		34	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.48: Categories of preference for zoom choice and moving the map compared to the type of Internet connection; task one

	EPFL		Swiss ADSL		Foreign	
Preference	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**
ZB+P	12	18 %	44	19 %	9	26 %
ZB+R	23	35 %	64	28 %	4	12 %
ZB+NP	1	2 %	10	4 %	0	0 %
SC+P	4	6 %	30	13 %	1	3 %
SC+R	11	17 %	33	14 %	5	15 %
SC+NP	1	2 %	6	3 %	2	6 %
MW+P	1	2 %	16	7 %	3	9 %
MW+R	8	12 %	18	8 %	6	18 %
MW+NP	1	2 %	4	2 %	2	6 %
NZ+P	0	0 %	3	1 %	1	3 %
NZ+R	3	5 %	3	1 %	1	3 %
NZ+NP	0	0 %	1	0 %	0	0 %
Total	65		232		34	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.49: Categories of preference for zoom choice and moving the map compared to the type of Internet connection; task two

	OS X		Windows		Linux		Other	
Preference	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**
ZB+P	6	11 %	16	6 %	0	0 %	0	0 %
ZB+R	28	50 %	100	39 %	12	60 %	1	100 %
ZB+NP	2	4 %	4	2 %	0	0 %	0	0 %
SC+P	5	9 %	4	2 %	0	0 %	0	0 %
SC+R	10	18 %	36	14 %	0	0 %	0	0 %
SC+NP	1	2 %	4	2 %	1	5 %	0	0 %
MW+P	1	2 %	9	4 %	0	0 %	0	0 %
MW+R	1	2 %	61	24 %	5	25 %	0	0 %
MW+NP	0	0 %	10	4 %	1	5 %	0	0 %
NZ+P	0	0 %	2	1 %	0	0 %	0	0 %
NZ+R	1	2 %	8	3 %	1	5 %	0	0 %
NZ+NP	1	2 %	0	0 %	0	0 %	0	0 %
Total	56		254		20		1	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.50: Categories of preference for zoom choice and moving the map compared to the operating system; task one

	OS X		Windows		Linux		Other	
Preference	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**	**#U**	**% U**
ZB+P	12	21 %	47	19 %	5	25 %	1	100 %
ZB+R	19	34 %	66	26 %	6	30 %	0	0 %
ZB+NP	2	4 %	8	3 %	1	5 %	0	0 %
SC+P	9	16 %	24	9 %	2	10 %	0	0 %
SC+R	11	20 %	35	14 %	3	15 %	0	0 %
SC+NP	1	2 %	8	3 %	0	0 %	0	0 %
MW+P	0	0 %	20	8 %	0	0 %	0	0 %
MW+R	1	2 %	28	11 %	3	15 %	0	0 %
MW+NP	0	0 %	7	3 %	0	0 %	0	0 %
NZ+P	1	2 %	3	1 %	0	0 %	0	0 %
NZ+R	0	0 %	7	3 %	0	0 %	0	0 %
NZ+NP	0	0 %	1	0 %	0	0 %	0	0 %
Total	56		254		20		1	

ZB: Zoom buttons, SC: Scale-choice, MW: Mouse-wheel; NZ: No preference for a zoom tool; P: Pan-buttons, R: Recenter by clicking on the map; NP: No preference for a tool to move the map

Table B.51: Categories of preference for zoom choice and moving the map compared to the operating system; task two

	NW		WM		TP		ST		TB		TS		OT	
Preference	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**
0% - 19.99%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%	0	0%
20%-39.99%	0	0%	3	1%	0	0%	0	0%	0	0%	0	0%	0	0%
40%-59.99%	0	0%	11	5%	5	5%	0	0%	0	0%	0	0%	0	0%
60%-79.99%	7	44%	67	31%	28	31%	1	25%	0	0%	1	50%	1	100%
80%-100%	9	56%	135	63%	58	64%	3	75%	1	100%	1	50%	0	0%
Total	16		216		91		4		1		2		1	

NW: Mouse without a wheel; WM: Mouse with a wheel; TP: Touchpad; ST: Pointing stick; TB: Track ball; TS: Touchscreen; OT: Other

Table B.52: Percentages the users spent on the map with their cursors during the task compared to the type of input device; task one

	NW		WM		TP		ST		TB		TS		OT	
Preference	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**	**#U**	**%U**
0% - 19.99%	0	0%	0	0%	3	3%	0	0%	0	0%	0	0%	0	0%
20%-39.99%	0	0%	4	2%	0	0%	0	0%	0	0%	0	0%	0	0%
40%-59.99%	3	19%	15	7%	10	11%	0	0%	0	0%	0	0%	1	100%
60%-79.99%	2	13%	83	38%	29	32%	1	25%	0	0%	2	100%	0	0%
80%-100%	11	69%	114	53%	49	54%	3	75%	1	100%	0	0%	0	0%
Total	16		216		91		4		1		2		1	

NW: Mouse without a wheel; WM: Mouse with a wheel; TP: Touchpad; ST: Pointing stick; TB: Track ball; TS: Touchscreen; OT: Other

Table B.53: Percentages the users spent on the map with their cursors during the task compared to the type of input device; task two

	EPFL		Swiss ADSL		Foreign	
Preference	#U	% U	#U	% U	#U	% U
0% - 19.99%	0	0 %	0	0 %	0	0 %
20%-39.99%	1	2 %	2	1 %	0	0 %
40%-59.99%	5	8 %	8	3 %	3	9 %
60%-79.99%	13	20 %	84	36 %	8	24 %
80%-100%	46	71 %	138	59 %	23	68 %
Total	65		232		34	

Table B.54: Percentages the users spent on the map with their cursors during the task compared to the type of Internet connection; task one

	EPFL		Swiss ADSL		Foreign	
Preference	#U	% U	#U	% U	#U	% U
0% - 19.99%	0	0 %	3	1 %	0	0 %
20%-39.99%	0	0 %	2	1 %	2	6 %
40%-59.99%	3	5 %	25	11 %	1	3 %
60%-79.99%	23	35 %	82	35 %	12	35 %
80%-100%	39	60 %	120	52 %	19	56 %
Total	65		232		34	

Table B.55: Percentages the users spent on the map with their cursors during the task compared to the type of Internet connection; task two

	OS X		Windows		Linux		Other	
Preference	#U	% U	#U	% U	#U	% U	#U	% U
0% - 19.99%	0	0 %	0	0 %	0	0 %	0	0 %
20%-39.99%	0	0 %	3	1 %	0	0 %	0	0 %
40%-59.99%	5	9 %	10	4 %	1	5 %	0	0 %
60%-79.99%	15	27 %	83	33 %	6	30 %	1	100 %
80%-100%	36	64 %	158	62 %	13	65 %	0	0 %
Total	56		254		20		1	

Table B.56: Percentages the users spent on the map with their cursors during the task compared to the operating system; task one

	OS X		Windows		Linux		Other	
Preference	#U	% U	#U	% U	#U	% U	#U	% U
0% - 19.99%	0	0 %	3	1 %	0	0 %	0	0 %
20%-39.99%	1	2 %	3	1 %	0	0 %	0	0 %
40%-59.99%	3	5 %	25	10 %	0	0 %	1	100 %
60%-79.99%	15	27 %	94	37 %	8	40 %	0	0 %
80%-100%	37	66 %	129	51 %	12	60 %	0	0 %
Total	56		254		20		1	

Table B.57: Percentages the users spent on the map with their cursors during the task compared to the operating system; task two

	Task one		Task two	
Parameter	**H**	**p**	**H**	**p**
Pointing device	1	0.02	0	0.35
Internet connection	0	0.48	0	0.18
Operating system	0	0.1	0	0.83

Table B.58: Statistical significance for the comparison of parameters related to the user's computer and preference of navigation tools

	Task one		Task two	
Parameter	**H**	**p**	**H**	**p**
Pointing device	0	0.99	0	0.11
Internet connection	0	0.13	0	0.12
Operating system	0	0.74	0	0.11

Table B.59: Statistical significance for the comparison of parameters related to the user's computer and relative time one the map with the pointing device

Comparison of parameters related to the user's computer and user performance

		Time		Rate		Errors	
Parameter	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
Mouse, no wheel	16	77.69 s	75.19 s	7.94	14.88	0.13	0.06
Mouse with wheel	216	97.24 s	99.11 s	11.17	16.06	0.11	0.1
Touchpad	91	108.19 s	118.46 s	10.21	17.19	0.11	0.07
Pointing stick	4	83 s	114.25 s	10.25	17.5	0.25	0
Trackball	1	46 s	78 s	4	14	0	0
Touchscreen	2	89 s	81.5 s	8.5	14.5	0.5	0
Other	1	106 s	213 s	9	22	0	1

Table B.60: Input device and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
NW vs WM	0	0.3602	0	0.5889	0	0.2936	0	0.9000	0	0.8209	0	0.6147
NW vs TP	0	0.1757	0	0.1352	0	0.5867	0	0.7997	0	0.8667	0	0.9675
WM vs TP	0	0.1707	1	0.0287	0	0.2936	0	0.7527	0	0.9310	0	0.3196

NW: Mouse without wheel; WM: Mouse with wheel; TP: Touchpad

Table B.61: Statistical significance for the comparison between input devices and user performance (task-completion time, rate of interaction and errors); both tasks

		Time		Rate		Errors	
Parameter	**#Users**	**Task1**	**Task2**	**Task1**	**Task2**	**Task1**	**Task2**
EPFL	65	67.54 s	82.91 s	8.94	17.31	0.15	0.03
Swiss ADSL/Cable	232	107.3 s	105.04 s	11.5	16.24	0.1	0.1
Foreign connection	34	102.09 s	133.62 s	8.5	15.15	0.12	0.15

Table B.62: Internet connection type and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
EPFL vs SC	1	0.0001	1	0.0277	1	0.0188	0	0.7985	0	0.2161	0	0.0801
EPFL vs FC	1	0.0021	1	0.0024	0	0.5098	0	0.8681	0	0.6296	1	0.0336
SC vs FC	0	0.5490	0	0.0673	0	0.2651	0	0.8813	0	0.7408	0	0.3973

EPFL: direct connection to the server. SC: Swiss ADSL / cable modem connection. FC: foreign connection

Table B.63: Statistical significance for the comparison between the Internet connection type and user performance (task-completion time, rate of interaction and errors); both tasks

		Time		Rate		Errors	
Parameter	#Users	Task1	Task2	Task1	Task2	Task1	Task2
OS X	56	78.3 s	85.79 s	8.88	14.45	0.09	0.07
Windows	254	103.07 s	106.48 s	11.19	16.16	0.12	0.09
Linux	20	104.2 s	111.95 s	9.5	23.55	0.05	0.05
Other	1	106 s	213 s	9	22	0	1

Table B.64: Operating system and user performance (task-completion time, rate of interaction and errors); both tasks

	Time				Rate				Errors			
	Task 1		Task 2		Task 1		Task 2		Task 1		Task 2	
Comparison	H	p	H	p	H	p	H	p	H	p	H	p
OS X vs Windows	1	0.0055	0	0.3742	1	0.0139	0	0.2190	0	0.4901	0	0.5875
OS X vs Linux	0	0.7146	0	0.7323	0	0.8612	0	0.0746	0	0.5872	0	0.7521
Windows vs Linux	0	0.2233	0	0.9428	0	0.0631	0	0.2686	0	0.3363	0	0.5086

Table B.65: Statistical significance for the comparison between operating system and user performance (task-completion time, rate of interaction and errors); both tasks

User satisfaction compared to user-related parameters

	Enough instructions		Understandable		Not too loaded		Needless elements	
Parameter	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Age	0	0.1548382	0	0.1701085	1	0.0000005	0	0.9636458
Gender	0	0.5186185	0	0.6491656	0	0.6639830	0	0.6966887
Handedness	0	0.0554913	0	0.0701729	0	0.4864766	0	0.9584627
Experience index	1	0.0070860	0	0.3241865	0	0.5369403	0	0.4407663
GPS usage	0	0.0563679	0	0.2404590	0	0.4963258	0	0.5312687
GIS usage	0	0.2448511	0	0.2669486	0	0.3356139	0	0.2992369
Computer skills	0	0.6931275	0	0.4896187	0	0.2492481	0	0.3050639
Map usage	0	0.7908079	0	0.4318709	0	0.4002610	0	0.1917656
Language	0	0.1280836	0	0.7235960	0	0.4114408	0	0.5342677

Table B.66: Statistical significance for the comparison between user satisfaction (elements "the system gives enough instructions", what is happening is understandable", "the system is not too loaded", "there are no needless elements") and user-related parameters

	GD		LD		BD		MN		S		GS	
Parameter	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Age	0	0.212	0	0.316	0	0.963	0	0.678	0	0.607	0	0.233
Gender	0	0.955	0	0.867	0	0.080	0	0.429	0	0.372	0	0.356
Handedness	0	0.706	0	0.432	0	0.235	1	0.021	0	0.325	0	0.155
Experience index	1	0.018	0	0.760	1	0.002	0	0.699	0	0.232	0	0.924
GPS usage	0	0.757	0	0.792	0	0.344	0	0.390	0	0.316	0	0.892
GIS usage	0	0.653	0	0.461	0	0.739	0	0.357	0	0.226	0	0.640
Computer skills	0	0.248	1	0.035	0	0.115	0	0.748	0	0.935	0	0.458
Map usage	0	0.884	0	0.146	0	0.332	0	0.322	0	0.517	0	0.976
Language	0	0.131	1	0.018	0	0.311	0	0.217	0	0.561	0	0.063

GD: graphical design, LD: logical design; BD: design of the icons / buttons and the functionality that is behind; MN: Map navigation; S: Speed; GS: General satisfaction

Table B.67: Statistical significance for the comparison between user satisfaction and user-related parameters

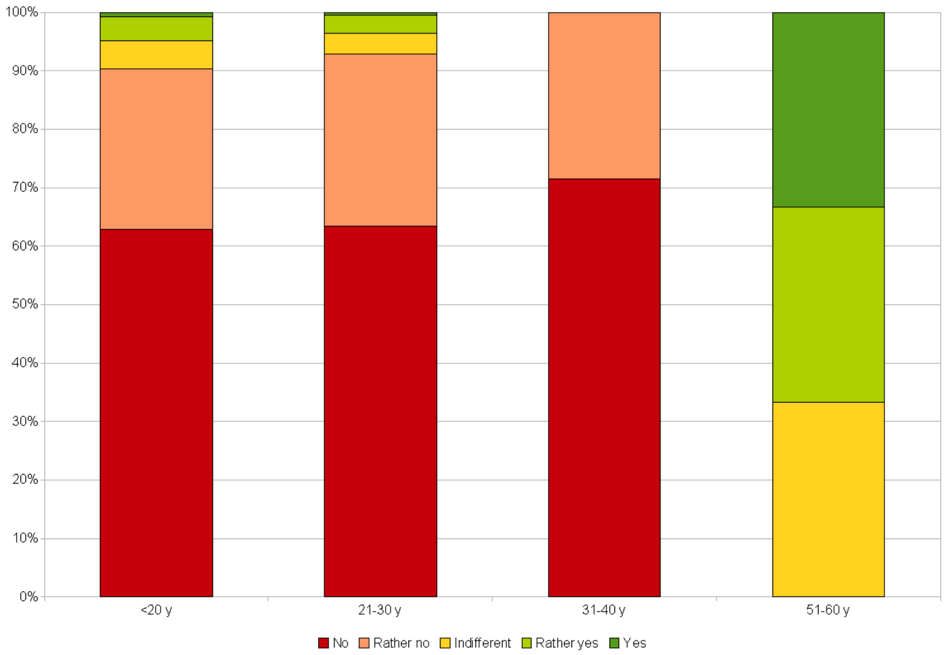

Figure B.1: Answers to the question “the system is no too loaded” according to the users’ age

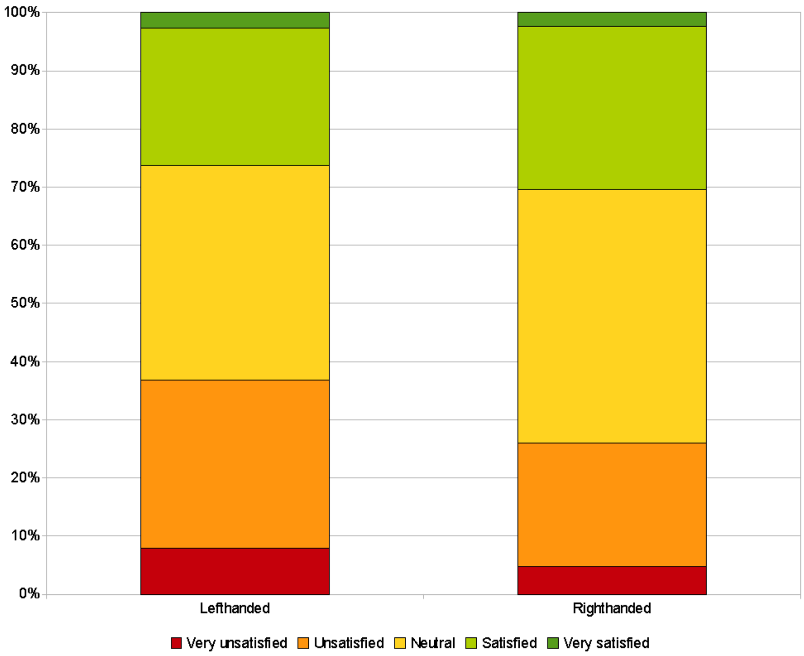

Figure B.2: Satisfaction with the graphical design according to the users’ handedness

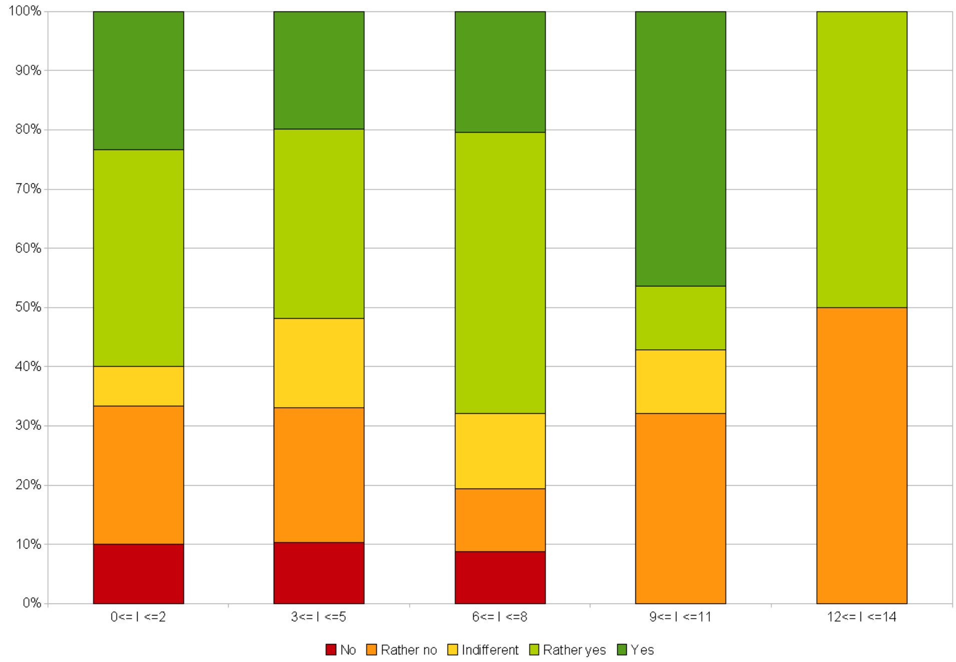

Figure B.3: Answers to the question “the system gives enough instructions” according to the users’ experience with similar systems

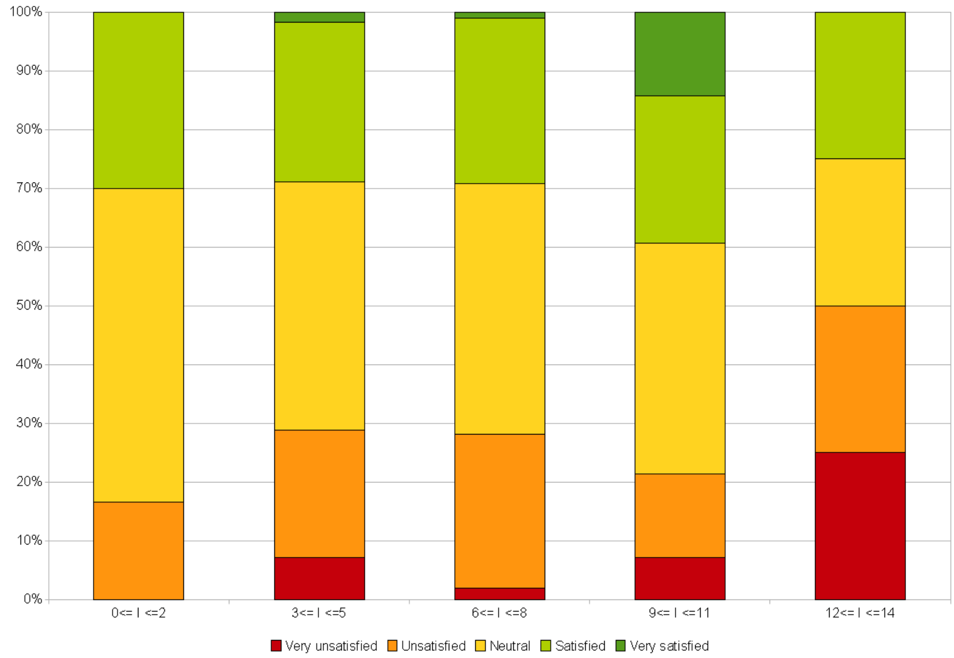

Figure B.4: Satisfaction with the graphical design according to the users' experience with similar systems

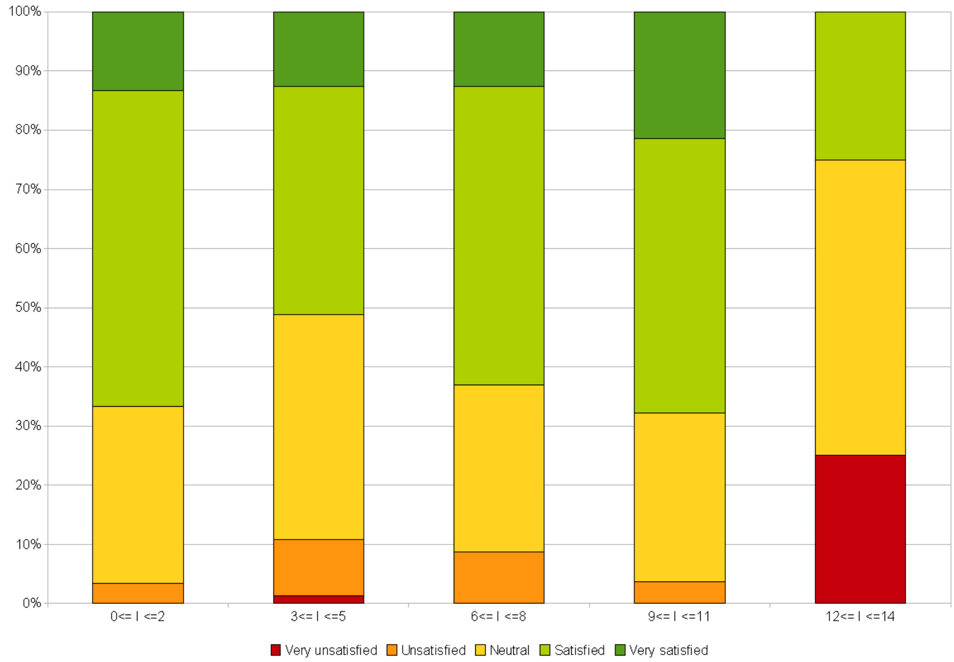

Figure B.5: Satisfaction with the relationship between the design of the icons/buttons and the functionality that is behind according to the users' experience with similar systems

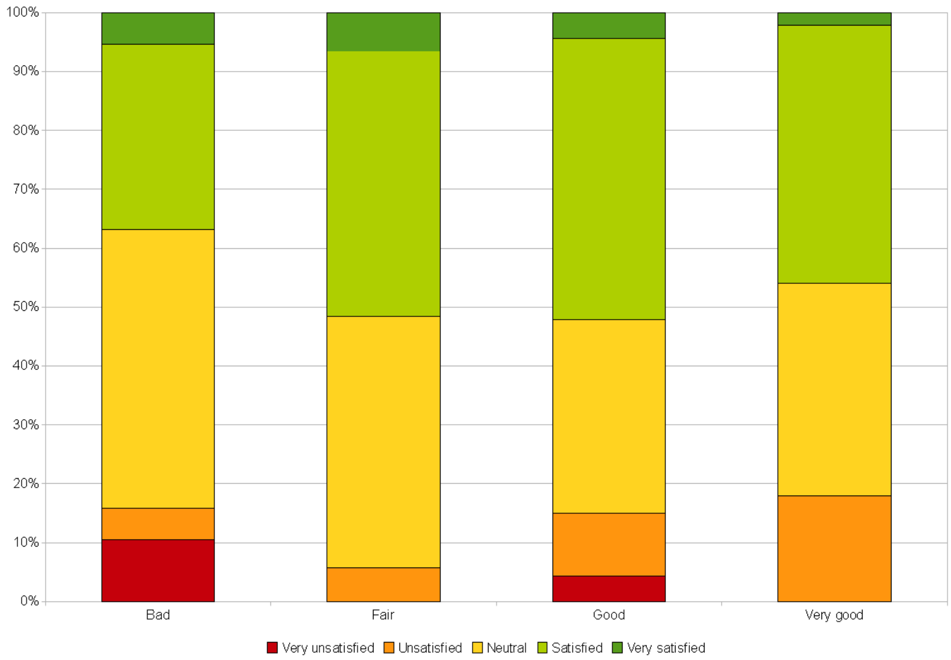

Figure B.6: Satisfaction with the logical design (sequence of actions) according to the users' computer skills

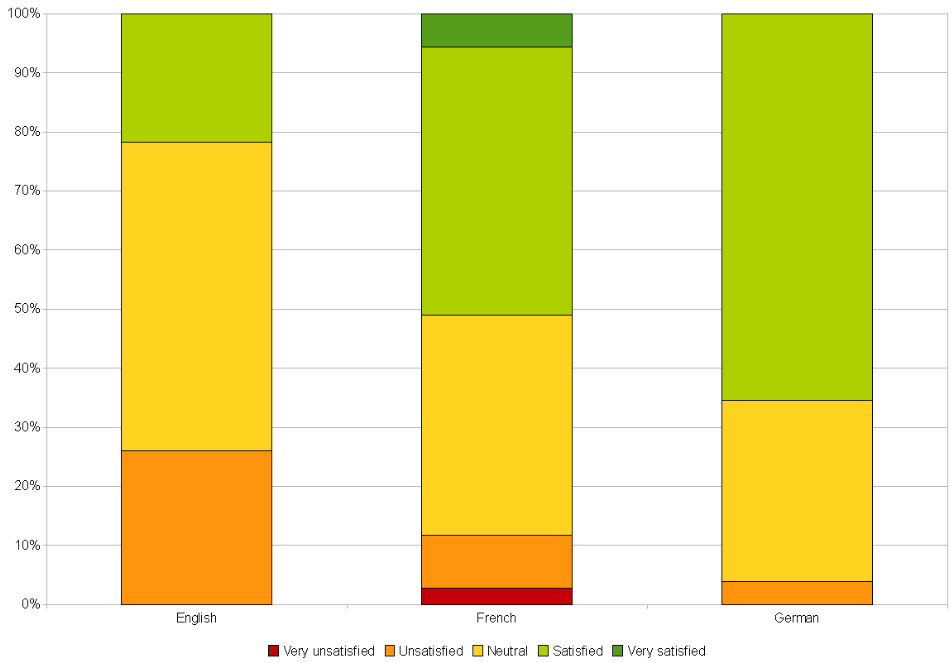

Figure B.7: Satisfaction with the logical design (sequence of actions) according to the language the users used

User satisfaction compared to parameters related to the user's computer

	Enough instructions		Understandable		Not too loaded		Needless elements	
Parameter	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Input device	0	0.6373507	0	0.4220476	0	0.9792139	0	0.8268928
Internet connection	0	0.9228285	0	0.7048992	0	0.7218776	0	0.1159891
OS	0	0.5851355	0	0.9293560	0	0.2691585	0	0.8553499

Table B.68: Statistical significance for the comparison between user satisfaction (elements "the system gives enough instructions", what is happening is understandable", "the system is not too loaded", "there are no needless elements") and parameters related to the user's computer

	GD		LD		BD		MN		S		GS	
Parameter	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**	**H**	**p**
Input device	0	0.5894	0	0.9585	0	0.8629	1	0.0003	0	0.8568	0	0.9411
Internet connection	0	0.3344	0	0.6386	0	0.6784	0	0.4731	1	0.0001	0	0.1416
OS	0	0.3701	0	0.0733	0	0.2572	0	0.5546	0	0.9854	0	0.8320

GD: graphical design, LD: logical design; BD: design of the icons / buttons and the functionality that is behind; MN: Map navigation; S: Speed; GS: General satisfaction

Table B.69: Statistical significance for the comparison between user satisfaction and parameters related to the user's computer

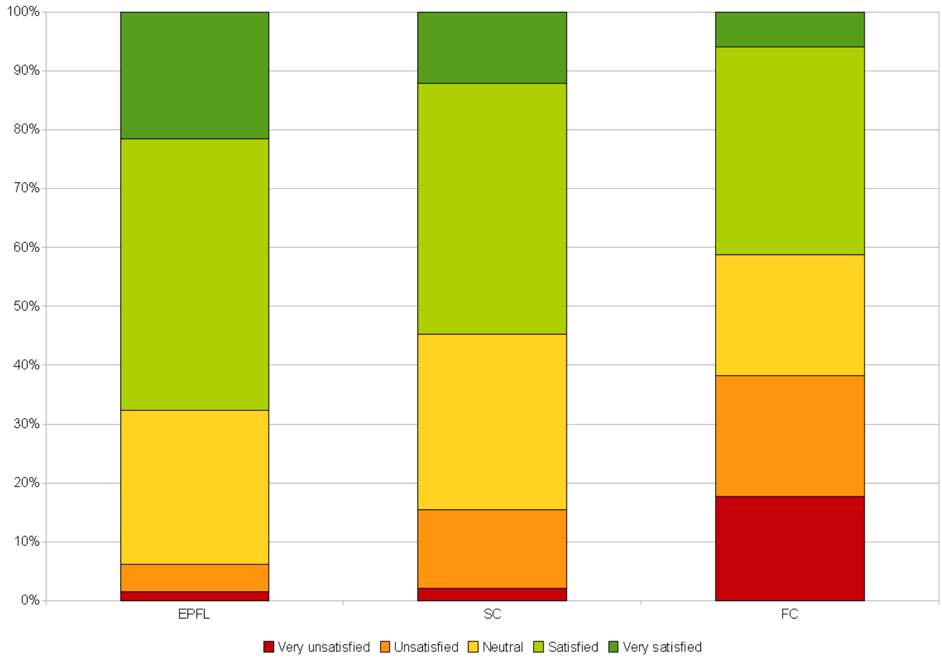

Figure B.8: Satisfaction with the system's speed according to the user's Internet connection; EPFL: direct connection at EPFL, SC: Swiss ADSL / cable connection; FC: Foreign connection

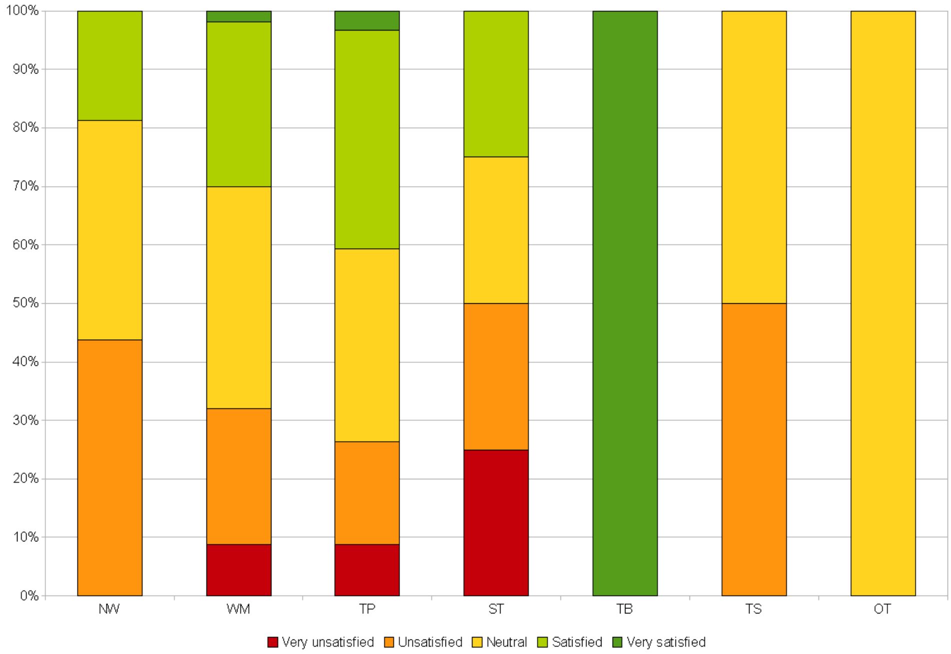

Figure B.9: Satisfaction with map navigation according to the pointing device used; NW: Mouse without a wheel; WM: Mouse with a wheel; TP: Touchpad; ST: Pointing stick; TB: Track ball; TS: Touchscreen; OT: Other

Curriculum vitae

Jens Ingensand

Born:	13.10.1977
Nationality:	German

Education and degrees

2010	**PhD** Ecole Polytechnique Fédérale de Lausanne, Switzerland
2004	**MSc in Applied Informatics With a Major in Interaction Design**, Chalmers, University of Technology, Gothenburg, Sweden, 2004
2002 - 2004	Masters-program in Human-Computer-Interaction, Chalmers University of Technology, Gothenburg, Sweden
2004	**MSc in Human and Economic Geography**, University of Gothenburg, Sweden
2000 - 2002	Human geography, logic programming and French, University of Gothenburg, Sweden
1998 - 2000	Geography, communication and media sciences, nordic philology and informatics, University of Basel, Switzerland
1998	Graduated from High school, Matura Typus B, Kantonsschule Heerbrugg, Switzerland

Work experience

2008 - present	Lecturer at the Swiss Federal Institute of Technology in Lausanne. (course in GIS technologies for Master students)
2004 - present	Assistant at the GIS-lab at the Swiss Federal Institute of Technology in Lausanne.
2002 - 2004	Research-assistant and web-master at the Department of Human and Economic Geography, University of Gothenburg, Sweden. Research: Visualization of conflicts of interests with geographical information systems (GIS) Teaching in geographical information systems
1999 - 2000	Helping-assistant for the computer network at the Department of Geography, University of Basel
1998 2003	Work experience at SFS-Holding AG, Heerbrugg, Switzerland Programming of a statistical computer-program to register consumption data.
1998	Homepage of the Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology, Zurich

Technical skills

Programming:	Java, PHP, Javascript, VBScript, Prolog, Shell, XML, SVG, XSLT
Databases:	PostgreSQL/PostGIS, MySQL, object-oriented databases
Operating systems:	Windows, Mac, Linux, Unix
Office software:	MSOffice, OpenOffice, Latex
GIS:	ArcGIS, ArcView 3.x, MapInfo, Manifold System, GRASS, OpenJump, QGOS, GVSIG, FME, IDRISI

Language skills

German	mother tongue
English	fluent(7 years of study, scientific publications and teaching)
French	fluent(9 years of study, scientific publications and teaching)
Swedish	fluent (3 years of study, scientific publications and teaching)
Italian	fluent (3 years of study, CELI 2 Universita degli studi di Perugia)
Swiss German	fluent
Danish	basic skills; Basel University
Spanish	basic skills; Level A, University of Lausanne

Publications

Book chapters

Ingensand, J. Golay, F. (2008) User Performance in Interaction with Web-GIS: A Semi-Automated Methodology Using Log-Files and Streaming-Tools. In: Bernard, L.; Christensen, A. F. & Pundt, H. (ed.) The European Information Society, Springer, p 433-443

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Journal papers

Ingensand, J. Golay, F. (2009) Task-oriented Usability Evaluation of a Web-GIS for a Real World Community. Submitted to: URISA Journal. Urban and Regional Information Systems Association. USA

Joost, S. Ingensand, J. Farkas, R. Milon, S. Campora, S. Waegli, A. (2009). GPS 4 PDG: géovisualisation de sujets mobiles lors de la patrouille des glaciers 2008. In: Flash Informatique spéecial été EPFL Lausanne

Aeberhard, B. Droz, P. Caloz, R. Ingensand, J (2007). Le réeseau interactif en viticulture (RIV), un projet novateur au service de tous. In: Revue Suisse de Viticulture, Arboriculture, Horticulture, vol. 39(3), p. 203-206

Ingensand, J. (2005) Google maps - Google entre dans le monde des systèmes d'information géographique. In: Infosociety, vol. 58, p. 4-6. Swiss Federal Office of Communications

Conference papers

Ingensand, J. Golay, F. (2008) Integrated, web-based information system to support collaborative resource management Presented at: VNU-HCM International. Conference for Environment and Natural Resources, Ho-Chi-Minh (Vietnam) March 17-20 2008

Ingensand, J. Caloz, R. Pythoud, K. (2005) Creating an Interactive Network for Wine-cultivation; Presented at: Inaugural Nordic Geographers Meeting, Lund (Sweden),May 11-13

Technical reports

Ingensand, J. (2008) Evaluation d'utilisabilité: Géocommande ASIT-VD. Technical report. EPFL Switzerland.

Kalbermatten, M, Golay, F. Ingensand, J. (2005) Manuel de modélisation standardisée des géodonnées. Technical report. EPFL Switzerland.

Ingensand, J. Vilhelmson, B. (2004) Utvecklingen av bebyggelsen i strandzonen vid Gullmarn, Research report, Series: Occasional papers / Department of Human and Economic Geography, University of Gothenburg. No: 2004:5

Master's thesis and student reports

Ingensand, J. (2004) Development of an interactive service for wine-cultivation in the Swiss canton of Vaud. Master thesis. Chalmers, University of Technology, Gothenburg, Sweden.

Ingensand, J. (2002) Strandskydd och bebyggelse vid Gullmarn - en undersökning av bebyggelseförändringar med hjälp av GIS. Master thesis, University of Gothenburg.

Ingensand, J. (2001). GIS och kartografisk visualisering. Student's report. Gothenburg University; Department of Human and Economic Geography.

Talks at conferences and workshops

Ingensand, J. (2008) Tracking, Monitoring und Visualisierung der Gletscherpatrouille 2008. Presentation held at the AHORN 2008 conference. Salzburg, Austria. November 20-21, 2008

Ingensand, J. (2008) 3D web-interfaces to the "Patrouille des glaciers"-race'. In: Carosio, A, Golay, F. & Brovelli, M. (ed.): Presentations of the 3rd Meeting of the Comitato scientifico italo-svizzero per la geoinformatizione (CSISGI). Report no. 305, Swiss Federal Institute of Technology, Zurich

Ingensand, J. (2007) Developing and evaluating web-GIS for wine-cultivation based on open-source components. In: Carosio, A, Golay, F. & Brovelli, M. (ed.): Impiego di dati LIDAR ad alta precisione: trattamento dei dati, controllo di qualita, modellazione e applicazioni tematiche. Report no. 304, Swiss Federal Institute of Technology, Zurich

Ingensand, J. (2005) Towards GIS for Non-GIS Experts. Presentation held at the Open Source Geospatial conference, Minneapolis (MN), USA June 1618, 2005

Ingensand, J. (2004) Developing Interfaces for Open Source GIS Applications According to Human Computer Interaction Guidelines. Presentation held at the Open Source GIS 2004 conference. Ottawa (ON) Canada, June 9-11, 2004