VISUAL ENHANCEMENT OF ANIMATED TIME SERIES TO REDUCE CHANGE BLINDNESS

MEKONNEN TESFAYE METAFERIA
March, 2011

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Enschede, The Netherlands, March, 2011

Thesis submitted to the Faculty of Geo-information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-informatics

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ABSTRACT

The ever–increasing storage capacity and the high processing power of computers enable use of interactive animations for visual exploration of spatio–temporal data. Despite the capabilities to emulate the real–world dynamics, animations are easily overloading viewers with a rapid sequence of changes, and exposure to change blindness. This is due to the limitations of human perception and cognitive processing capabilities relative to the vast data streaming power of animations. Literatures reveal inattentional blindness, split of attention and retroactive inhibition as possible causes of change blindness. This knowledge helps to identify ways that possibly reduce the problems from a perceptual/cognitive perspective. This research aims at visual enhancement of the focus with a simultaneous suppression of the surrounding context to reduce problems related to change blindness in animated time series. The assumption is that users who want to focus on an area and/or on attribute values of interest do not want to lose track completely of what is happening in the surroundings. The reduction of the problems are approached by trying to influence top–down perception processes (i.e., to facilitate focused attention) and/or by improving bottom–up perception processes through effective graphical representation. Solutions are sought for visual enhancement of the focus and suppression of the context. Methods that could be employed for simultaneous display of both the focus and the surrounding context are examined for this purpose. Two interactive tools are developed and implemented in a prototype using the transparency technique of the cue based methods. The first one lets the user select an area of interest and make the context subdued, keeping the original graphical representation of features. The other tool lets users display a selected range of attribute values of interest in a prominent way, while simultaneously suppressing the unselected attribute values (the context). The two above methods can also be used in combination to have a specific range of attribute values in a selected area of interest. Finally, the proposed methods are evaluated for usability. The outcome of the test showed that participants who made use of the proposed new interactive tools perform the test tasks in a better way than those who were working without these new tools with respect to the three usability metrics: effectiveness, efficiency and satisfaction. The test also showed the need for further improvement of the proposed tools in particular and interactive animation in general.

Keywords

visual exploration, time series, interactive animation, change blindness, focused attention, overview + detail, zooming and filtering, focus + context, visual highlighting methods

ACKNOWLEDGEMENTS

First of all, I would like to thank the Almighty God, for His blessings that empowered me to accomplish this great career in my life.

Next, my heartily thanks go to Dr. Connie Blok for her careful guidance and enthusiasm throughout the course of the research period. Her ardent encouragement and concern from the preliminary to the concluding level was marvellous. I owe my deepest gratitude also to Dr. Raul Zurita-Milla, who has given me his heart whelming full support in making this research a magnificent experience.

I would like to make a special reference to Mr. Martin Schouwenburg, the programmer in the GI-department, if not his kind cooperation and help, I could not have managed the programming stuffs for the research. My special thank also extends to Dr. Corné van Elzakker, for his kind assistant during the usability testing ensuring the working conditions of the test equipment and sharing me his experience after being a test person in the pilot test. It is an honour for me to thank Dr. Ir. Wietske Bijker, Dr. Ir. Kees de Bie, Drs. Wan Bakx and Drs. Raymond Nijmeijer, who forwarded invaluable comments and ideas for further improvement of the developed prototype. I am also indebted to many of ITC staffs and students for taking part in the usability test which contributed a lot to the completion of this work.

I am grateful to Atkilt Girma, Tagel Gidey and Berhanu Kefale, PhD students here at ITC. Atkilt, your skilful help in designing the usability test tasks and providing the case study data, is greatly appreciated. Tagel, your support especially at the very beginning of this research is unforgettable. Thanks for your time Bire in the proofreading. All GFM friends and fellow Ethiopians, let me take this opportunity to say thank you for the sweet memories we have had together in the Netherlands.

Finally, I would like to express my undying gratitude to my wife Enat and my baby girl Meiraf, for the love and support that you showed to your schooling husband and dad. You sacrificed a lot for my sake. Wolde, shall I mention you here for the entire thing you did to them or that is just an obligation to a friend? May God bless you even the more. I am also thankful to all my parents, friends and colleagues back home, for the encouragement you offered me during all my stay abroad, it was my strength. Mother and father, your old age prayer has brought me to the end in peace. May God keep you in His tender care.

Last but not least, I offer my special thanks to: the Netherlands Fellowship Program (NFP) for its financial support to pursue this study, ITC for its quality and systematic way of teaching and shaping personality, and General Wingate TVET College for providing me the chance to make use of this opportunity.

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Chapter 1
Introduction

1.1 MOTIVATION AND PROBLEM STATEMENT

Due to the dynamic nature of our universe, there is a continuous change in all aspects of the globe which will continue in the future. Geoscientists make use of time series of geospatial data to explore and understand these continuous geographic changes. Visual exploration is a process of making such geospatial data visible in a particular use context: private audience (map generated for own needs) with the objective of revealing unknowns, making use of a high degree of interaction (MacEachren and Kraak, 1997). It allows users to visually explore the data, identify relationships among different variables, and observe the data from various perspectives to have an overview through interactive browsing (MacEachren and Kraak, 1997).

The ever-increasing storage capacity and the high processing power of computers have made room for interactive animations to be used for visualization and exploration of spatio–temporal data to stimulate visual thinking about geospatial-temporal patterns, relationships and trends that support knowledge construction (Kraak and Ormeling, 2010). This is due to the animation's capabilities to emulate the real–world dynamics, to represent processes and track changes, and to support search operations through large amounts of data (Blok, 2005). In comparison with individual static maps, animation has a power to grab user attention because of its ability to explain processes, reveal patterns and relationships, and depict trends of geospatial data (Kraak, 2007). The broad application of animation exploiters range from ordinary users (spatial knowledge dissemination) to skilled consumers (data exploration for knowledge construction) (Harrower and Fabrikant, 2008).

However, animations are claimed for overloading viewers with a rapid sequence of changes. Users of animated data representations could easily be overwhelmed if many changes happen all over the display area which might be too fast or too slow to be noticed, and in either case, important changes between consecutive scenes may not be detected (Blok, 2005). This leads to a well known visual perception problem called change blindness which is described by Simons and Rensink (2005, p.16) as "a striking failure to see large changes that normally would be noticed easily". This visual perception phenomenon can affect successful assessment of changes in visual exploration of animated time series.

Change blindness may arise due to different reasons; as a result motion signals may fail to draw attention to important changes. For instance, if users' attention is engaged in a specific task of detecting changes, they may not observe other clearly visible but sudden and unexpected change which is referred to as inattentional blindness (Simons and Chabris, 1999). Split of attention is also a possible cause for change blindness which might happen, for example, when users try to observe both the legend and the animation content at the same time (Kraak and Ormeling, 2010). Failure to observe changes in a visual scene could be further induced if the change happened during a saccade or if flickering occurred in between images as well (Goldsberry and Battersby, 2009).

Many of the issues that bound the use of animated time series are related to the limitations of human perception and cognitive processing capabilities (Goldsberry and Battersby, 2009). According to Harrower (2007), the problem is due to the limited information–processing capabilities of human beings relative to the vast data streaming power of animations. Therefore, focused attention on an object is needed to perceive the change; otherwise, what is in the visual memory will be replaced by the next display which makes comparison to detect the change impossible (Rensink et al., 1997). To this end, the human visual system needs to employ a careful attention management mechanism to selectively process important information which is relevant to the current visual task (Geerinck et al., 2009). Easily recognizable graphical representations of patterns in the visual scene are also important to reduce the cognitive processing load of the viewer. This is due to the power of human vision to extract information from graphical representations (Blok et al., 1999).

Many authors have suggested an interactive animation design to increase the efficiency for exploratory use and to reduce perceptual or cognitive problems related to change blindness with animation (Blok, 2005; Fabrikant, 2005; Kraak, 2007; Harrower and Fabrikant, 2008). However, interactive animations still need improvement. For example, if users want to focus their attention on a selected area of interest in the visual scene, usually, not more than a basic zooming function is offered in interactive animations. Moreover, when zooming is applied to select an area of interest, information about the rest of the displayed area (the context) will be lost. This hinders users to relate the changes in their area of interest with the surrounding context for better understanding.

This research will concentrate on methods that help users to have focused attention on changes in a selected area of interest by visually suppressing the surrounding context area. This may also be achieved by selecting range attribute values of interest with a simultaneous visual suppression of the unselected ones. It will adopt previous studies' recommendations and suggestions to enhance the effectiveness of animation and take the cognitive process of the human visual system into account to address problems related to change blindness. The research will focus on users of animated time series who might employ the findings of the study for visual exploration tasks, one important application of which is to monitor changes in a phenomenon under investigation through exploration and analysis of the data (Blok, 2005). These users could be geoscientists who are dealing with spatial dynamics to discover patterns, relationships and trends in a geospatial data.

1.2 RESEARCH IDENTIFICATION

1.2.1 Research objectives

The main objective of this research is to visually enhance area of interest and/or attribute values of interest and simultaneously suppress the context to reduce problems related change blindness in animated time series. The following specific objectives are defined to achieve the main objective:

1. To explore causes of change blindness and identify ways to reduce the problem from a perceptual/cognitive perspective.
2. To translate the identified ways into methods that visually enhance area and/or attribute values of interest and suppress the surrounding context.
3. To select potentially suitable methods that enhance area and/or attribute values of interest and suppress the surrounding context from a theoretical point of view.
4. To develop and implement the suitable method(s) in a tool for demonstration and evaluation purpose; this tool will be integrated into a basic version of *aNimVis* [1] prototype.

[1] *aNimVis – Animated Image Visualization (aNimVis) prototype was developed for the research of Blok (2005), mainly suitable for qualitative evaluation and exploration of the dynamics in time series.*

5. To perform usability evaluation for the proposed method(s) using a case study data.

1.2.2 Research questions

The following research questions are formulated in order to address the aforementioned objectives:

1. How do people perceive changes in an animation and what are the causes of change blindness?
2. What are the possible ways to reduce change blindness from a perceptual/cognitive perspective?
3. What are the possible methods to enhance visual representation in areas and/or attribute values of interest and suppress the surrounding context?
4. What are the potentially suitable methods for visual enhancement and visual suppression in order to reduce the effect of change blindness?
5. Which method(s) is (are) suitable to be implemented in a prototype?
6. Which method(s) is (are) appropriate for the usability testing?
7. How effective is (are) the proposed method(s) compared to the existing methods in reducing change blindness and helping users to focus attention?

1.2.3 Research methodology

To achieve the objectives there will be a comprehensive literature review throughout the study period. In addition, four different levels of methodology, namely: *Conceptual level, Operational level, Implementation level and Evaluation level* will be pursued as depicted in Figure 1.1.

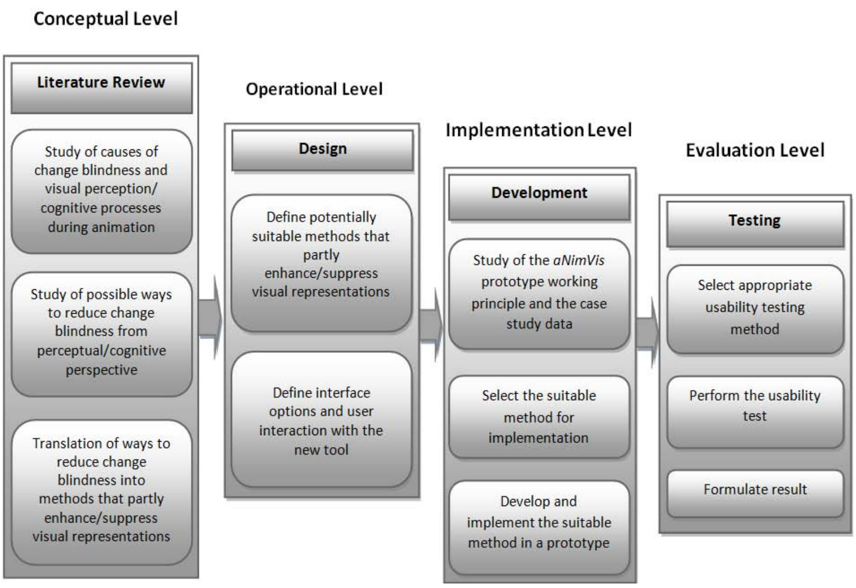


Figure 1.1: Main research phases (adopted from (Ogao, 2002))

A brief description of the specific objectives and the respective research questions to be addressed at each level is given as follows:

- *Conceptual Level:* at this level there will be an intensive literature study in order to explore causes of change blindness and to understand how people perceive changes during visual exploration of animated time series. Possible ways to reduce change blindness from a perceptual/cognitive perspective will be identified and translated into methods that partly enhance/suppress visual representations of the scene. This will address the first three research questions that lead to the achievement of the first and the second specific objectives.
- *Operational Level:* the main interest here is to select methods suitable to design an interactive tool that adds functionality to the *aNimVis* prototype whereby visual enhancement of area and/or attribute range of interest and suppression of the surrounding context is achieved. It will start with defining potentially suitable methods from the already identified once at the conceptual level. Specific issues like interface options and focus area selection alternatives for the new tool will be addressed here. At this level, the fourth research question will be answered and the third specific objective will be achieved.
- *Implementation Level:* this phase targets towards the achievement of the fourth specific objective by answering the fifth research question. It encompasses the creation and integration of the suitable method into an interactive tool designed in the operational phase. The suitable one will be identified from the potential methods. The application (working principle) of *aNimVis* prototype and the case study data to be used will be studied for the creation and implementation of the tool.
- *Evaluation Level:* at this level, the sixth and the seventh research questions will be answered and the last specific objective will be attained. To this end, the newly implemented method will be tested for its usability so as to find whether it aids geoscientists for monitoring task. A proper usability testing method will be selected in order to achieve reliable test data and users opinions for further improvement of the tool. The main contributions and conclusions of the research will also be outlined after analysis of the usability testing data, and discussion about the results. Recommendations for improving the proposed methods and for pursuing further work in this and similar research fields will be presented in addition.

1.3 THESIS OUTLINE

The thesis is organized in six chapters:
Chapter 1 – constitutes motivation and problem statement, research objectives, research questions and the adopted research methodology to address the problem.
Chapter 2 – is a brief discussion of visualization in general and visual exploration of animated time series in particular. The perceptual–cognitive process and related problems are also explained.
Chapter 3 – discusses possible solutions and potential methods to reduce the perceptual cognitive problems with animated time series.
Chapter 4 – is about the design and the implementation of the suitable solution. There is a brief discussion of the *aNimVis* prototype and the case study data in order to make a final selection of the methods to be implemented.
Chapter 5 – is all about testing and evaluation of the implemented method. Selection of suitable usability testing method(s) will be made at the beginning of the task in order to get valid and complete test data. The chapter ends with a discussion of the usability test results.
Chapter 6 – in this chapter conclusions and recommendations for further work will be drawn based on the overall process the study and the usability testing result of the research.

Chapter 2
Visualization and perceptual–cognitive processes

2.1 INTRODUCTION

As we discussed in the introductory chapter of the thesis, visual exploration is a process of seeing that involves human perceptive and cognitive capabilities. Given an exploratory environment with relevant tools for the task at hand, it allows to visually explore graphical data representations from various perspectives to gain insight about it.

This chapter highlights the process of visual exploration and the perceptual–cognitive problems that might be encountered during the process. The main purpose of the chapter is to lay the base for determining possible ways that enhance visual exploration of animated time series. To this end, visualization and the perceptual–cognitive processes during visual exploration are reviewed.

The constitutive parts of the chapter start with a brief discussion of visualization from different perspective based on the map use cube (Sections 2.2). Next, visual exploration tasks and questions are explained in which most focus is given to the time (when) characteristics of the data (Section 2.3). Under Section 2.4, animation for visual exploration of time series is described in more detail as it is the tool this research is concerned about. The cognitive processes taking place during visualization are summarized including the human cognitive architecture and the cognitive load theory (Section 2.5) which lead to a discussion of change blindness – the common cognitive problem with animation (Section 2.6). A brief summary is given at the end of the chapter (Section 2.8).

2.2 VISUALIZATION

Visualization is a process of making data perceptible to the mind or imagination of the viewer (Andrienko and Andrienko, 2005). It is mostly associated with graphical representation of the data and facilitates rapid understanding of relationships that are not directly observed from the raw data. So, it is possible to say that visualization is a way to gain knowledge, and basis for new discoveries by thorough and careful examination of the data under study. MacEachren and Kraak (1997) briefly explained visualization from different perspectives using the so called map use cube (Figure 2.1).

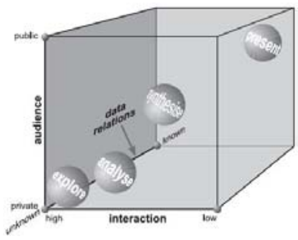


Figure 2.1: Map use cube (MacEachren and Kraak, 1997)

When visualization use refers to exploration, it is a process of examining unknown data with high interaction to have an overview of the data and generate hypothesis for further spatial analysis operations. Visualization use for analysis is related to testing the hypotheses: to find and quantify data relations. Visual synthesis is a process of presenting a summary of knowns for group of concerned people (e.g. experts) of a possible new insight. Visual presentation in the map use cube aims at the transfer of known information to the public. The main concern of this research is on the exploration corner of the cube.

Visual exploration makes use of abductive reasoning (reasoning to the best explanation) in which explanatory hypotheses are formed and evaluated (Blok, 2005). It starts with no or vague hypotheses about the data and tries to develop a hypothesis about relationships, patterns, trends, etc., by exploring the data. The hypotheses are evaluated later to judge whether they fit into a coherent pattern of cognitive representations.

Visual exploration can be used to perform preliminary investigation of large unstructured, multifaceted spatio–temporal datasets. As stated by Wood et al., the process of visual exploration requires “the selection and aggregation of records by time, space and attribute, the ability to transform data and the flexibility to apply appropriate visual encodings and interactions” (Wood et al., 2007, p.1176).

2.3 VISUAL EXPLORATION TASKS AND QUESTIONS

The main goals of visual exploration are discovery, explanation, knowledge acquisition and decision making (Blok, 2005). Users need to have some application with a sequence of tasks in mind to achieve either of these goals by visual exploration of the underlying data. Modelling a certain phenomenon, forecasting a possible event to happen and monitoring to understand cause and effect of geospatial process are some of the applications that a user might bear in mind to engage in visual exploration.

Visual exploration tasks could be enhanced by the characteristics of the spatio–temporal data which are exhibited in the attribute space (what), the location space (where) and the temporal space (when) (Kraak and Ormeling, 2010). These characteristics are used to visually analyze the data to accomplish the visual exploration tasks in mind, which are mainly pattern related tasks, i.e., identification and comparison (Blok, 2005). Thus, the “what–where–when” questions are basic to achieve the visual exploration tasks.

Koussoulakou and Kraak (1992) made use of the three spatial reading levels of Bertin (1983) *elementary, intermediate and overall*[1] for the temporal (when) component of spatio–temporal data in which the elementary level refers to a certain moment in time, the intermediate level refers to a certain period of time, and the overall level refers to the whole time temporal trend of the process.

Peuquet (1994) also developed a “Triad frame work” for spatio–temporal data to organize information related to the “what–where–when” triad which possibly permits users to pose the following “three basic kinds of questions”:

1. when + where → what: describe the objects or set of objects (what) that are present at a given location or set of locations (where) at a given time or set of times (when).

2. when + what → where: describe the location or set of locations (where) occupied by a given object or set of objects (what) at a given time or set of times (when).

[1]*According to Bertin (1983), the three levels spatial reading indicates whether a question refers to a single data element (elementary), to a group of elements (intermediate) or to the whole phenomenon characterized by all elements together (overall). (cited in Andrienko et al., 2003)*

3. where + what → when: describe the times or set of times (when) that a given object or set of objects (what) occupied a given location or set of locations (where).

Due to the availability of long time series data it is possible to answer questions related to the identification (trends) or the comparison (cause and effect relationships) tasks of visual exploration. To this end, Andrienko et al. (2003) further categorize Peuquet's basic questions into elementary and general data analysis tasks with respect to time. The elementary tasks in the classification refer to individual time moments and the general tasks are about the characteristics of an object or set of objects over a given period of time interval. The elementary tasks can further be distinguished on the intended search target (time or locations), the cognitive operations to be involved (identification or comparison) and the search level with respect to space and objects. Giving priority to the temporal component of the spatio–temporal data, Andrienko and colleagues have generalized the tasks into four categories as summarized in Table 2.1 below.

Table 2.1 Elementary and general levels of visual exploration tasks (Becker, 2009)

	Elementary *what + where*	General *what + where*
Elementary *when*	Describes characteristics of this object (location) at the given time moment	Describe the situation at the given time moment.
General *when*	Describe the dynamics of characteristics of this object (at this location) over time.	Describe the evolution of the overall situation over time

2.4 ANIMATION FOR VISUAL EXPLORATION OF TIME SERIES

Tools and techniques are necessary to visually explore spatio–temporal data from different perspectives; though, human imaginative mind is the primary tool for visual exploration as it operates predominantly with images (Andrienko and Andrienko, 2005). Visual exploration tools are means to interactively build and/or manipulate graphic representations of (geo)data in a computer environment (Blok, 2005). The main concern of (geo)visualization is to facilitate the human perceptual cognitive process making use of appropriate tools that empower their pattern–recognition and information–extraction abilities during the exploration of complex geospatial data (MacEachren, 1995). In this regard, Kraak (2000) mentioned three types of visual representation tools to explore time series of geospatial data for change detection from a cartographic point of view. These are:

- Single map – change events are represented by graphic variables and symbols
- Series of maps – sequential display of successive snapshots to depict changes over time
- Animated map – change events are deduced from real movement on the map itself

These tools are not equally effective for visual exploration of time series of spatio–temporal data. According to Turdukulov (2007), single static map for change detection is less effective as it needs visual interpretation and memorization to identify the image feature that underwent the change. Effectiveness of series of maps depends on "the appropriate number and choice of the small multiples, that is, how many and which of the key events (macro steps) are selected to discretely represent the continuous, dynamic process" (Harrower and Fabrikant, 2008, p.58). Compared to the single and the series of maps, animation is a suitable method to explore dynamics in large time series of remote sensing data (Turdukulov, 2007).

Animation is a moving representation of data that portrays change over time, space and/or attribute to represent the process of change itself rather than the outcomes of the change (Lobben, 2003). It has a power to reveal the micro steps between changes which might not be depicted by static graphics (Blok, 2006; Slocum et al., 2001). Harrower (2002) stresses the ability of animation to represent both the space–time structure of the geographic system at a given time and the behavior (trend) of that system over time as a means for having better understanding of the complex process of geographic changes.

Animations could be categorized as a view–only or an interactive animation based on the level of control it provides to the user (Kraak and Brown, 2001; Lobben, 2003). View–only animation delivers little or no control. In case of interactive animation, a user may have a considerable amount of control over the course of the animation that helps browsing through the data for better understanding. Interactive animation is the best for visual exploratory analysis of spatio–temporal data as proposed by different authors (for further reference see: Blok, 2005; Fabrikant, 2005; Harrower and Fabrikant, 2008; Kraak, 2007).

Kraak and Klomp further classified cartographic animations into successive build up, changing presentations and time series animations based on the dynamic or static nature of the location, attribute and time component of the dataset (Kraak, 2007; Kraak and Klomp, 1995). Successive build up animations depict the spatial internal relations of the data presenting the attribute and/or location with respect to time where the temporal component is fixed. In case of changing representations, all components of the data are fixed and a particular data is animated from different perspectives (graphic or classification). Time series animation depicts change of spatial patterns over time in which changes in the attribute and/or location component of the dataset is plotted against time. In time series animations the attribute value of the data appears or vanishes at various locations according to the given time scale (Lobben, 2003). It is this ability of animation that "facilitate understanding of the process rather than the state" as described by Harrower (2002).

However, the overwhelming behavior of animations is also well explained by different authors. Blok (2005) mentioned that both too slow and too fast display of data makes the viewer unable to observe the change. Animated time series data may cause tension and overwhelm the perceptual abilities of the user with irrelevant details due to complexity of raw satellite imagery (Harrower, 2002). According to Goldsberry and Battersby (2009), much of the issues that bound the use of animated time series are related to the limitations of human perception and cognitive processing capabilities which will be discussed in detail in the next section.

2.5 PERCEPTUAL–COGNITIVE PROCESSES DURING VISUAL EXPLORATION

Vision is a path for perception whereby visual stimuli like graphical representations are made perceptible to the mind or imagination of the viewer. Perception in this context involves recording and organization of stimulus materials into concepts through visualization (Andrienko and Andrienko, 2005). A cognitive process is an iterative process to derive meaning by constructing some kind of mental representations from what we perceive (Blok, 2005). Understanding this perceptual–cognitive process taking place in the human mind is essential for designing and implementing visual exploration techniques and tools.

Researchers in cognitive psychology and education developed theories that explain the way how people look and learn from dynamic graphical representations and tried to understand the conditions where these representations work or fail (Harrower, 2007). Most of the studies are done to provide effective instructional design principles which could be adopted for design and implementation of visualization tools, as well. The forthcoming sections briefly discuss the perceptual–cognitive process based on the human cognitive architecture and the cognitive load theory.

2.5.1 Human cognitive architecture

Human cognitive architecture deals with the organization of our cognitive structures. It is a basis to understand how we perceive things. According to Sweller (2002, p.1501), human cognitive architecture is a combination of "a working memory of limited capacity and duration with partially separate visual and auditory channels, and an effectively infinite long–term memory holding many schemas that can vary in their degree of automation".

All conscious cognitive processes are taken place in the working memory. However, due to its limited capacity, we may fail to process new information and get the required knowledge from it (Paas et al., 2003; Sweller, 2002). Any information held in a working memory will be lost within few seconds unless it is rehearsed. The limited capacity and duration of the working memory could be improved by appropriate implementation of visual aids (Ware, 2008).

Contrary to the working memory, the long–term memory has unlimited capacity. The contents of the long–term memory are highly condensed knowledge schemata which categorize elements of information according to how they will be used (Harrower, 2007; Sweller et al., 1998). An already stored schema lets the working memory perceive many interacting elements as a single element which reduces the strain of the working memory (Sweller, 2002). Ware (2008), pointed out two classes of long–term memory information: explicit and implicit. Little of what we see and do is stored in the explicit memory and the implicit memory is what is retained from whatever we do, see or hear. The explicit memory plays an important role in communication because we have to recall explicitly the thing first to establish the communication with it.

There is an iterative interaction between the cognitive structures as depicted in Figure 2.2. The overall process is described by MacEachren (1995). It starts with transferring the "perceptual image" to the working memory after issues like discriminability, distortion, organization and priorities are carried out. Then the contents of the working memory will be encoded onto the long–term memory. Knowledge in the long–term memory will be brought back to the working memory either to accept what is already met or to prompt reorganization to direct search of the visual scene.

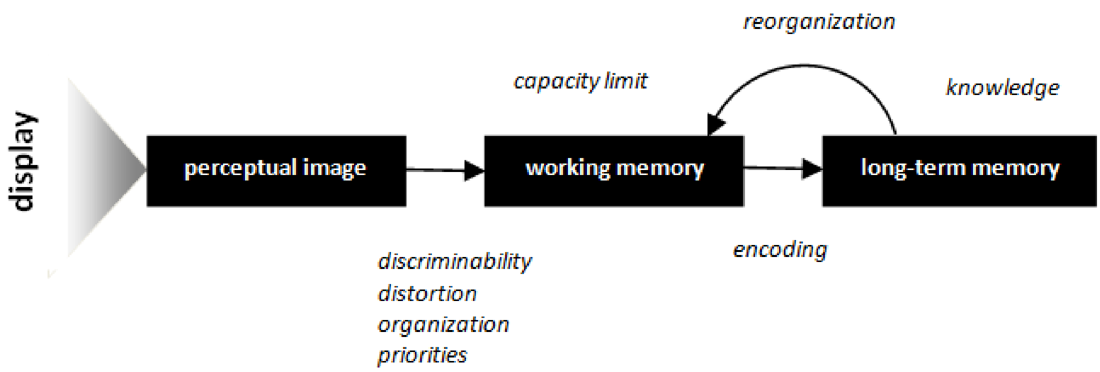


Figure 2.2: Iterative interaction between cognitive structures (MacEachren, 1995)

2.5.2 The process of perception and the cognitive load theory (CLT)

The process of perceptions is a sequence of steps that begins with vision. An image from the surrounding environment is transmitted through the lenses of the eye and projected on the retina. The retina is a light–sensitive layer that covers the back wall of the eyeball. Visual details or patterns are visible via fovea – the central region of the retina. The more widely distributed cells around the fovea are motion detectors where vision is vague. Most useful (or task related) information is extracted in the fovea and transmitted to the brain through the optic nerve for further processing (Blok, 2005; Ware, 2008).

According to Ware (2008), the act of perception is determined by a bottom–up process – driven by visual information and a top–down process – driven by demand or task. Both processes taken place at three different more generalized levels (Figure 2.3). In the bottom–up process information driven waves passes to the brain via the optic nerve. In the first feature–processing stage, meaningless features are successively selected and filtered to form patterns in the second pattern–finding stage which then forms a small number of visual objects in the third stage. These objects are made from the task we need to perform and held in mind for a second or two due the limited capacity of the working memory. In case of top–down process, an attention–driven wave originates from the brain to filter out task relevant information from the unrelated ones. It intends to achieve some goal which might be a cognitive task.

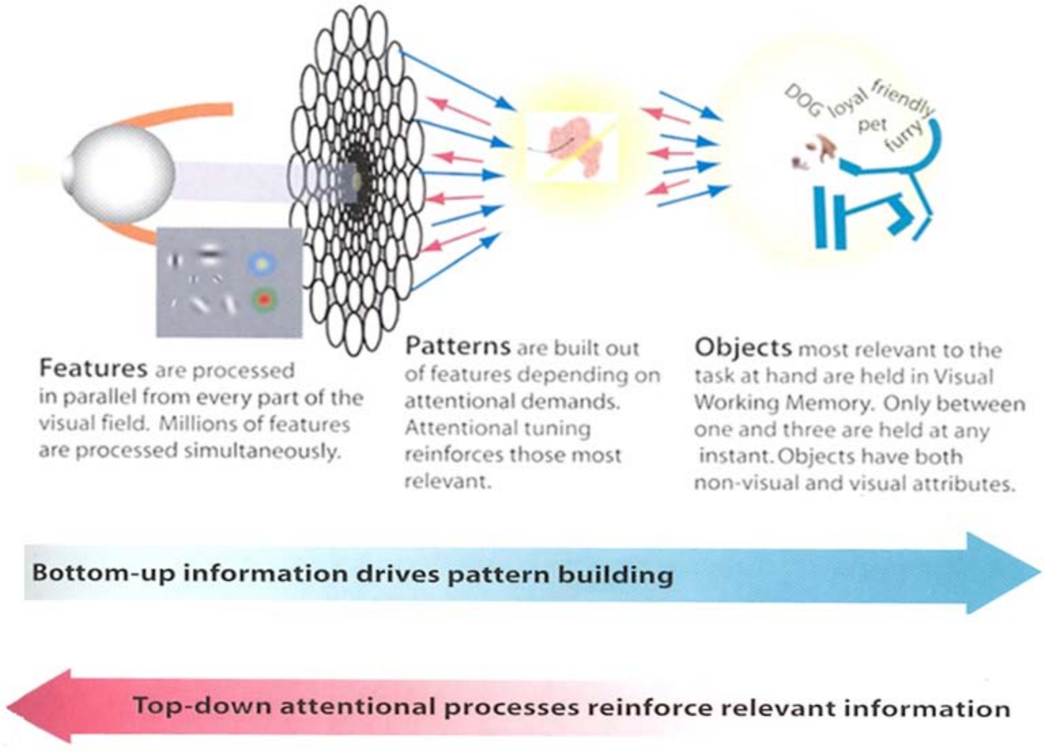


Figure 2.3: Process of perception (Ware, 2008)

The working memory processes and stores information in the long–term memory in the form of schemata with this sequential perception routine. However, when lots of information elements appear to be processed at the same time, there will be a heavy cognitive load on the working memory that hinders the effectiveness of acquiring new knowledge or performing a task (Harrower, 2007). Cognitive load theory (CLT) deals with this limited working memory capacity and intends to reduce the unnecessary cognitive burden on it such as distracting sounds or poorly organized graphical user interfaces (Van Merrienboer and Sweller, 2005; Harrower, 2007).

2.5.3 Types of cognitive loads

According to CLT, there are three different types of cognitive loads that imposed on working memory during the processing of novel information:

1. **Intrinsic cognitive load** – refers to the number of elements to be processed simultaneously in the working memory and depends on the complexity of the material to be 'learned' and the expertise of the learner (Van Merrienboer and Sweller, 2005). Harrower's good example for this is the high intrinsic load due to the complexity of a map to be read (Harrower, 2007).

2. **Extraneous cognitive load** – refers to a load that doesn't help learning. It makes working memory busy with activities that do not have a direct relation with new knowledge construction. It might arise from distractions and poor design of the material to be learned (Harrower, 2007; Van Merrienboer and Sweller, 2005). The additive behavior of intrinsic and extraneous loads may result in fewer working memory cognitive resources for schema construction and automation during learning (Sweller, 2002).

3. **Germane cognitive load** – refers to effective cognitive load that results from the manner the information (material) is presented to the learner and their active engagement with the material (Harrower, 2007; Paas et al., 2003). Whenever there is a free working memory resource, learners may use it for schema construction that directly relates to the learning process. Even though it creates a cognitive overload but it is germane – that enhances learning (Sweller, 2002).

All the three loads are additive where the ultimate sum cannot exceed the total working memory capacity to acquire new knowledge (Paas et al., 2003). Paas et al. (2003) further discuss the iterative relation between the cognitive loads in which the intrinsic cognitive load could be reduced by improving the instructional materials which in turn reduces extraneous cognitive load to make the working memory free for germane cognitive load that enhances learning.

The overall study of CLT helps for design and implementation of computer applications that enhance the effectiveness of animation. According to Harrower, "the effectiveness of a computer interface or map design is partly dependent on managing extraneous cognitive load, and researchers have begun to use CLT to design better computer interfaces and software" (Harrower, 2007, p.352).

2.6 CHANGE BLINDNESS: A PERCEPTUAL–COGNITIVE PROBLEM WITH ANIMATION

In our discussion of animation for visual exploration (Section 2.4), it is explained that animation portrays the process of the change itself in a better way than the static maps, including the micro steps between major changes. It is also discussed that animation overload users with a rapid sequence of changes and lets important changes pass unnoticed. Even if several interaction mechanisms are employed, animation still suffers from a well known visual perception phenomenon: change blindness (Cater et al., 2003). The following discussion is about this cognitive problem with animation.

2.6.1 What is change blindness?

Change blindness is a visual perception problem in which clearly visible large changes in a visual scene may pass unnoticed (Nowell et al., 2001). It could happen in both the real–world scenario and computer assisted visualization like time series animations. Evidences from carefully designed experiments show that viewers fail to notice change of an actor in motion pictures and replacement of a conversation partner in a discussion held between two persons (WWW-1). (for further reference see: Rensink et al., 1997; Simons and Chabris, 1999; Simons and Levin, 1997).

2.6.2 How does it happen?

According to Rensink (2002a), we are amazingly blind to changes – unable to detect transformation or modification of something over time. The change detection process includes noticing the existence of a change, identification of what the change is and reporting where it is (localization). When a change happens, it produces visual transient (motion signals) that attract attention to the change location so that the observer can perceive it (Rensink et al., 1997). In order to understand what the change is, one has to compare the encoded representation of the location where the change happened in the working memory with what is there after change. However, due to the limited capacity and duration of the working memory, the encoding may not have taken place accordingly. This causes absence of a consciously accessible representation of the changed feature which is a possible reason for change blindness to occur. Thus, failure to change detection means either the transient fails to attract attention or the encoding and comparison process was not successful. But it must be noted that inability to detect changes does not imply absence of a consciously accessible representation because change blindness could also happen due to the failure of comparison of the representation before and after the change, even if there is a complete representation of the changed features (Simons and Ambinder, 2005).

With respect to the encoding of the representation of the changed feature, Simons (2000) and Nowell et al. (2001) pointed out five possible theories for change blindness to happen, as summarized below.

- **Overwriting** – is a complete replacement of an already existing mental representation with a blank interval or a new scene. This makes comparison difficult for the desired change detection and leads to change blindness as there is only the abstract representation of the initial display.

- **First impressions** – it is failure to encode the detailed representations of the changed scene even though features of the initial object or scene are encoded accurately. However, the detailed representation of the changed scene may not be as such important if the meaning of the initial scene is not affected by the change and the goal of perception is to understand the meaning of the scene.

- **Nothing is stored** – it suggests that only abstracted information of the visual scene is stored internally once we perceive it, no need of storing the visual world. It holds true as long as the visual world remains unchanged. If the scene is changed, it will not be possible to compare the detail representations to detect the change.

- **Nothing is compared** – all about the scene may be stored without any awareness of the difference between them. When comparison is triggered for detecting the change, it may not go beyond the memory traces of the old representation which leads to failure in change detection even if all the details are represented.

- **Feature combination** – it suggests that the stored representation is neither the whole representation of the old nor the new scene; it is rather the partial combination of both. It is an older and totally discredited theory that doesn't have any implication for both change detection and change blindness.

2.6.3 Causes of change blindness

Different studies suggest different reasons and explanations for causes of change blindness that might triggered either of the aforementioned theories to be happened. For example, change detection may fail if the changes are happening during a blank screen (a temporal gap between the original and altered stimulus), saccade (rapid rotation of the eyeball), or an eye blink. In addition to these, the following phenomena are widely described as potential causes of change blindness (Simons, 2000; Simons and Chabris, 1999; Harrower, 2007; Blok, 2005).

- **Inattentional blindness** – it is inability to clearly perceive visible but sudden and unexpected change due to the engagement of users' attention in a specific task of change detection (Blok, 2005; Simons and Chabris, 1999). For example, if viewers are attending task specific features, changes happening even in the central scene might pass unnoticed. This might be either the changes are accompanied by other attention distracting stimuli or the changes may not have strong signals to be perceived. Cater et al. (2003) explained inattentional blindness as a task driven (top–down) process that influences visual attention directing focused attention to few goal specific objects whereby task irrelevant objects would normally be ignored even if they are clearly noticeable.

- **Split attention effect** – is an effect that might arise when users try to mentally integrate two or more diverse sources of information in order to have a complete understanding of the visual display (Harrower, 2007; Kraak and Ormeling, 2010). A typical example for this is trying to use the map and the map legend at the same time to get the full meaning when neither of them provides the meaning of the complete scene by itself. The effect is more amplified for animated maps than for static ones. This is because users may miss part of the animation display whenever they try to see "the temporal legend to orient themselves in time, or a data legend to understand what the symbols mean, or other parts of the mapping interface to control the map" (Harrower, 2007, p. 273).

- **Retroactive inhibition** – it is a limitation due to lack of sufficient time for the complete encoding of visual representations from the working memory to the long–term memory. Since animation displays the data in a continuous series of elements, there has to be enough time to remember and understand the first display so that the next display will be meaningful. Failure of having this enough time will result in a kind of "cognitive traffic jam" which is referred to as retroactive inhibition (Harrower, 2007).

2.7 SUMMARY

In this chapter, a closer look at visualization is made from different perspective based on the map use cube. Visual exploration tasks and questions are explained giving more emphasis for the time (when) characteristics of the data. Animation is also described as a suitable tool for visual exploration of time series of spatio–temporal data – taking into account the perceptual–cognitive problems and limitations with it. Understanding of the human cognitive structures and the cognitive load theory is a base to design new or improve existing visual exploration tools. In this context, the human perceptual–cognitive process is explained briefly whereby the the root causes of change blindness, the well–known visual perception problems with animation, is figured out. The coming chapters will investigate ways to reduce this visual perception problem and help users get focused attention during visual exploration of animated time series.

Chapter 3

Reducing change blindness from a perceptual–cognitive perspective

3.1 INTRODUCTION

Attention can operate only on a few items at a time as already discussed in Chapter 2. But there are many items in the real–world scene. To bridge the gap, careful attention management mechanisms have to be employed that facilitate attending the right item at the right time so as to react with the environment properly. This chapter is about possible solutions that are supposed to manage attention and reduce the problem of change blindness during visual exploration of animated time series. It starts with a discussion of the need for focused attention (Section 3.2). Reducing the extraneous and the intrinsic cognitive loads lets attention free for better visualization. Graphical representation of a scene has a role in this regard. Section 3.3 discusses how graphical representations influence the visual display and the application of Gestalt perceptual grouping principles for effective graphical representations in animated time series. Possible ways to emphasize changes in the scene are also described. The overall discussion is summarized by identifying methods that enhance area of interest and suppress the surrounding context (Section 3.4) and concluded by pointing out the potential ones to reduce change blindness (Section 3.5). Finally, a brief summary is given under Section 3.6.

3.2 FOCUSED ATTENTION

The process of perception is enhanced by the visual task that the viewer undergoes and the visual attention given to perform the task in order to encode the information. When the observer is task oriented, all available attention resources will be directed to detect the change that meet the task at hand (Rensink, 2002a). Even though attention can easily be drawn to any change in the scene, it is primarily attracted to task relevant changes for precise representation of the changed environment (Rensink et al., 1997).

A number of studies emphasize focused attention as a prerequisite for conscious perception in order to select task related aspects of the visual scene for localization (where is it), identification (what is it), and understanding of objects in the environment (Cater et al., 2003; Nowell et al., 2001; Rensink et al., 1997; Simons and Rensink, 2005). When changes are happening in the scene, they are accompanied by a motion signal which is either unique or a bit larger than the background noise in order to get focused attention (Rensink, 2002a). Once objects get focused attention, they are likely to be further processed for complete understanding which is a high–level interpretation of motion based on low–level processes (Rensink et al., 1997).

According to Rensink's (2002a) coherence theory, low–level processing results in unstable proto–objects which can be altered by new stimuli if they don't get focused attention. While focused attention is employed, the proto–objects will form a coherence field both in time and in space that represents a distinct object. The object representation stays not long and dissolves back to unstable proto–object at a release of focused attention as it breaks the feedback loop.

Features which have got a focused attention will be loaded into a long–term memory and will be perceived whenever they undergo changes whereas the unattended ones are directly replaced by new features without any awareness of replacement (Rensink et al., 1997). After observing a natural scene, for instance, one can mostly remember those task related features which have got a focused visual attention. Changes that occurred in the central scene will get more visual attention than those in the peripheral even if they are of equally prominent (Simons and Rensink, 2005).

Simons and Ambinder (2005) summarized the need for focused attention in four points. Firstly, change blindness is highly likely to happen if attention is distracted from the change signal. Second, focused attention is more attracted by central objects or visually distinctive objects than other changes. Thirdly, attention is necessary, but it does not guarantee the absence of change blindness and finally, change detection requires comparison of the encoded features before and after the change.

This study tries to support users to have focused attention during exploratory task by investigating different approaches that help manage attention for effective visualization. These include improving the graphical representation of the scene and visual enhancement/suppression of representations.

3.3 GRAPHICAL REPRESENTATION OF THE SCENE

3.3.1 How graphical representations influence perception

The effectiveness of visual exploratory tasks depends, amongst others, upon the attention given to it which is directly influenced by the graphical representations of the scene. As we have discussed in Chapter 2, pattern identification and comparison are the main exploratory tasks performed by users of geographic data representations with various backgrounds. Easily recognizable graphic representations enhance pattern finding and analyzing their characteristics, pattern comparison for anomalies and relationships discovery, and determining trends in pattern developments (Blok et al., 1999).

Desolneux et al. (2008) described how graphical representations influence perception. They used the so called optic–geometric illusions – figures with simple geometric arrangements which have strong perceptive distortions. Two of the illusions are presented here to explain the power of graphical representations on scene determination.

- **The Hering illusion** – a figure built from two parallel lines and a number of converging lines that meet at a point symmetrical to the parallel lines (Figure 3.1). Observers perceive the parallel lines as a curved lines influenced by the converging lines.

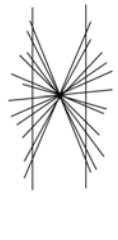


Figure 3.1: Hering illusion (Desolneux et al., 2008)

- **Zoellner illusion** – in which the parallel diagonal lines in the box (Figure 3.2) look converging and diverging alternatively because perception is influenced by the small and slanted straight segments crossing the diagonals.

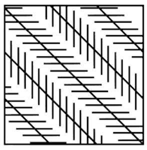


Figure 3.2: Zoellner illusion (Desolneux et al., 2008)

According to MacEachren (1995) cartographers started to deal with Gestalt[1] principles for designing effective graphic representations some 30 years ago, despite the fact that there was no proof for their relative strength. The principles lay the theoretical foundation for cartographic design rules, guidelines and conventions for understanding of the perceptual organization of the visual scene. The coming sections discuss the relevant principles for this study and describe their direct implication in order to attain users' attention during visual exploration of animated time series.

3.3.2 Gestalt principles for graphical representation of animated time series

As it is already discussed, pattern identification and comparison to explore and analyze relationships is a complex visual exploration task in animated time series due to the variation of the patterns in display time. According to Blok et al. (1999) (discussed under Section 2.6), this pattern identification and comparison task overburdens the viewer since it relies on pre–attentive, quick and partly parallel processing and further integration of the reaction. The processing overload as a result of the complex visual exploration task could be reduced if the graphical representations of patterns are made easily recognizable making use of, amongst others, Gestalt grouping principles.

Gestalt is a theory of visual perception that attempts to describe how atomic perceptual units (lower–level primitive) of a graphical image organize to form a unified whole image (higher–level structure) without any knowledge of the image content (MacEachren, 1995; Slocum et al., 2009). Perceptual grouping refers to the human visual ability to group the atomic perceptual units. If lower–level primitives or an already formed group have some common characteristics, they will be grouped together and form a new larger higher–level structure, a Gestalt (Desolneux et al., 2008). The Gestalt principles guide vision by grouping the information from sensory input in the simplest possible way. Among the Gestalt grouping laws, relevant principles to this research are discussed here as follows partly based on MacEachren's (1995) book *"How Maps Work"*.

The law of similarity

This grouping law refers to human perception tendency to group similar elements that share visual characteristics as color hue, color value, size, shape, etc., together and perceive as part of the same (Desolneux et al., 2008). The application of this law can facilitate comprehension of the graphics by having similar properties and common structures grouped together. For instance, in Figure 3.3a, two squares appear to be different from the group due to the different color and size they possess. Our tendency of associating similar things together made us perceive black and

[1] *Gestalt means form or configuration in German (Ware, 2008)*

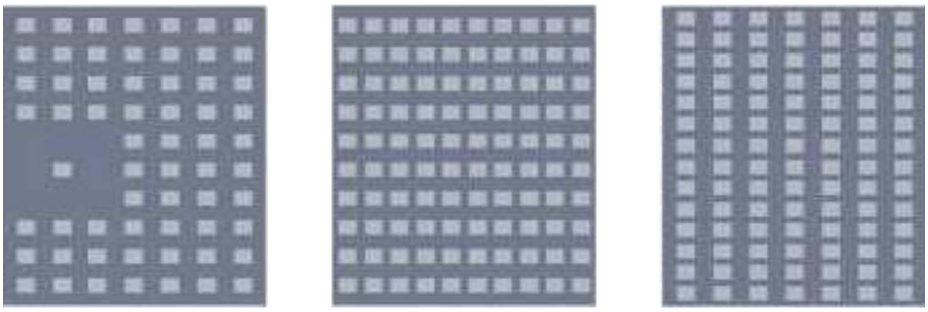
white rows alternately influenced by their color similarity (Figure 3.3b). Columns are perceived in Figure 3.3c due to the association of similar shapes.

(a) (b) (c)

Figure 3.3: Law of similarity (Mwakisunga, 2010)

The law of proximity

According to Gestalt law of proximity, objects that are close to one another appear to form groups. This holds true irrespective of shape and size of objects. In Figure 3.4a, even if it has the same shape and size with the others, one square appears to be different from the group only due to its relative distance from the neighbouring squares. The horizontal spacing between the squares is greater than the vertical spacing in Figure 3.4b. This made the squares to be perceived as rows. The squares appear to be arranged in column due to the lower horizontal separation between them relative to the vertical separation in Figure 3.4c. The principle allows to group sensory inputs as per their spatial locations. It could be applied to place parts close together in order to show the relationship between graphic elements.



(a) (b) (c)

Figure 3.4: Law of proxmity (Mwakisunga, 2010)

The law of simplicity

This law is basis for the rest of Gestalt principles as it states that human mind tends to group objects in the best, simplest and most stable shape. It is how we interpret ambiguous and complex visual situations and try to understand the meaning. This law applies to arrange features in the spatial domain as the simplest possible presentation in order to convey the meaning they have to communicate. For example, when we see the image in Figure 3.5, we think that it represents two overlapping squares (Figure 3.5a) but what we actually seeing is a square next to an L–shaped region (Figure 3.5b).

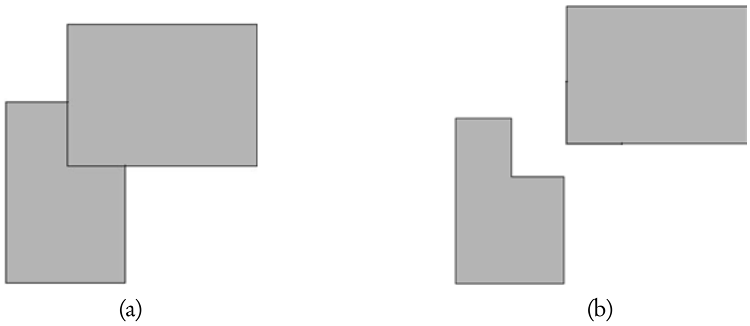


Figure 3.5: Law of simplicity (MacEachren, 1995)

The law of common fate

The law of common fate demonstrates the tendency of grouping objects that share the same moving direction. This law overrides the other laws of perceptual grouping to achieve a new group due to their "common fate". According to MacEachren (1995), common fate plays a role in the way groups are perceived in cartographic animations. It makes objects that change together to be seen as a group even if they are not moving. It could be applied to direct viewers' eyes to an area or region of interest since it is a common perception trend to follow the path of moving objects.

The law of objective set

This law refers to human perception tendency towards a stable group. Once perceptual units are seen as a group, perception will try to retain this group even if the position of those units is changed overtime (Blok, 2005). Objective set creates an impression of having a stable grouping in a dynamically presented set of change maps in a better way than in static small multiples (MacEachren, 1995).

Both perceptual grouping principles objective set and common fate could be applied to influence the perceptual organizations while addressing the basic spatio–temporal domain questions "when," "how long," "how often" and "what is the trend" in animated time series (Blok et al., 1999).

Figure–ground

The principle of figure–ground is about the relationship between an object and its surroundings. In addition to grouping and organization, perception also involves in distinguishing an object from its surrounding. Perception organizes and groups the visual inputs to attract attention in order to identify the figure from the ground. Once an object gets attention and forms a figure, it appears to be in front and the area around the object becomes the background and this may possibly be reversed if attention is shifted from the figure to the ground. A common example for the figure–ground concept is the vase–face ambiguous figure that illustrates a white vase outlined by a black profile (Figure 3.6). At any moment one can perceive either the white vase as a figure and the black profiles (which form two faces) as a ground or vice versa. As it is not possible to perceive both images at once, it needs a conscious decision of the mind whether to see a face or a vase.

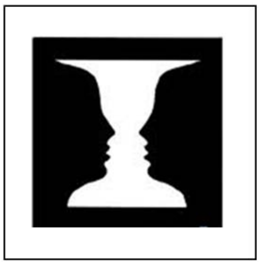


Figure 3.6: The vase–face ambiguous figure

Figure–ground segregation is important to address the basic "what–where–when" visual exploration questions in order to identify and compare patterns in the spatial domain (Blok et al., 1999). This is because viewer perception is influenced by graphic stimuli that attract attention to separate the figure from the ground. "Figure" in this context refers to patterns to be identified and compared in order to accomplish the visual exploration task.

3.3.3 Emphasizing changes in the visual display

In the previous section, the role of perceptual organization is explained as one approach to manage and effectively utilize the limited capacity of attention. Continuing our discussion of attention management for effective visual exploration, this section concentrates on the ways to accentuate changes so that they could easily seize users' attention.

Shneiderman (1996) argues that humans remarkable perceptual abilities of detecting changes in size shape color, texture, etc., are underutilized due to the design of the visual display. Improvement requires, in addition to what we have discussed so far, for making changes to attract viewer's attention in order to see a particular part of a display. According to Rensink's coherence theory (discussed under Section 3.2), only few items are represented in stable form and perceived as a single object with both spatial and temporal coherence as long as they attain focused attention. Despite the many aspects of the visual scene, coherent representation is needed for a single object at any specific time. Thus, a careful coordination of attention is necessary to form a coherent, detailed representation of the object and its properties required for the task at hand.

Accentuating changes is proposed here to support observer's attention to see (or not to see) a particular part of the visual scene. The approach is discussed by Rensink (Forthcoming; 2007; 2002b) as a coercive graphics that takes control of attentional allocation for better change detection and lets user attend whatever relevant for the task at hand. According to his explanation, this attentional coercion could be achieved by any of the following three ways.

High–level interest

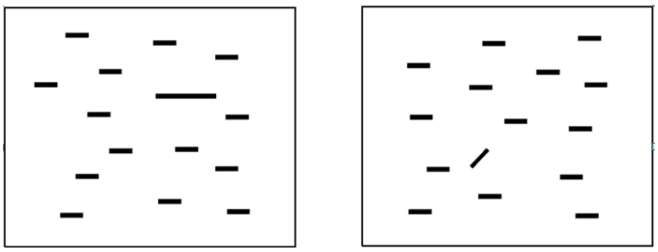
It involves a voluntary direction of attention to an item influenced by semantic factors such as viewers' interest in a particular object or event. This could override any change emphasizing technique if viewers' are very much task oriented and the interest for a specific item is sufficiently high.

Mid–level directives

It makes use of featural cues (as of Low–level salience) on the basis of their meaning (as of High–level interest) in order to direct attention to a given location other than viewers' own interest. Rensink's (Forthcoming) good example for this is an image of a pointing figure that directs attention towards the pointed feature.

Low–level salience

Attention is highly attracted by items which have salient properties (see below) of the low–level features: proto objects across space and time. Saliency is "differences in the density of features in a region, with large differences creating the highest level of saliency" (Rensink, Forthcoming, p.17). It plays a role in attentional allocation thereby higher attention is given to more salient region. Thus, changes could be emphasized by highlighting the target item in a way that enhances its saliency making use of some featural cues. The low–level salient properties may include brightness (contrast), color (hue), length, orientation, blinking, etc. Attention is easily drawn to items which have different feature properties relative to the surroundings. For instance in Figure 3.7, the lines with different length (a) and different orientation (b) easily draw attention due to their unique featural cue relative to the neighborhood representation.



(a) (b)

Figure 3.7: Length (a) and orientation (b) cues (Rensink, Forthcoming)

Brightness (contrast) refers to visual differences between low–level features properties that attract observers' attention towards the more brightly–lit region. It adds interest to the visual display by providing a graphical variety and allow us to differentiate features according to their importance (Slocum et al., 2009). Blinking is a repeated on/off symbolization in order to attract attention but it can be annoying for the user (Blok, 2005).

Emphasized changes in the visual display enhance our perceptual ability for visual information extraction. Any suitable highlighting technique can be employed to make change features more salient than the rest so as to get observers' attention from a field of thousands of items. The coming section explore methods that might be used to employ the aforementioned concepts in order to enhance/suppress visual representation of a scene.

3.4 METHODS FOR VISUAL ENHANCEMENT AND SUPPRESSION

So far we have seen how graphical representations determine the visual scene. Human perception is so sensitive that it can be influenced highly with the visual display which might either enhance or hinder the task at hand. The perceptual–cognitive problems, especially with animation (Section 2.6), could be reduced or aggravated according to the design and display of the graphics in the scene. The main factor is the limited capacity of attention while attention could be easily directed towards the most prominent feature in the display. Managing this precious resource effectively could facilitate the visual exploration task. Enhancing user selected area and/or attribute values of interest with simultaneous suppression of the surrounding context is the way proposed for this research in order to get focused attention for effective exploration of animated time series. The following discussion is about the different possible methods for the practical implementation of visual enhancement or suppression.

Shneiderman (1996) provides a "Task by Data Type Taxonomy" to visualize data, which might be either of the seven data types: 1–, 2–, 3–dimensional data, temporal and multi–dimensional data, and tree and network data. The proposed tasks for visual analysis of these abstractions of reality are: overview, zoom, filter, details–on–demand, relate, history and extract. Keeping Shneiderman's visual information seeking mantra, our discussion will concentrate on temporal data type visualization in combination with the tasks with visual enhancement of the area and/or attribute values of interest by a simultaneous suppression of the context. Focus is on overview + detail, zooming and filtering, focus + context and some related cue based techniques.

3.4.1 Overview + Detail

This visualization technique is used to display both the context (overview) and the area of interest (detail) simultaneously in different presentation space where the area of interest is visually enhanced for a better detailed display (Cockburn et al., 2008). It lets users stay oriented with respect to the surrounding context in case of zooming down into a specific focus area. It is common technique especially in mapping and image–processing software. There are different approaches to implement the technique. Figure 3.8 shows one example of Overview + Detail technique in Google maps. The magnifying glass technique is another example that provides an enlarged area of interest (the detail) with the surrounding context (the overview) in different presentation space.

Figure 3.8: Google map, overview + detail example (Cockburn et al., 2008)

3.4.2 Zooming and filtering

Zooming and filtering enables to focus on user selected area and/or attribute values of interest and excludes irrelevant things for the task at hand. It supports both detailed and contextual views, but not simultaneously as of overview + detail techniques. It involves a successive time sequential (temporal) separation between views where users zoom in (magnify) or filter to get an enhanced focus and zoom out (minimize) or no filter for the context alternatively according to their interest (Cockburn et al., 2008). Most standard desktop application interfaces have zooming functionality to browse through the underlying dataset. In order to have a smooth transition from the context to the detailed view of the focus, a zooming animation technique is usually employed that helps viewers to relate the pre– and post–zoom state of the data preserving their mental map.

3.4.3 Focus + context

Unlike the previous two methods that separate the display of detailed and contextual information, focus + context visualization integrates both views into a single display where all parts are always visible with enhanced view of the focus seamlessly within the surrounding context (Cockburn et al., 2008). It uses different magnification factors across the information surface that causes intentional distortion to the visualization. Fisheye view is one common technique of this category. It employs non–linear magnification for the focus while downscaling the context that results in a distortion (Shadaram, 2010), as shown in Figure 3.9. Another examples of this technique include hyperbolic trees (Kreuseler et al., 2000) and stretchable rubber sheet (Sarkar et al., 1993) as cited in (Kosara et al., 2001).

Figure 3.9: Fisheye view, focus + context visualization (Cockburn et al., 2008)

3.4.4 Cue–based techniques

The graphical portrayal of objects in the visual display would be modified by the application of most of the abovementioned visualization techniques during the presentation of the focus and the context. In the cue based approaches, objects with certain properties will be made more prominent than the context by assigning some visual cues without loss of their original graphical representations (Cockburn et al., 2008; Kosara et al., 2002). In addition to shape it also preserves color and size of the objects which are important for data interpretation (Robinson, 2009). Due to the many different techniques, we confined ourselves to a few methods that are more pertinent to be adopted for animated time series based on Robinson's (2006; 2009) discussion.

Color–based highlighting

It is most commonly used technique in which objects that need special attention become outlined or filled with a brighter color. Color–based highlighting can be achieved by making the outline around the focus using various line widths, colors or stroke styles. It could also be employed in soft edges (Figure 3.10a) and specular (Figure 3.10b) effects to make it more realistic and to elevate the focus higher than the context.

(a) (b)

Figure 3.10: Color–based highlighting (Robinson, 2009)

Depth of field highlighting

Depth of field (Figure 3.11) is a technique adopted from photography and cinematography in which out of focus objects are made blurred based on the distance from the camera so that viewer's attention is attracted by important parts of the scene (Kosara et al., 2001). In information visualization, it is used to separate a particular data set from the surrounding context by creating contrasting sharpness. Kosara et al. (2001) extend this concept to the semantic of field where the appearance of objects depends on the semantics of the scene rather than spatial depths within the scene. The human perception behavior to separate the field of view into either figure or ground can be enhanced by semantic field of depth technique in which blurred objects are perceived as ground whereas the sharp ones become figure (Kosara et al., 2002).

Figure 3.11: Depth of field (Robinson, 2009)

Transparency

This technique is also another way of combining overview with detail in a layered display. It is used to soften the surrounding context relative to the focus (Figure 3.12) preserving the integrity of color and symbol information. Determining the proper level of transparency for the graphical displays is a challenge. This may cause some categories to disappear from the display if an inappropriate amount of transparency is assigned to them.

Figure 3.12: Transparency (Robinson, 2009)

Contouring

The contouring technique is based on the assumption that perception is influenced by objects which have multiple outlines (contours) around as they look lifted up from the surrounding context. Making the contours vary with number, color, width etc, might be necessary to visually enhance the contours so that the outlined object easily gets focused attention. Figure 3.13 shows an area outlined by three contours dark–to–light color gradient from inside to outside.

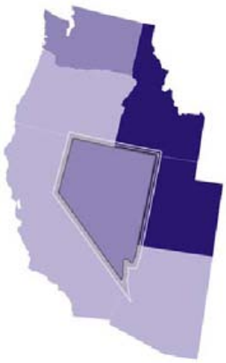


Figure 3.13: Contouring (Robinson, 2009)

3.5 POTENTIAL METHODS FOR REDUCING CHANGE BLINDNESS

Simultaneous enhancement of the focus and suppression of the surrounding context is achieved through different techniques. We tried to explore some of these techniques irrespective of their suitability for animated time series visualization. The cognitive load they might have and the technical implementation for animation were also not systematically taken into account in the discussion. The latter will be considered in Chapter 4. Here an attempt is made to evaluate the techniques and identify the potential ones with respect to their ability to attain viewers focused attention so that the problems related to change blindness could be reduced.

The common problem with the non–cue based techniques is either spatial or temporal distortions. In case of the overview + detail technique, the need for an additional display window causes viewers to switch their eyes back and forth between the screens every now and then to relate the separate views. This creates an extra cognitive load that might hinder the visual exploration task (Baudisch et al., 2001; Cockburn et al., 2006). It is also highly vulnerable to the split of attention effect which is more severe when it happens in animation than in static displays as it is already discussed (Section 2.6). Even if the windows are separated in the z–axis (as with magnifying glass) so that overviews are merged with the detail, the context scene could be distorted at the edge of the glass and occluded partially by the details viewed through the lens (Cockburn et al., 2006; Shadaram, 2010).

Zooming and filtering technique possibly creates substantial cognitive load due to the temporal separation of views it employs. Viewers can not have both the context and the detail at the same time to assimilate the relationship between them for better understanding (Cockburn et al., 2006). When zooming–in or filtering is used for detail representation, the context information will be lost, letting viewers not to have a complete perception of the whole scene. In case of zooming–out or change to no filtering, there will no be detailed representation. This technique can be combined with the other visualization methods to magnify or minimize user selected areas according to the task at hand.

Focus + context visualization technique could highly reduce the working memory load required to assimilate the information presented in distinct views in case of the prior two methods since it employs a single coherent display which in turn enhances users' ability to comprehend and manipulate the information. However, spatial relationships such as distance and direction are not preserved due to the distortion of the information space which might let users unable to assess such spatial properties (Baudisch et al., 2001; Cockburn et al., 2008, 2006). The technique can be improved by, for example, reducing the amount of the context data to have enough space for both displays rather than the spatial distortions. It can also be enhanced by a suitable combination with the cue–based methods such as depth of field technique whereby display of objects depends on the semantics of the scene rather than the spatial depths within the scene.

In case of the cue–based techniques, features to be highlighted or suppressed are based on user defined criteria, not necessary on their spatial relations. The techniques easily draw viewers' attention to relevant objects keeping the context information (Kosara et al., 2002). Although the cue–based methods discussed here refer to static visual techniques, they could also be adopted to dynamic visualizations such as animated time series. However, it is clearly seen that feature occlusions might happen especially for color–based highlighting and contouring techniques. Some features may also disappear from the display if inappropriate level of transparency is assigned in case of the transparency technique.

3.6 SUMMARY

Different ways to reduce change blindness from a perceptual cognitive perspective are discussed in this chapter. Focused attention is found to be a preliminary requirement for successful visual exploration. Effective graphical representation of the scene is another way to reduce the cognitive problems as it grasps user attention while exploring through animated time series. Gestalt laws are discussed in this regard to have some guiding principles for effective graphical representations. Coercive graphics is also discussed as a means to accentuate changes in the display in order to get viewers focused attention. The overall discussion is made to improve the graphical representation (bottom–up process) in order to support users to better focus attention (top–down process).

We have also discussed potential methods that can be used to implement the identified ways into practice. It is obvious that viewers cannot attend to changes displayed all over the visual scene at any time. Rather it is overwhelming viewers than enhancing exploration. All displays also may not be equally important for the task at hand. The methods discussed as solutions are combinations of visual enhancement of the focus and suppression of the surrounding context. Finally, the potential ones are highlighted based on their ability to attain viewers focused attention.

Chapter 4

Design and implementation

4.1 INTRODUCTION

Different methods are identified for visual enhancement of the focus with a simultaneous suppression of the context in Chapter 3. This chapter is about the design and the implementation of the suitable ones into an already existing prototype called *'Animated Image Visualization – aNimVis'*. In order to select and implement suitable methods from the already identified ones, it is necessary to understand the working principle of the *aNimVis* prototype. The chapter starts with a brief discussion of the working principles of this prototype (Section 4.2). NDVI data was used with the *aNimVis* prototype to validate it in a real-world practical application task. The usability test of the proposed solutions in this research is also intended to be made with NDVI data. Thus, a brief explanation is further made about NDVI data in Section 4.3. Section 4.4 is about perceptual cognitive problems with the *aNimVis* prototype while displaying animated NDVI data and how the effect is reduced by the interaction controls provided in the prototype. The discussion under Section 4.5 is about identification of suitable methods to be implemented in the prototype. Minimum requirement is set in order to come up with suitable methods that reduce change blindness, supporting users to have focused attention. The *aNimVis* prototype is now on the way to be integrated with ILWIS and so will be the proposed solutions for testing. Section 4.6 starts with a discussion of the basic changes in the new version of the prototype and extends to cover implementation and user interface design issues for the selected methods. Finally, the chapter concludes with a brief summary (Section 4.7).

4.2 ANIMATED IMAGE VISUALIZATION - *aNimVis* PROTOTYPE

Animation requires additional visualization variables along with those used for static maps. These variables specifically focus on the temporal dimension and, therefore, they are commonly known as dynamic visualization variables. Table 4.1 shows the four main dynamic visualization variables: moment of display, duration, order and frequency (Blok, 2005, 2006; Slocum et al., 2009). The *aNimVis* prototype was developed for the research of Blok (2005) to investigate use of the dynamic visualization variables for animated time series. The prototype helps users manipulate the dynamic properties of the animation by interaction in order to acquire relevant information from time series (Blok, 2006). The *aNimVis* prototype takes into consideration the unnecessary overloading of the perceptual system that hinders quick pattern identification and comparison (Blok, 2006, 2005).

Interactivity is one way of making animation effective, although practical investigation results do not always show a positive result in this respect (Blok, 2006). The *aNimVis* is an interactive prototype that employs dynamic visual variables to represent the temporal dimension of the geodata in the same way as graphic variables encode the characteristics of the data in the spatial dimension. It makes use of different interactive controls (summarized in Table 4.2.) to manipulate the characteristics of the underlying geodata.

Table 4.1 Definition of dynamic visualization variables (Blok, 2005)

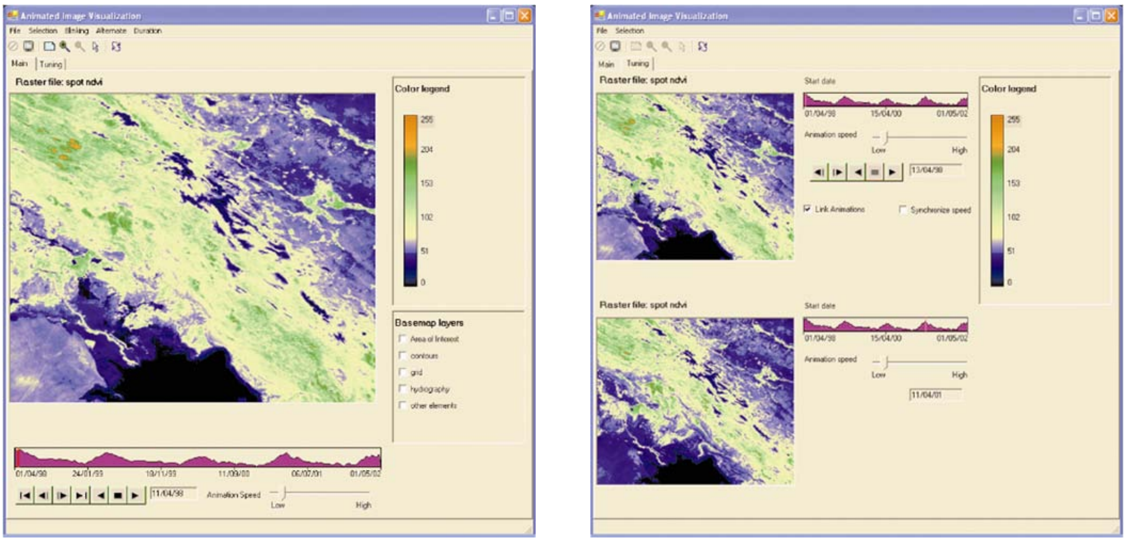
Dynamic visualization variables	Definition
Moment of display	Position of state or a change in the representation in display time
Order	Structured states or changes in the representation in display time. Order is structured because it is based on a chosen principle or criterion (e.g. chronological or based on particular attribute values)
Duration	Length in display time of a state or change in representation
Frequency	Repetition or number of identical states or changes in representation per unit of display time

Table 4.2 Interaction with dynamic visualization variables implemented in *aNim Vis*

Dynamic visualization variables	Type of interaction	Description
Moment of display	Selection / deselection	Time : moments, periods Location : zooming Thematic attribute : 1 or 2 thresholds, interval Graphic representation: classification and color
	Animation manipulation	Video player controls: forward, backward, stop Tuning: simultaneous running of two chronologically ordered animations
Order	Manipulation of display sequence	Time: backward play, alternate moments Thematic attributes: alternate values Graphic representations: alternate classification /color
Duration	Manipulation of length of display time	Time: change of display time Thematic attribute: display time based on occurrences of a value, interval
Frequency	Repetition	Time: blinking moments Thematic attributes: blinking values, intervals Looping : viewing (parts of) the animated representation more than once

Users interact with the animation controls in order to generate task oriented effects in the representation that enhance visual exploration. For example, the dynamic behavior effect is automatically generated when the user starts to play the animation, and rate of change could become an effect by use of the control that changes the display speed.

The *aNim Vis* prototype has two main interfaces that facilitate user interactions with the underlying data in order to identify and compare patterns to achieve the visual exploration task (Figure 4.1). There are various controls common to both the main window and the tuning window interfaces that let users interact with the animation. Some of these controls are the time bar - an active temporal legend enhanced with a graph of data values (like average NDVI values per image) to display position in time; media players - to play, stop and step forward/backward the animation; display speed control - to adjust the display speed as per the user interest, and some menus. Base map layer options (only for the main window) give background information to the changing NDVI patterns and there are more menus here. The tuning window is intended to display two temporal animations at the same time. It enables users to explore pattern similarity or differences in a specific time of interest. Two control check boxes are provided to link the animation and to synchronize the speed.



(a) (b)

Figure 4.1: The *aNimVis* prototype interfaces – the main window (a) and the tuning window (b)

4.3 NDVI – THE CASE STUDY DATA

The Normalized Difference Vegetation Index (NDVI) is used by different authors as a measure of photosynthetically active vegetation or biomass (Birky, 2001; Chen et al., 2004). It is a numerical indicator generated by using the read (R) and near–infrared (NIR) bands of remote sensors, mathematically expressed as:

$$\frac{(NIR - R)}{(NIR + R)}.$$

The output values range from -1 to 1. Negative and zero NDVI values indicate water and bare soil respectively. Values near +1 indicate high greenness. The principle behind is that the green plant chlorophyll strongly absorbs visible light of the electromagnetic spectrum, on the other hand the cell structure of the leaves reflects the near-infrared light which is strong for healthy vegetation and weak for the unhealthy ones. The result of these makes vigorously growing healthy vegetation to have low red-light reflectance and high near-infrared reflectance, thus high NDVI values (Hayes and Sader, 2001).

NDVI has a wide range of applications. It can be used for monitoring plant health and growth as well as for estimates of green biomass from multispectral satellite data whereby prediction and early warring of droughts and famines are possible (Biswas, 2004; Hayes and Sader, 2001).

SPOT 4 NDVI was used as a case study to validate the *aNimVis* prototype with real–world practical tasks. Monitoring is one of such tasks, used to keep track of visible changes in order to get insights about the dynamic behavior of a phenomenon (Blok, 2005). The *aNim Vis* prototype can be employed for monitoring vegetation cover changes such as whether an area with low NDVI values shrinks or expands, in which direction it develops, how fast the process is and how often is the repetition cycle of the process, etc. In *aNim Vis*, the values are stretched to 0 - 255 to maximize the range of display on color monitor.

4.4 PERCEPTUAL COGNITIVE PROBLEMS WITH *aNimVis*

Straight forward running of an animation of an NDVI time series using the *aNim Vis* research prototype is susceptible to perceptual cognitive problems as any animation of satellite imagery data. This is due to the occurrence of changes resulting from the frequent variation of pixel values all over the display area that differ in speed and magnitude while the animation is running. As we already discussed, viewers' perception and cognition is easily overwhelmed by such presentations and focused attention can only be given to a limited number of objects. This obstructs the pattern identification and comparison tasks of visual exploration. Thus, the visual perception problem – change blindness – is likely to happen in *aNim Vis*. Failure to scan the whole image item–by–item due to weak motion signals or masking of motion signals by any kind of interruptions results in–inability to detect changes. Giving task–related attention to only few items leads to inattentional blindness – failure to observe clearly visible changes, which causes change blindness as well.

Proper application of the dynamic visualization variables in the *aNim Vis* prototype were assumed to reduce the perceptual cognitive problems in the animation by generating the required task oriented effect. For instance, too fast or too slow changes could be controlled by adaptations of the pacing or the rate of change effect. Visual isolation (or filtering) can be applied to exclude overwhelming signals in order to give focused attention to few task related items at a time. Emphasis affects selected elements of the animation so that viewers' focused attention is attracted. In addition to all these, making use of the media player buttons and reviewing the animation appears to be a good approach to tackle the perceptual cognitive problems with *aNim Vis*. However, other effects such as synchronization – simultaneous display of two animations and re-expression – an alternative graphic representation for the default representation of the data rather lead to change blindness if not carefully employed. When blinking is used to emphasize selected elements, viewers may react negatively due to its annoying display, despite its ability to reveal severe anomalies and to attract viewers' attention (Blok, 2005; Evans, 1997).

The primary purpose of the *aNim Vis* research prototype was to investigate the ways to use dynamic visualization variables in such an interactive environment in order to gain knowledge from time series in a monitoring context. It took into consideration the possible perceptual cognitive problems that might hinder the monitoring task and provided some solution in a way as discussed above. However, the problems of change blindness are not yet solved. Users may get easily overwhelmed and become unable to detect changes, affecting the outcome of their visual exploration task. The following section discusses methods that potentially further reduce the perceptual cognitive problems in animated time series such as *aNim Vis*.

4.5 SUITABLE METHOD TO ADDRESS THE PERCEPTUAL COGNITIVE PROBLEMS WITH THE *aNimVis* PROTOTYPE

Interactive visualization needs to be efficient in the way it lets the user to dig out and find as much relevant data as required for the task at hand (Ware, 2004). Shneiderman's (1996) Visual Information Seeking mantra provides a strategy for efficient digging: overview first, zoom and filter, then details on demand. Overview gives a general impression about the entire data. Zoom in on items of interest helps for better detailed representation. Filtering can be used to isolate task irrelevant items. Details – on – demand provides details of an item or group of items when needed. This visualization strategy is taken into consideration in order to come up with suitable methods that reduce the perceptual cognitive problems in animated time series. To this end, users will have the overview of the data first. Then, the required interaction with the animation could be made for displaying the data as per their interest to enhance the visual exploration task.

In chapter 3, focused attention is discussed as a preliminary requirement for effective visualization. Possible ways to attain sustained focused attention are also explained briefly. The potential methods explained under Section 3.5 are all directed towards attaining focused attention in order to reduce the problem of change blindness. However, the implementation of the methods for animated time series requires additional thorough investigation as they all have their own limitations.

For the goal at hand, i.e., visual enhancement of animated time series in order to reduce change blindness, some minimum requirements are set for proper selection of a suitable method. First priority is given to the simultaneous display of both the 'figure' (user selected area and/or attribute values of interest) and the context (ground) in the same window. This is done to reduce the cognitive load required to integrate the different views. Temporal separation (not having both the context and the focus at the same time) as in the case of conventional zooming (see Section 3.4.2) and spatial separation as in overview + detail techniques (see Section 3.4.1) create a cognitive load that possibly leads to the split of attention effect. Next priority is given to the spatial relations and graphical representations of features in the visual display. The spatially distorted graphical representations of features exhibited in focus + detail techniques impede users to assess spatial relations of the data such as distance and orientation and hence, hinders visual exploration tasks.

In this regard, the cue-based techniques appear to be suitable approaches for simultaneous representations of user selected 'figure' and the surrounding context (ground) in the same visual display. The techniques help to make task related objects more prominent than the surrounding context preserving the original graphical representations. The principle behind the techniques could also be adopted for animated time series in order to enhance visual exploration tasks. The coming section discusses the method from an implementation point of view and users' interaction with the animation in order to achieve the intended result.

4.6 IMPLEMENTATION AND USER INTERFACE DESIGN ISSUES

4.6.1 Integration of the prototype in ILWIS

ILWIS (Integrated Land and Water Information System) is a windows–based, integrated GIS and Remote Sensing software with different applications such as display of raster and multiple vector maps in map windows, interactive retrieval of attribute information, image processing facilities, manipulation of maps in a Map Calculator, GIS analysis tools, etc (WWW-2).

ILWIS uses a slide–show technique to animate multiple raster maps that are combined in a map list. The maps are displayed one after the other in a user defined rate to depict multi–temporal changes over time. The map list for the slide–show can be, for example, time series of satellite images of the same area, derived products from satellite images, such as NDVI maps, classified satellite images and thematic raster maps such as land use maps. This type of slide–show functionality is offered by other software also. However, since it has little or no possibilities to interact with, it bombards viewers with a sequence of changes that lead to change blindness as discussed in Chapter 2.

The *aNim Vis* research prototype was integrated in ILWIS partially while this research is undergoing. It possibly improves the slide–show application of ILWIS by additional functionalities such as making use of dynamic visualization variables controls for better visualization, when the integration is completed. Due to the process of integration, the new version has lost most of *aNimVis* original user interface appearances (Figure 4.1). However, since the principle behind the newly integrated application is that of the *aNimVis*, it doesn't affect the discussion made about it so far. Figure 4.2 shows the current user interface of the new version integrated in ILWIS.

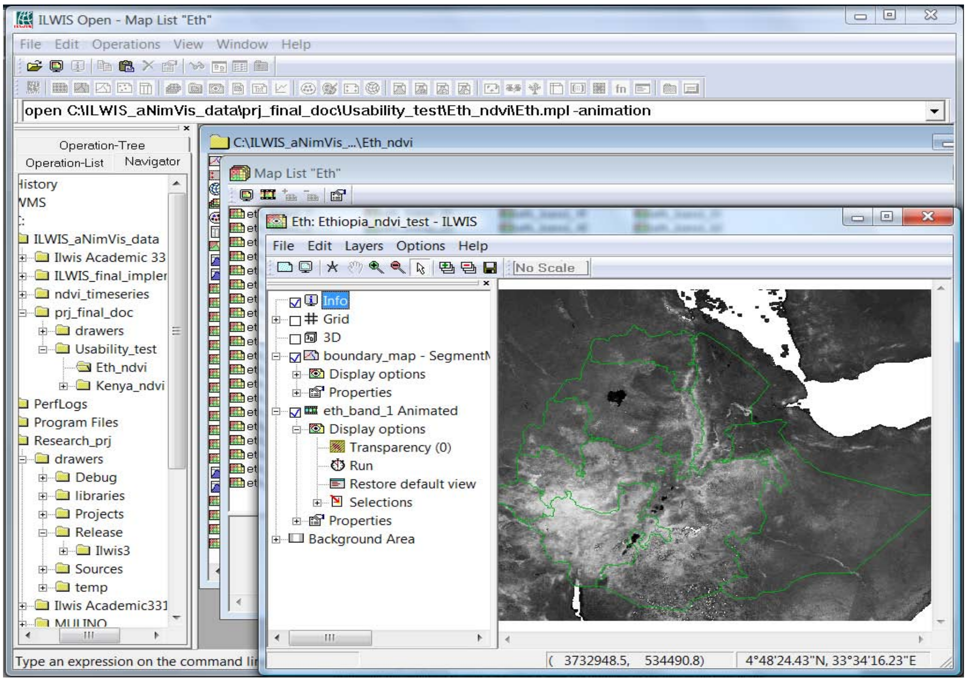


Figure 4.2: The current interface of the new version

4.6.2 Implementation

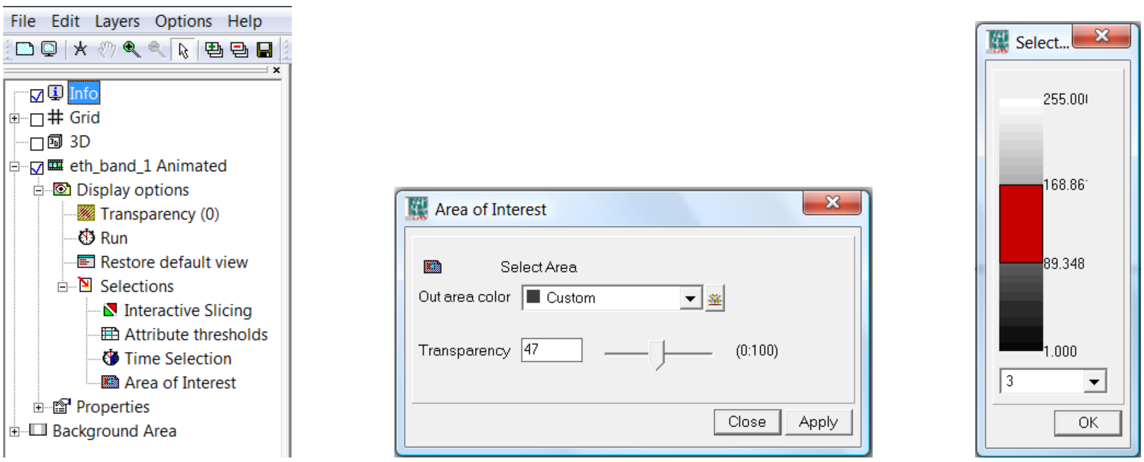
In our discussion of Gestalt perceptual grouping laws, we have seen the figure–ground effect in which objects that get focused attention are perceived as a figure and whatever lies behind becomes a ground. According to Ware (2004, p.196), all Gestalt laws contribute to separate the figure from the ground. The perception of figure – ground could also be enhanced by the cue–based techniques such as transparency and depth of field highlighting techniques that let the figure stand out with respect to the ground in order to get focused attention. 'Figure' applies to what we discussed all through our explanation as area and/or attribute values of interest and 'ground' is the surrounding context.

However, due to time constrain and the immaturity of the under development prototype, the potential methods of the cue-based techniques could not be implemented and tested. Besides, the implementation of the techniques to attain the desired figure-ground effect is not a straightforward application. For example, if we look at the depth of field highlighting technique, features appears to be more blurred and they may even disappear totally when they get farther away from the central focus point. In case of color highlighting and contouring cue-based techniques, important features could be occluded when the outline of the focus area is highlighted or contoured to make the figure more prominent than the ground. Although determining the appropriate level of transparency for displays is a challenge for transparency technique, features in the surrounding context will get equally suppressed irrespective of their distance from the focus point. In addition to this, it keeps the whole context with the same appearance in the visual display, keeping the original representation of the selected features unchanged. Moreover, from an implementation point of view, the transparency technique could be achieved by a layering technique with least cost of computer processing power compared to the depth of field technique which requires preprocessing of the whole data at the expense of high processing cost.

Taking into account Shneiderman's (1996) visual information seeking mantra, we intend to implement the technique in such a way that it gives the overview of the data at the start of animation use. Then, users will have to interact with the animation in order to get their area or range of attribute values of interest or both at a time, with simultaneous visual suppression of the surrounding context. The interaction is intended to be done in two different ways: a window selection for area of interest and a legend bar selection for range of attribute values of interest. In the first case, when users make a window selection, everything inside the selected area will remain as its initial presentation in the display whereas the surrounding context is subdued. On the second alternative, users can select attribute values of interest to display them in such a way that they attract attention by simultaneous suppression of the unselected attribute values, which would be the surrounding context. The combination of both interactions is also possible: to focus on certain attribute values in a specified area of interest. These interactions could be made in different ways. However, an–easy to interact user–interface is desired as described next.

4.6.3 User interface design

Interaction is a user-controlled manipulation of data elements through an interface in order to create an effect on the display (Blok, 2005). User interfaces let users interact with the data to obtain the required information via the display. According to Ware (2004), in the process of interacting and displaying the required information, a few seconds of delay could increase the cognitive load and reduce the information uptake rate of the user. This could result from poor and complex user-interfaces. Therefore, user-interfaces have to be easy to interact and user friendly in order to keep users continuing to think about the task in mind rather than worrying about how to interact with the interface. Ware further advices to design interfaces based on previously learned ways of doing things. For the implementation of the proposed method, attempt is made to adopt the already familiar ways of the ILWIS user interfaces as shown in Figure 4.3.

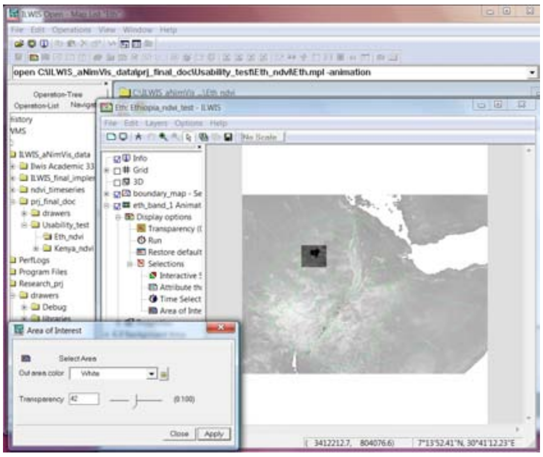


(a) (b) (c)

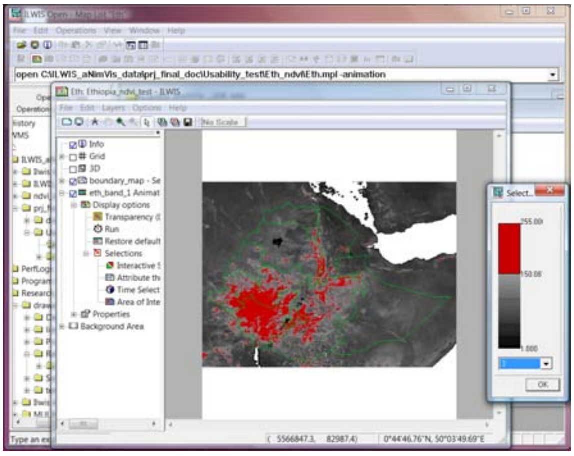
Figure 4.3: User–interfaces for the proposed methods: (a) Interaction navigator window, (b) Area of interest selection user–interface, (c) Attribute values of interest selection user–interface

Both the area of interest ( ) and the attribute values of interest ( ) selection icons are listed in the interaction/navigator pane (Figure 4.3a) at the left side of the animation window together with other interaction icons. The user–interfaces (Figure 4.3b and Figure 4.3c) for both interactions are activated by double clicking the respective icons.

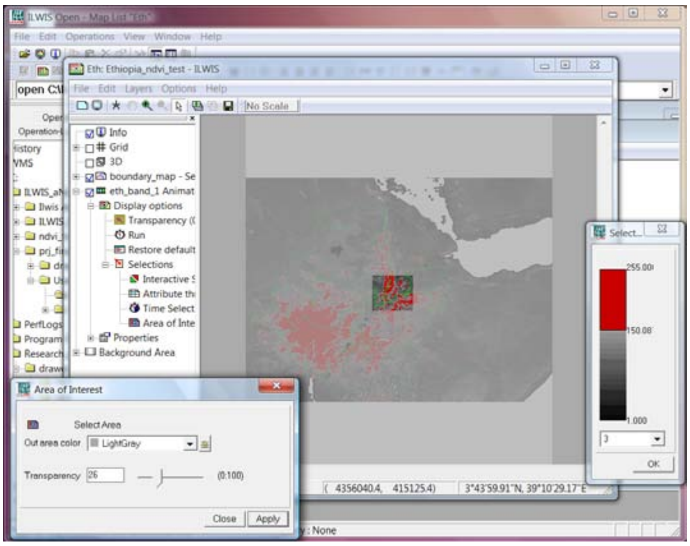
The interaction to select the area of interest is analogous with the conventional zooming interaction. In most cases, this commonly used interaction lets users make a window (a rectangular/square box) selection of the area of interest. After having selected an area of interest (the 'figure'), color and the percentage of the transparency could be adjusted interactively for the appropriate determination of the transparency level in order to suppress the context (the 'ground') (Figure 4.4a). For the selection of range of attribute values of interest, an already implemented attribute selection interface of the new version (Figure 4.3c), using sliders, is directly adopted. Users have the option to adjust the transparency level and set color for attribute values they are interested in (the 'figure') with a simultaneous suppression of the unselected ones (the 'ground') (Figure 4.4b). The combination of both interactions is depicted in Figure 4.4c. Figure 4.4 Shows screen shots for the possible interactions of the proposed tools.



(a) Aarea of interest selection interaction



(b) Attribute values of interest selection interaction



(c) Combination of both interactions

Figure 4.4: Screen shots for the proposed tools interactions

4.7 SUMMARY

The chapter points out a potential method to reduce change blindness. The selection was made based on some minimum requirements set to address the problem. In addition to this, the working principle of the *aNimVis* research prototype is taken into consideration. The proposed method employs Gestalt figure-ground principles to get focused attention on user selected area and/or attribute values of interest (the figure) by a simultaneous suppression of the ground (the context) displayed on a single visual environment. This is expected to reduce the cognitive load due to the temporal and spatial separation of views and to enhance focused attention for effective visual exploration task.

The transparency technique from the cue–based approaches is selected for implementation, to be achieved by two different interactions, or a combination of both. The first one lets users select an area of interest which makes the context subdued, keeping the original graphical representation of features. The other interaction lets users display the selected range of attribute values of interest prominent by simultaneous suppression of the unselected ones (the context). Both interactions can be combined to have focused attention on selected attribute values in a specified area of interest.

Appropriate user–interfaces are required to achieve the intended results. User-interfaces allow users to interact with the underlying data and to control the display. An easy–to–interact user–interface keeps users focusing on the task in mind. Doing things in an already accustomed way helps for the simplicity of the user–interface to be designed and makes interaction easily adaptable. In this regard, since the proposed methods are to be implemented in ILWIS, the design of the user–interface followed the usual way of interactions in ILWIS.

Chapter 5

Testing and evaluation

5.1 INTRODUCTION

The perceptual cognitive problems during visual exploration of animated time series are discussed in Chapter 2; they lead to the identification of ways and potential methods to reduce problems related to change blindness (Chapter 3). A potentially suitable method is selected and implemented in the new version of the *aNim Vis* research prototype, integrated in ILWIS as described in Chapter 4. The overall goal is supporting users to have focused attention so as to reduce the perceptual cognitive problems induced during visual exploration of animated time series.

This chapter concentrates on the usability testing and evaluation of the proposed solution for its efficiency, effectiveness and satisfaction. It starts with a general explanation of usability and usability testing (Section 5.2) followed by a discussion of test design issues such as defining the test goal, selecting an appropriate usability testing methods for the developed application, task preparation and recruiting test participants (Section 5.3). Section 5.4 is about the test procedure, it explains the testing environment, the materials that have been prepared for the test and it outlines the overall process of the test. The analysis of the usability test and the results are presented with respect to the general goal of usability testing: establishing the effectiveness, efficiency and satisfaction of the proposed tools (Section 5.5). A discussion is made based on the results in Section 5.6. The chapter ends with a brief summary (Section 5.7).

5.2 WHAT IS USABILITY AND USABILITY TESTING?

According to International Organization for Standardization, usability refers to the extent to which a product can be used by specified users to achieve specified goals with effectiveness (accuracy and completeness), efficiency (minimal resource expenditure) and satisfaction (freedom from discomfort; positive attitudes) in a specified context of use (WWW-3). It refers to quick and easy accomplishment of a task by the product users (Dumas and Redish, 1999).

Usability testing is a discipline that is concerned with the quality of users interaction with a product (Hornbæk, 2006). It is a process of acquiring information about a product's effectiveness, efficiency and satisfaction, usually involving observation of potential users while making use of the product to perform practical tasks (Barnum, 2002). It then provides direct information about how users interact with the product and their problems with the interface being tested (Nielsen, 1993). The primary goal of usability testing is to identify usability problems and to gain information about the product so as to make recommendations for future enhancement that possibly help for the improvement of the product (Dumas and Redish, 1999). As any of human computer interaction products, a (geo)visualization tool also needs to pass through a usability testing process to find whether it aids geoscientists during their exploratory tasks.

5.3 DESIGNING THE TEST

5.3.1 Defining goals

The main objective of this research is to reduce problems related to change blindness during visual exploration of animated time series. It is tried to be addressed by offering solutions that possibly support users to better focus attention during pattern identification and comparison tasks of visual exploration. To this end, an interactive tool that helps users to focus attention on a selected area and/or attribute values of interest is developed, maintaining the context as discussed in Chapter 4. Hence, the developed tool has to be evaluated for its usability. The main goal of the usability testing, therefore, is to measure the proposed tools relative to an animation without the proposed solutions for their:

- Effectiveness – through task completeness and accuracy of answers;
- Efficiency – through the time taken to complete each task; and
- Satisfaction – through users rating in terms of confidence, preference, feeling, etc.,

Usability goals for a new version of an existing application can be derived from the previous version whereby the target usability could be set as an improvement that encourages users to change their system (Nielsen, 1993). Accordingly, the general goal of the usability testing for this research is intended to be achieved by performing the same visual exploration task, making use of an animation with versus without the proposed solutions. In which animation without the proposed solutions could be referred as a previous version of the one with the proposed solutions. Tasks with different spatial and temporal reading levels are used to measure and compare the correctness and completeness of accomplished tasks (effectiveness) and the time required to complete the tasks (efficiency). Participants would also be asked to rate their confidence and express their opinions after performing the task (satisfaction).

5.3.2 Selecting usability testing method

Usability testing employs different methods for the collection of data related to usability parameters (mentioned above) while users are performing tasks using a system (Dumas and Redish, 1999; Van Elzakker and Wealands, 2007). Some of these methods are explained in brief as follows.

Think aloud

This method involves vocalizing thoughts and actions while making use of the system to perform a set of specified tasks. It allows first hand insight into the thought process associated with different tasks (Nielsen, 1993). To this end, users are asked to verbalize what they are thinking, feeling, doing, etc., in the course of completing the task. The think aloud method provides a wealth of qualitative data from a fairly small number of test participants (4 ± 1) to find most usability problems (Nielsen, 1993, 1992). Some weaknesses are that participants could face a problem to verbalize their thoughts as it can be difficult to translate thoughts into words and might be forced to say something different from what they were really thinking about. The analysis may also take a long time (Van Elzakker and Wealands, 2007).

Observation

Observation involves visiting a user while s/he is performing a task using the system to be tested for usability, taking care of not interfering with their work (Nielsen, 1993). It can be employed to select, watch and record the behavior and characteristics of the user during the task accomplishment, which might not be easily obtained from other methods. It is also an important method especially when users are unable (or not willing) to express their thoughts while they are interacting with the system (Luna-Reyes and Andersen, 2003). However, users may change their behavior if they are aware of being observed (Van Elzakker and Wealands, 2007). It could be difficult for the observer to watch and collect data being quiet for a long period of time so that users are not affected to perform their task in the same way as they normally do (Nielsen, 1993).

Questionnaire

Questionnaire provides extensive coverage and enables capture of plenty of information, perhaps even about the cognitive process during problem solving without actual execution of a task (Van Elzakker and Wealands, 2007). It can also be used to discover specific needs of various user groups and the difference between them in making use of the system (Nielsen, 1993). However, most questionnaires are rigid in structure and do not allow the respondents to qualify their answers. Especially when the problem is complex, questionnaires may not provide useful and comparable results (Van Elzakker and Wealands, 2007). Lack of gestures and visual cues in questionnaires, as opposed to day to day visual communication, may affect answer on sensitive issues or attitude which might require probing (Luna-Reyes and Andersen, 2003).

Interviews

Interviews involves a verbal interaction between the interviewer and the interviewee in order to collect detailed information about the usability of the system to be tested. It can be carried out in such a flexible way that the interviewer has a freedom to formulate the questions if there is an indication of misunderstanding in the interviewee's response (Nielsen, 1993). It could be either structured, where a set of pre–determined questions are asked consistently; or unstructured, where questions are formulated spontaneously within the interview framework (Van Elzakker and Wealands, 2007). However, interviews are not applicable for a large number of people as it is time consuming and costs more to conduct personal interviews; moreover, it could also easily be biased if the interviewer is not consistent even with his voice tone and inflection (Barnum, 2002).

Combination of the methods

From this discussion of a subset of usability testing methods, it can be easily inferred that a single method may not be sufficient to come up with convincible test results. This might be due to the diversified nature of the usability testing goals and the product to be tested. Thus, a combination of appropriate methods is required for the collection of complete and relevant data in order to achieve the intended usability goal, since the collaboration could cover the weaknesses of the individual methods.

Performing a task using animated time series involves a complex cognitive process as depicted in the animation use model (Figure 5.1). According to Van Elzakker and Wealands (2007), information about the cognitive processes that take place in the minds of the participants are required in order to know why they are doing it and what they are thinking in addition to what they are actually doing. The think aloud method therefore is an important source of information on cognitive processes as it generates direct data on the ongoing thought processes during the task performance (Blok, 2005; Van Elzakker and Wealands, 2007; Jaspers et al., 2004). However, it could not provide valid and complete usability test data by itself.

Thus, for this particular research, the think aloud method has been selected in combination with observation, questionnaire and unstructured interview. The observation method helps to observe and record the participants' activities and reactions while performing the task. The interview is useful to collect participants' comment, feeling and opinions about the tool they have been used for the test. The questionnaire is important to gather participants' personal data and opinion. The overall procedure of the test is also organized in a questionnaire form so that participants can read and respond accordingly.

5.3.3 Preparing the task

Blok (2005) introduced a model that describes how tasks are processed during visual exploration of animated time series (Figure 5.1).

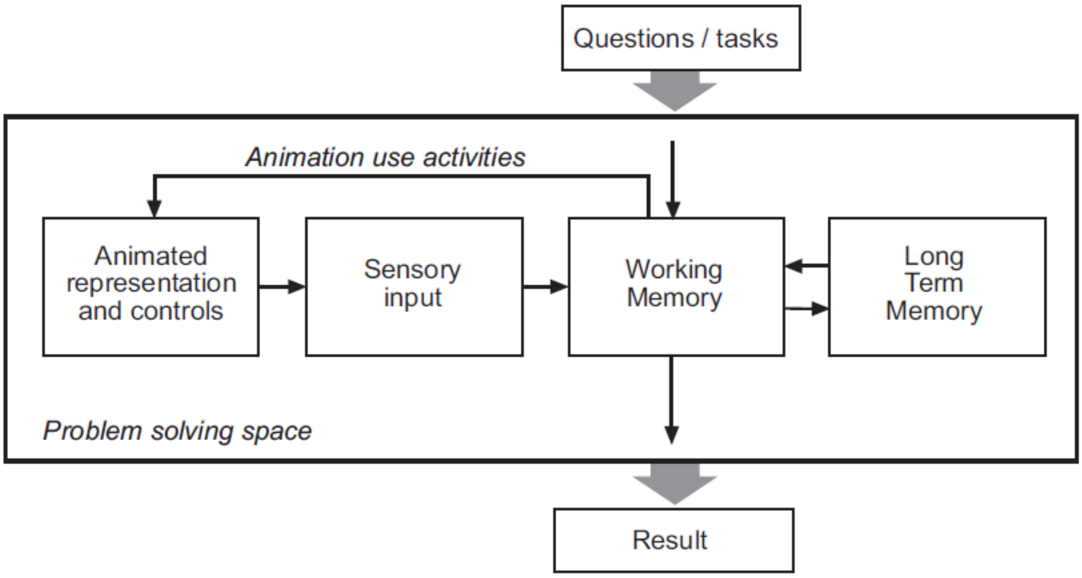


Figure 5.1: Animation use model (Blok, 2005)

According to the model, questions or tasks activate the working memory, in which visual exploration processes based on sensory input and exchange of information with knowledge and experience stored in long-term memory are executed. The process involves animation use activities – such as cognitive tasks of pattern identification and comparison – and interaction with animation controls for better representation that enhance the cognitive tasks. The new knowledge constructed from this process may eventually be stored in the long-term memory.

In this research, practical tasks were given (like identification and comparison of patterns). The use activities had to be employed in an animation with the proposed tools and one without those tools to be able to conclude if the proposed tools improve the usability of exploration of animated time series. The test tasks need to be representative of possible tasks which could be performed by the system and they have to provide coverage for the functionalities of the system to be tested (Nielsen, 1993). To achieve this, tasks at different temporal and spatial levels were formulated (Table 5.1/Appendix D.2) based on a scenario that employs a practical application of visual exploration of animated time series (Appendix D.1). The sequence of the tasks is outlined according to Shneiderman's (1996) visual information seeking mantra: overviews first, zoom and filter, details on demand. Both the scenario and the tasks were refined and agreed with a natural resource expert (a PhD student who worked a lot with NDVI data and time series) and the thesis supervisors before the test is commenced. The reading level, the cognitive process and the stage in the mantra for each task is summarized in Table 5.1 below.

Table 5.1 Summary of the tasks

No.	Task	Reading Level		Cognitive task	Stages in mantra
		Spatial	Temporal		
1	Where are constant NDVI values exhibited?	Overall	Overall	Identification	Overview
2	Where are the lowest ($\approx<$ 50) NDVI values exhibited during the first year of the study period?	Overall	Intermediate	Identification	Filter Detail-on-demand
3a 3b	What noticeable changes do you observe in the south eastern part of the country during the first year of the study period? Are there any maximum ($\approx>$ 150) NDVI values exhibited in this particular area during this period?	Intermediate	Intermediate	Comparison	Zoom and filter Detail-on-demand
4a 4b	How is the NDVI variability in the north-eastern part of Ethiopia relative to its surroundings during the study periods? In which of the two years do the highest ($\approx>$ 150) NDV values cover the largest part of this area of interest?	Intermediate	Overall	Comparison	Zoom and filter Detail-on-demand

5.3.4 The dataset

Two different SPOT 4 VEGETATION images – synthesis products with maximum NDVI values per pixel over 10 days (three images per month) of 1km spatial resolution – were prepared. For demonstration and familiarization, one year NDVI data of Kenya was used. Two consecutive years of NDVI data of Ethiopia, acquired from 1998–04–01 to 2000–03–25, were employed for the actual test. The images had a spatial cover of the whole of Ethiopia ($\approx$1.15Million square kilometer) and were represented in a gray scale, where the brighter pixels represent the highest vegetation index values while the darker shades of gray for low NDVI values represent other land features such as bare soil and water bodies. The administrative boundary map of Ethiopia was overlaid on top of the NDVI image in order to locate areas with their regional administration.

5.4 EVALUATION PROCEDURE

The test took place from January 12 to 19, 2011, excluding Saturday and Sunday in between. It was conducted in two groups with 8 test persons in each, as explained before. The second group worked with the new version of the prototype and was allowed to interact with the attribute values and area of interest selection tools in addition to the usual media player controls and zooming in/out functionalities. The first group was allowed to use the same interaction functions, except attribute values and area of interest selections. The overall procedure and the necessary materials prepared for the test are described in the following subsections.

5.4.1 Test materials

Different test materials were prepared before the actual commencement of the test. The first one is a short step–by–step user guide for familiarizing with the prototype/tool (Appendix C). It was prepared for each group according to the interaction levels allowed to each. The prototype/tool was demonstrated by the steps depicted in this material. It was handed over to the test participants at the start of the test so that they could easily refer to it whenever they find it necessary.

The second material was the task description that explained the general and detailed steps of the test. It started with a brief sketch of the test scenario and enlightened the test data to be used. It also explained what is expected from the participant while performing the tasks, making use of the think aloud method. Instructions were given in this document that explained how to access the test data and respond to respective tasks. The document was organized in such a way that it helps all participants pass through a similar test procedure. This document is given in Appendix D.

Pre– and a post–task questionnaires were also prepared for the test. The pre– task questionnaire (Appendix A.2) was prepared to collect potential test participants' background information. These include participants' familiarity with, and exposure to, animated time series, NDVI data, ILWIS and the case study area, Ethiopia. It was made available online making use of a free account from a web–based survey solution provider (WWW-4), and the link was sent to potential participants together with an invitation letter (Appendix A.1) for the usability test. The post–task questionnaire (Appendix D.3) inquired participants' feelings and opinions about the prototype/tool; it was answered at the end of the practical session.

Finally, a check list (Appendix B.1) and a test schedule (Appendix B.2) were prepared to run each and every activity of the test in a pre–determined order and to have a similar situation and test environment for all participants. The check list pointed out every necessary task to be checked and completed before, during and after each session. The test schedule was prepared based on convenient date and time of the test participants, collected in advance through test invitation letter via email.

5.4.2 Participant recruitment

In order to get convincible results, usability test participants need to represent people who actually use the product (Dumas and Redish, 1999). This research is focused on users of animated time series who might employ the developed tool to enhance their visual exploration tasks. The actual users' domain may include geoscientists who are dealing with spatial dynamics to discover patterns, relationships and trends in a geospatial data. In this respect, there are a number of highly experienced potential users at ITC, both among staff and students. Making use of this opportunity, a homogeneously organized team of test participants are formed into two groups.

According to different usability engineering literatures, 3 – 5 test participants per test could reveal the usability problem of a product (Dumas and Redish, 1999; Nielsen, 1993; Nielsen and Molich, 1990). However, to reduce the risk of failure and errors that could happen during the test, a total of 16 participants (8 per group) are recruited for this particular research. There were 2 PhD and 2 MSc graduates. The rest were PhD (3) and MSc (9) students from different departments. 10 participants either know ILWIS already a long time, or they used it during their MSc study. 11 test participants had experience of working with NDVI for a minimum of 2 months. 7 participants made use of visual exploration of animated time series for different purposes. Only 3 participants are highly familiar with the case study area (Ethiopia). A division into two homogeneous groups was attempted as shown in Table 5.2.

Table 5.2 Test participants profile

Group	Code	Sex	Education	Experience in NDVI	Experience in ILWIS	Familiarity with time series	Familiarity with study area
1 (without the tools)	TP-01	M	MSc	Yes	Yes	Yes	Moderately
	TP-02	F	MSc	Yes	Yes	Yes	Not at all
	TP-03	M	MSc	Yes	Yes	Yes	Highly
	TP-04	M	MSc	Yes	No	Yes	Highly
	TP-05	M	MSc	Yes	No	No	Slightly
	TP-06	F	PhD	No	No	Yes	Not at all
	TP-07	F	PhD	No	No	No	Not at all
	TP-08	M	MSc	No	No	No	Not at all
2 (with the new tools)	TP-09	F	PhD	Yes	Yes	Yes	Slightly
	TP-10	M	PhD	Yes	Yes	Yes	Not at all
	TP-11	M	MSc	Yes	Yes	Yes	Highly
	TP-12	M	MSc	Yes	Yes	Yes	Not at all
	TP-13	M	MSc	Yes	No	Yes	Not at all
	TP-14	M	PhD	Yes	Yes	No	Not at all
	TP-15	M	MSc	No	No	No	Not at all
	TP-16	F	MSc	No	No	No	Slightly

5.4.3 Test environment and facilities

The test was conducted in the usability testing room of the Geo–Information Processing (GIP) department. It was a tidy and silent test room equipped with necessary equipment to run the test: video camera to record the test participant's interactions with the prototype/tool and the thinking aloud, and a laptop computer installed with the new version of the prototype integrated in ILWIS. A desktop was also made ready with all required installation if inconveniences are occurred with the laptop. There were also a comfortable chair, table and sufficient light in the room. Care had been taken to arrange all the furniture and the equipment not to attract any special attention of the test participant. Figure 5.2 shows the test environment.

Figure 5.2: The GIP Department Usability testing room

5.4.4 Pilot testing

A pilot test has to be carried out in the same manner as of the actual test in order to ascertain any deficiencies in the test procedure, such as tasks descriptions, timing of the sessions, and to debug the equipment, software and materials that have already been prepared for the test (Dumas and Redish, 1999). This gives a chance to adjust any problem with the test methods and materials so that the real usability test can be conducted in a safe condition.

For this research, three pilot tests were made before the commencement of the actual test and some potential problems are figured out especially in the test documents. The following measures were taken immediately in order to reduce the test defects and increase the usability test quality. Sequence of the test activities are corrected and made coherent. The list of activities with the respective estimated time is also explained on the cover page of the document in order to let the participant know what activity comes after the other. Heading is given in the documents to let the participant know the activity s/he is currently doing. The test tasks were also rephrased for better understanding and a graphical gray scale legend is incorporated for better estimation of the NDVI values while performing the task.

5.4.5 Test sessions

The test sessions were individual sessions in which the test was conducted only in the presence of the participant and the test researcher. Before the beginning of every session, everything was checked to see whether it is appropriately prepared (as depicted in the check list). At the beginning of the test, a general introduction about the test was given for each participant, stressing that s/he is not the one to be tested, but rather the tools they are going to use to perform the tasks. The purpose of the test, the test procedure, the total number of tasks to be performed and the test method to be employed (think aloud) were also explained to ensure that participants are at ease and fully informed about each and every activity of the test. All required test materials (the test introduction, step–by–step guide for hands-on practice, the task description and the post–task questionnaire) were handed over to the participant at arrival. Questions were allowed at any phase of the test.

The familiarization with the prototype/tool was taken place for about 10 minutes after the introduction and demonstration phase. Both the demonstration and the hands–on practice for familiarization varied according to the group (Appendix C), and were carried out based on the respective step–by–step guides using one year NDVI data of Kenya. The participants were encouraged to think aloud and tell what they were doing and thinking while practicing. All the selected usability testing methods (Section 5.3.2) were employed and every activity was recorded on video, including the thinking aloud.

Immediately after the familiarization phase, participants started to work with the actual usability test making use of the NDVI data of 2 consecutive years for Ethiopia. The researcher was sitting in a position that let him observe the participants activity, but out of the participant's sight. Infrequent reminding to think aloud and some communication to answer participant's questions were made if needed while the test was in progress. In general, no significant problems happened, and the test went fine for most sessions. However, after the first five participants, the test was carried out using the desk top computer due to the very slow response time that the laptop experienced through time.

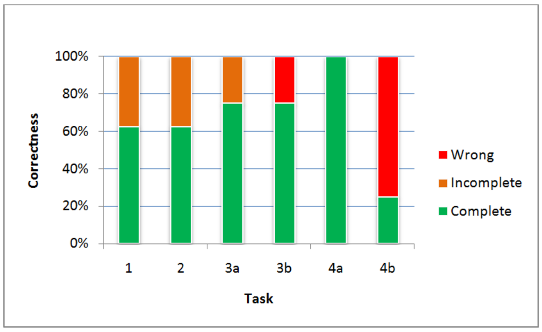
Finally, participants were asked to complete the post-task questionnaire and they were interviewed for their suggestions, remarks, comments, etc., in order to understand their level of satisfaction and obtain suggestions for further improvement of the developed tool. At the end, all participants were thanked for their precious time and contribution. A backup was taken after each session and proper labeling was made for every participant's test data.

5.5 TEST RESULTS

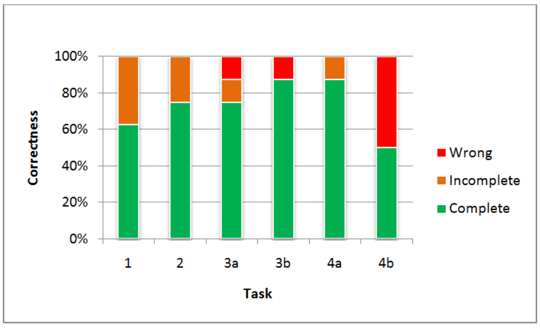
The think aloud test data and all animation use activities were collected from the video recording and the participants' written answers on the test document, and organized in a spread sheet in such a way that it facilitates the analysis. The following sections discuss the test results (Appendix E) with respect to the three usability parameters: effectiveness, efficiency and satisfaction.

5.5.1 Effectiveness

Effectiveness of the proposed tools is analyzed from the comparison made between the correctness of answers given for each task by the two groups. Model answer was prepared to evaluate the responses correctness. For this purpose, correctness is classified into correct and complete (further referred to as complete), correct but incomplete (further referred to as incomplete) or wrong answers given to each task. Responses that do not provide at least half of the possible correct answers for a given task are considered to be incomplete and those which do not address the question directly are marked as wrong. The effectiveness result summary is given in Appendix E.1. Figure 5.3 shows the correctness of each group per task in percent.



(a) Group–1



(b) Group–2

Figure 5.3: Summary of task correctness

The first task was identification of areas with stable NDVI values (all over the country) throughout the study period. 3 participants' answers from each group were incomplete (see Appendix E.1). Most group–2 participants made use of the default settings of the Attribute threshold dialog. However, TP–09 and TP–11 from this group identified places with stable NDVI values using the gray scale representation as the Group–1 participants.

The second task was identifying values below a certain threshold ($\approx< 50$). 4 participants from Group–1 were trying to check the NDVI values by a mouse clicking on the image while the animation was running, the rest identified by careful visual inspection where the bottom dark black values given in the legend were exhibited. 3 participants of this group were not able to locate all the expected places where these values are clearly visible, resulting in incomplete answers. All Group–2 participants used the Attribute threshold dialog to select and represent values below the given threshold with the default red color. However, 2 of the participants (TP–15 & TP–16) did not locate the places exhaustively enough, so their answers were marked as incomplete.

Task 3 had two questions. The first one was pattern identification in a specific part of the study area in a specified period of time. The second question was identification of NDVI values above a certain threshold ($\approx> 150$) in the same area and study period with that of the first question. Group–1 participants were looking at a wider range around the focus area and tried to visually inspect the pattern. All Group–2 participants made a proper use of both Area of interest and Attribute threshold tools to address the task, except TP–09. However, 2 participants from each group failed to correctly identify the NDVI pattern for the first question: 3 (TP–03, TP–07 & TP–15) of them provided incomplete answer and 1 (TP–16) gave wrong response. 2 from Group–1 (TP–03 & TP–04) and 1 from Group–2 (TP–09) did not succeed in identifying the presence of the values for the second question.

The last task was more complex, participants were expected to identify and compare NDVI variability of a specific area with its surroundings (Task–4a) during a given period of time. They were also asked to compare area coverage of NDVI values above a certain threshold within the focus area for a different period (Task–4b). Except one participant (TP–16, incomplete answer) from Group–2, all test participants addressed the first task (Task–4a) correctly. This was due to the clearly visible and easily differentiable low NDVI variability of the focus area relative to the surrounding. TP–16 was comparing the variability within the focus area instead of comparing it with the surroundings, even though he employed both the Area of interest and the Attribute threshold tools properly. The difference between the groups arose during the second task performance (Task–4b), in which only 2 participants (TP–01 & TP–03) of Group–1 were able to provide correct answers. On the other hand, the task was addressed correctly by half of the Group–2 participants, helped by the proposed tools implemented in the prototype they were working with.

For better comparison, the participants' correctness was calculated in percent whereby Group–2 participants exhibited a bit higher percent of complete (72.92%) and lower percentage of incomplete (14.58%) and wrong (12.50%) answers than Group–1 participants who scored 66.66% for complete and equally 16.67% for both incomplete and wrong answers. In addition, none of Group–1 participant had all answers correct and complete whereas 3 participants (TP–10, TP–13 & TP–14) of Group–2 correctly completed all the tasks. Figure 5.4 shows the comparison of the effectiveness of the two group participants according to the complete, incomplete and wrong answers provided for each task. From this result, it can be inferred that the integrated tools contributed to better task performance, hence to the effectiveness of Group–2 participants.

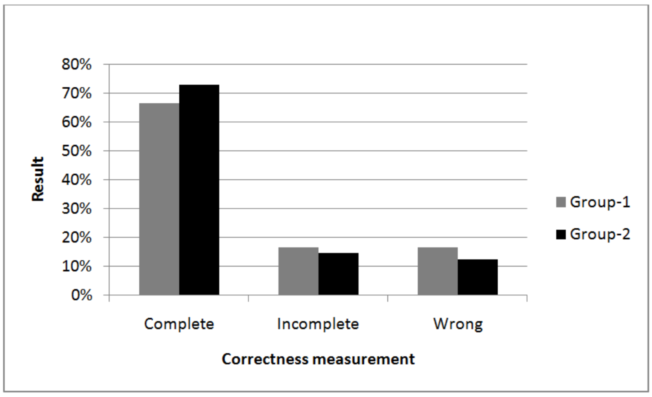


Figure 5.4: Effectiveness of the two groups according to the participants' complete, incomplete and wrong responses provided to all tasks.

5.5.2 Efficiency

To determine the efficiency achieved by employing the tools, the average time taken to perform the given tasks is compared for the two groups. Time spent for each task by the two groups are organized in a table and presented in Appendix E.2. Figure 5.5 shows the average time (in minutes) spent on each task and the overall average for all the tasks in both Groups.

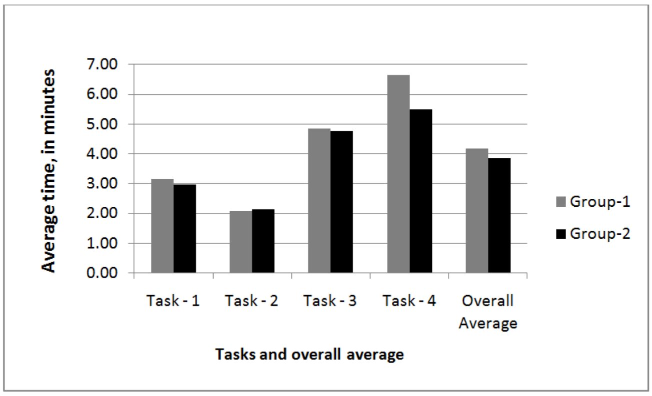


Figure 5.5: Average time (in minutes) spent on each task and overall average in each group

The average time of Group–1 participants for the first task was 3.15 minutes. 3 participants took above 5 minutes. All of them were trying to become more confident on their answer. TP–4 & TP–5 were using a mouse click to display and compare the NDVI values while the animation was running. TP–08 spent time on examining places with stable NDVI values. On the other hand, TP–06 and TP–07 were completing the task in less than a minute with only one animation run, while others used more than one run to be more confident in their respond. The average time for Group–2 participants was 2.99 minutes in which TP–13 and TP–14 took more time relative to the other participants. They were interacting with the Attribute threshold dialog for better visualization of constant NDVI values.

The average time spent on task 2 was 2.09 and 2.15 minutes respectively for Group–1 and Group–2 participants. This is the only task whereby Group–1 participants headed Group–2 with respect to time. TP–05 and TP–06 took most time from Group–1. TP–05 was using a mouse click for displaying the NDVI values and TP–04 was not able to manage the display speed of the animation. In Group–2, relatively high time is recorded for TP–10, TP–11 and TP–13. TP–10 ran the animation 3 times before answering the question to be sure in the answer. TP–11 remembered using Attribute threshold after spending some time to address the task with gray scale representation. TP–13 took much time for explaining the pattern observed in the animation after identifying the places.

Group–1 participants' average time for task 3 was 4.86 minutes in which most time was recorded for TP–01 and TP–04. TP–01 spent much time on forwarding his idea for the improvement of the prototype. TP–04 was did not limit himself to the focus area and tried to display and check NDVI values by mouse click even frame by frame. Group–2's average time for this task was 4.78 minutes. Participants TP–10 and TP–16 spent more than 6 minutes. TP–10 took much time for interacting with the Attribute threshold dialog to display the images in different colors. TP–10 remembered to use the Area of interest selection tool after spending some time to address the task. TP–13 took the third largest time in the group explaining why the low values are exhibited after identifying the places.

All test participants spent more time in task 4 than in the other tasks. The average time of Group–1 participants' for this task was 6.66 minutes and that of Group–2 was 5.49 minutes. In Group–1, TP–08 spent the highest time, exploring the whole study area misinterpreting the question at first. TP–05 also spent much time in order to relate two different seasons of the study periods by repeatedly rewinding the animation backward and forward. From Group–2, TP–13 spent the highest time partly interacting with the Area of interest dialog to select suitable transparency level and color to subdue the area outside the context.

The average time for all the tasks shows the efficiency of Group–2 participants: they completed the task in less (3.85 minutes) time than Group–1 participants (4.19 minutes). In general, it can be concluded that Group–2 participants were efficient in their task execution due to the prototype they were using with Attribute threshold and Area of interest selection tools.

5.5.3 Satisfaction

The participants' satisfaction is drawn from their confidence rate in performing the tasks. The overall ratings given for working with the prototype and its usefulness to address a specific task were also considered. In addition, participants' reaction while performing the tasks (drawn from the think aloud) and their general comments given during the unstructured interview made at the end of the test session were taken into account in order to measure satisfaction. The average satisfaction score is calculated on a scale that ranges from 5 to 1, where 5 = very good, 4 = good, 3 = satisfactory, 2 = poor and 1 = very poor. The collected data on user satisfaction is given in Appendix E.3. Figure 5.6 shows participants ratings for the satisfaction metrics used in the research.

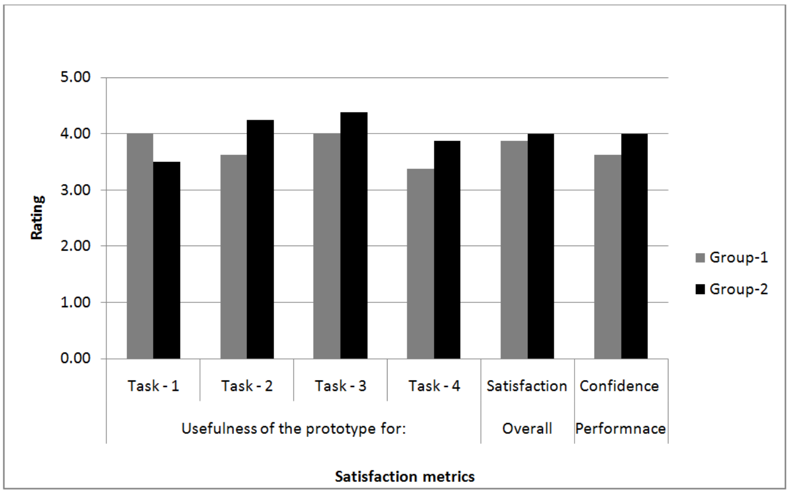


Figure 5.6: Comparison of participants' satisfaction

The average scores for the overall level of satisfaction with the prototypes were 3.88 for Group–1 and 4.00 for Group–2 participants. This was also reflected during the task execution due to the absence of some functionality; specially for selecting a range of NDVI values (Group–1) and the way they were interacting with the Attribute threshold dialog in order to select a range of values (Group–2). Adjusting the display speed of the animation was cumbersome for both groups.

Participants' satisfaction with the prototype they were working with varied for each task and in each group. Group–1 participants showed relatively high satisfaction with the prototype while answering Task–1 and Task–3 (average score for both was 4.00). They were less satisfied for Task–2 (3.63) and even less for Task–4 (3.38). On the other hand, Group–2 participants were well satisfied with the prototype in order to address Task–3 (4.38) and Task–2 (4.25). The satisfaction score went down for Task–4 (3.88) which was identification and comparison of specific NDVI values over the study periods. Participants had the lowest satisfaction score (3.50) for Task–1 which was identification of stable NDVI values all over the study area throughout the study period.

The confidence rate of participants in task performance was also used for measuring satisfaction. Group–1 participants felt less confidence (3.63) than Group–2 participants (4.00). It was also observed from the think aloud session that group–2 participants showed some level of satisfaction specially while they were interacting with Attribute threshold and Area of interest selection dialogs, keeping aside the problems and comments they mentioned (discussed in the coming section) for further improvement.

5.6 DISCUSSION

As discussed in Sub section 5.3.3, the test tasks were tried to be prepared in a way that triggers user cognitive processes from simple to complex. But the test results did not reveal the complexity of the tasks in an evenly manner. However, the highest average time (6.66 minutes for Group–1 and 5.49 minutes for Group–2) and the lowest number of complete answers was (2 for Group–1 and 4 for Group–2) recorded for Task–4, obviously the more complex one. Both groups' participants were also less satisfied especially while executing the second part of this task as they were complaining how to compare different seasons in a single animation window.

Test participants used different approaches to address the tasks according to the prototype they were using. Some of Group–1 participants (TP–3, TP–4 and TP–5) made use of a random mouse click while the animation was running in order to display and checks the NDVI values for different times and places. Surprisingly, only one participant used zoom in to select and focus on the given area of interest while performing Task–4. However, except TP–02, all of them proposed in one way or the other the concept of area of interest selection and/or the attribute threshold of specific NDVI values in the unstructured interview made at the end of the test session. Except TP–09, all of Group–2 participants used the Area of interest and/or the Attribute threshold tools according to the task, despite the inconveniences they encountered due to the not very user friendly–interactions with the respective dialogs. Five participants for Task–4 and two participants for Task–3 used zooming in together with Area of interest. This contradicts with the expert view, who performed the same task at the start of the session and didn't find the Area of interest tool very necessary as he could use conventional zooming for focus area selection.

Despite the usability scores, a number of problems were observed from user reactions and tonal variations in the thinking aloud method. Most complains belong to the immaturity of the prototypes and absence of some basic functionality such as time selection, looping (viewing (parts of) the animated representation more than once) and tuning (simultaneous running of two chronologically ordered animations). These are fully functional in the original *aNimVis* prototype and are expected to be incorporated in the newly developing one. The time selection is already implemented but it is excluded from the task not to encounter with more bugs that might arise while interacting with it. Participants were also unhappy with the slow response time of the computer and an irregular display speed of the animation. Bugs arose frequently while interacting with the Area of interest and Attribute threshold values selection tools due to the immaturity of the developed tools which is also common with other interactions of ILWIS. These all contributes to the drop down of the usability test results especially for the satisfaction metrics. The common and more relevant problems to this research are presented as follows:

Attribute threshold dialog

- Interaction to select a range of NDVI values of interest was not a trivial task for the users. It was done by dragging the upper or lower limits of the selected values, but could not be done precisely.
- The selected range of attribute values was represented as a class, masking their original gradual variation in the NDVI values off the background gray scale representation.
- Legend + map should be linked: they need to have same appearance if the transparency is changed, but this is not the case for the attribute threshold legend.

Area of Interest dialog

- The Select area button doesn't appear as a button in the Area of interest dialog that made participants confused to interact with it properly specially for the first time.
- Selection of the focus area was not so friendly that participants could not make a precise selection as they might need to be.
- The transparency layer covers the whole window while users' intention was only to apply it for the map outside the focus area and it should actually be in that way.
- After selecting the area of interest, users need to see a preview of the change they make to the context area in order to adjust both the transparency and the color that suit their interest. This is now done by a trial and error way of interaction which has to be done repeatedly until it meets their preference.

General

- The Time and the Area of interest dialog boxes were big relative to the map window, it troubled participants to position them in a convenient palace so as to not cover the animation.
- Participants were confused with the unusual way of interacting with the **Ok** button in the Time and Attribute threshold dialog: the dialog will be closed if **Ok** is clicked - users expect to use **Ok** in order to apply and see the effect.

5.7 SUMMARY

This chapter discusses the result of the usability testing held with 16 participants distributed over two groups. The think aloud method was employed in combination with observation, pre– and post–task questionnaires and an unstructured interview made at the end of each session. Tasks were defined at different spatial and temporal levels in order to measure the three usability metrics: effectiveness, efficiency and satisfaction. The test was done under fairly equal test conditions in both groups; the difference was that one group did not make use of the proposed tools to address the tasks. The outcome of the test showed that participants who made use of a prototype with the interactive tools proposed in the research perform the tasks better than those who were working without these tools with respect to the usability metrics: 72.92% versus 66.67% complete answers for effectiveness, 3.85 minutes against 4.19 minutes for efficiency according to the average time taken for the tasks and a better satisfaction (4.00 versus 3.63) based on the participants ratings. Based on the feedback from test participants, the overall usability test results and the experience achieved through this research, recommendation will be drawn in the next chapter which might be useful for further improvement of the proposed tools in particular and interactive animation in general.

Chapter 6

Conclusions and recommendations

6.1 CONCLUSIONS

The main objective of this research was to visually enhance area of interest and/or attribute values of interest and simultaneously suppress the context to reduce problems related change blindness in animated time series. Five specific objectives were defined with respective research questions in order to achieve the main objective through the different phases of the adopted research methodology (Figure 1.1). This section summarizes the results achieved under each specific objective. Both the specific objectives and the respective research questions are presented here for easy reference.

- To explore causes of change blindness and identify ways to reduce the problem from a perceptual/cognitive perspective.

  ✓ How do people perceive changes in an animation and what are the causes of change blindness?

  ✓ What are the possible ways to reduce change blindness from a perceptual/cognitive perspective?

  An intensive literature study was made at the start of the research to comprehend the process of perception and to explore causes of change blindness during visual exploration of animated time series. The human cognitive architecture is a basis to understand the process of perception. It is a combination of a working memory of a limited capacity and an infinite long–term memory that contains highly condensed knowledge schemata. The process of perception starts with transferring the visual display to the working memory and then to the long-term memory. It could be determined by bottom–up processes (driven by visual information) and top–down processes (driven by demand or task). Change blindness may arise due to absence of consciously accessible representations of the changed features in the working memory. It could happen when changes are taking place during saccade or eye blink. In addition, inattentional blindness, split of attention and retroactive inhibition are also discussed as possible causes of change blindness. Reduction of the problems can be approached by trying to influence top-down perception processes (i.e., to facilitate focused attention) and/or by bottom-up perception processes through effective graphical representation.

- To translate the identified ways into methods that visually enhance area and/or attribute values of interest and suppress the surrounding context.

  ✓ What are the possible methods to enhance visual representation in areas and/or attribute values of interest and suppress the surrounding context?

  The assumption in this research is that users who want to focus on an area of interest and/or on attribute values of interest (a 'figure') do not want to lose track completely of what is happening in the surrounding (the context or 'ground'). This could be achieved by simultaneous visual enhancement of the focus and suppression of the surrounding context. Hence, the approach is to improve the graphical representation (bottom–up processing) in order to support users to better focus attention (top–down processing). Different methods are thoroughly examined in the study. Overview + detail, zooming and filtering, focus + context and cue based techniques are identified as potential methods in this respect together with some of the limitations they might have.

- To select potentially suitable methods that enhance area and/or attribute values of interest and suppress the surrounding context from a theoretical point of view.

  ✓ What are the potentially suitable methods for visual enhancement and visual suppression in order to reduce the effect of change blindness?

  A comprehensive review of the methods was made to achieve this objective. Overview + detail techniques present the focus and the context in a separate window that might create an extra cognitive load and cause a split of attention effect. Zooming and filtering employs a temporal separation in which both the focus and the context could not be attained at the same time: no context in case of zooming–in or filtering and no details while zooming–out or change to no filtering. The main problem of focus + context technique is a spatial distortion which might affect the spatial relationship between features. These problems could be more severe when happening in animation. The cue based techniques rather appear to be suitable approaches to make features selected on certain user defined criteria more prominent than the surrounding by assigning some visual cues without loss of their original graphical representations. Color based highlighting, depth of field highlighting, transparency and contouring are identified and discussed from this approach. Color based highlighting is used to outline or fill the area and/or attribute values of interest with a brighter color to get focused attention. Depth of field highlighting creates contrasting sharpness to attract attention towards the focus area. Transparency is a layered display of both the context and the focus whereby the surrounding is softened or blurred relative to the focus. Contouring is making multiple outlines around the focus in order to lift it up from the context to attract viewers' attention.

- To develop and implement the suitable method(s) in a tool for demonstration and evaluation purpose.

  ✓ Which method(s) is (are) suitable to be implemented in a prototype?

  Different ways are identified for the implementation of the cue based techniques which generally employ the human perception behavior to separate the figure (the focus) from the ground (the context). Their limitations are discussed from the perspective of visual exploration tasks. In the depth of field highlighting technique, features appear to be more blurred and may even disappear totally when they get farther away from the central focus point. In case of color highlighting and contouring, important features could be occluded when the outline of the focus is highlighted or contoured to make it more prominent than the context. Despite the problem of determining an appropriate transparency level and color, the transparency technique is selected for implementation due to its suitability to suppress the context equally irrespective of the spatial relationship of features with the focus whereby the user selected area and/or attribute values of interest get enhanced relative to its surroundings. The transparency level and color can even be managed according to a user's preferences. In addition, it could be properly implemented by a layering technique with least cost of computer processing compared to the others which might even need a preprocessing before running the animation which could lead to a slow performance. An appropriate user interface was designed to implement this technique in an already existing prototype (actually it was the under development version of *aNimVis*, a new toolbox for ILWIS) whereby a selected area and/or attribute values of interest get enhanced with a simultaneous suppression of the surrounding context and/or the unselected attribute values. Both interactions can also be combined to have focused attention on selected attribute values in a specified area of interest.

- To perform usability evaluation for the proposed method(s) using a case study data.
  - ✓ Which method(s) is (are) appropriate for the usability testing?
  - ✓ How effective is the proposed method compared to the existing methods in reducing change blindness and helping users to focus their attention?

The main goal of the usability testing was to evaluate the proposed methods for their effectiveness, efficiency and satisfaction. A complementary set of methods: think aloud, observation, questionnaires and interview were employed for the test whereby the weakness of the one is covered by the strength of the other in order to achieve a reliable test result. The test was designed in two groups /8 participants per group/, more or less with the same testing environment. Both groups were working with the same prototype using an NDVI time series as a case, except that the first group was not allowed to interact with the (newly implemented) tools: attribute threshold and area of interest selection. This made the comparison of the results possible by the measurement of the three usability parameters: effectiveness, efficiency and satisfaction.

According to the effectiveness metrics set for the test (complete, incomplete and wrong answers) the group with the new interactive tools exhibited a better performance with 72.92% complete, 14.58% incomplete and 12.50% wrong answers, against 66.66%, 16.67% and 16.67% respectively for the other group. Efficiency was measured by the average time taken per task in each group. Except for the second task (Task–2), the group using the new tools also performed all the tasks faster, resulting in an overall average time of 3.85 minutes, versus 4.19 minutes for the other group. Test participants were asked to rate working with the prototype, the usefulness of the prototype for each task and their task performance confidence in order to measure the third usability parameter, satisfaction. In all ratings the group with the interactive tools showed a better satisfaction except for the usefulness of the prototype for Task–1 where a bit lower satisfaction was exhibited relative to the other group. However, the results for the second group were not as high as expected due to different reasons. The programing bugs for ILWIS and the immaturity of the developed tools are some of the factors in this regard.

6.2 RECOMMENDATIONS

The main objective of the research has been addressed, but some improvements can be achieved. This section presents recommendations for further improvement of the proposed tools in particular and interactive animations in general. The recommendations are based the experience acquired in the research period and from the usability testing methods employed for evaluation of the proposed tools.

- All the solutions for the problem were proposed through an intensive literature review. The design and implementation of the proposed solutions are also done based on these theoretical evidences. However, as the solutions are intended for users, potential users of animated time series need to be consulted for their preference and further requirement towards the proposed solutions.

- The proposed tools were implemented in a prototype which itself was not fully developed. Moreover, it was integrated in ILWIS. This reduced the system response time and caused bugs to arise now and then that contributed to a drop in user satisfaction during the usability testing. Future related work might consider to develop an own application for the implementation and evaluation of such research tools.

- Provide a better approach to select area of interest in such a friendly way that users could make a selection as precise as possible.

- Provide a preview to see the effect while adjusting the color and transparency level of the context after selecting the area of interest so that users made their preference at ease.

- Selection of NDVI values of interest is better to be done either by entering the required range of values or the current sliding approach has to be improved in such a user-friendly way that users can confidently select the required values.

- Selected NDVI values has to be represented as a gradual variation of the selected color rather than appearing as an attribute class with a range of values highlighted in the same color.

- The attribute threshold legend needs to adjust itself and appear to be the same as the values it represents in the map if users made a change in the transparency level of the selected values.

- Reducing the size of the dialog boxes and integrating the related once (the Time, the Attribute threshold and the Area of interest dialogs) together is better to have a wider map space and reduce the burden of positioning the floating dialogs in a convenient place so as to not cover the animation.

Bibliography

Andrienko, N. and Andrienko, G. (2005). *Exploratory analysis of spatial and temporal data: a systematic approach*. Springer - Verlag, Berlin.

Andrienko, N., Andrienko, G., and Gatalsky, P. (2003). Exploratory spatio-temporal visualization: an analytical review. *Journal of Visual Languages & Computing*, 14(6):503–541.

Barnum, C. (2002). *Usability testing and research*. Longman, New York.

Baudisch, P., Good, N., and Stewart, P. (2001). Focus plus context screens: combining display technology with visualization techniques. In *Proceedings of the 14th annual ACM symposium on User interface software and technology*, pages 31–40. ACM.

Becker, T. (2009). Visualizing time series data using web map service time dimension and svg interactive animation. Master's thesis, ITC, Enschede.

Bertin, J. (1983). *Semiology of graphics : diagrams, networks, maps*. The University of Wisconsin Press, Madison.

Birky, A. (2001). NDVI and a simple model of deciduous forest seasonal dynamics. *Ecological Modelling*, 143(1-2):43–58.

Biswas, S. (2004). Conceptual design for visualisation of spatio - temporal data using animation with linked graphics. Master's thesis, ITC, Enschede.

Blok, C. (2005). *Dynamic visualization variables in animation to support monitoring of spatial phenomena*. PhD thesis, Universiteit Utrecht, ITC, Utrecht, Enschede. ITC Dissertation 119.

Blok, C. (2006). Interactive animation to visually explore time series of satellite imagery. In *Visual Information and Information Systems*, pages 71–82. Springer.

Blok, C., Kobben, B., Cheng, T., and Kuterema, A. (1999). Visualization of Relationships between Spatial Patterns in Time by Cartographic Animation. *Cartography and Geographic Information Science*, 26(2):139–151.

Cater, K., Chalmers, A., and Dalton, C. (2003). Varying rendering fidelity by exploiting human change blindness. In *Proceedings of the 1st international conference on Computer graphics and interactive techniques in Australasia and South East Asia*, pages 39–46. ACM.

Chen, J., Jönsson, P., Tamura, M., Gu, Z., Matsushita, B., and Eklundh, L. (2004). A simple method for reconstructing a high-quality ndvi time-series data set based on the savitzky-golay filter. *Remote Sensing of Environment*, 91(3-4):332–344.

Cockburn, A., Karlson, A., and Bederson, B. (2006). A review of focus and context interfaces, Citeseer. Technical report, HCIL-2006-09. Retrieved from http://citeseerx.ist.psu.edu, last accessed November, 04 2010.

Cockburn, A., Karlson, A., and Bederson, B. (2008). A review of overview+ detail, zooming, and focus+ context interfaces. *ACM Computing Surveys (CSUR)*, 41(1):1–31.

Desolneux, A., Moisan, L., and Morel, J. (2008). *From gestalt theory to image analysis: a probabilistic approach*. Springer Verlag.

Dumas, J. and Redish, J. (1999). *practical guide to usability testing*. Intellect, Portland.

Evans, B. (1997). Dynamic display of spatial data-reliability: does it benefit the map user? *Computers & Geosciences*, 23(4):409–422.

Fabrikant, S. (2005). Towards an understanding of geovisualization with dynamic displays: Issues and Prospects. In *Proceedings of the 2005 Spring Symposium of the American Association for Artificial Intelligence, Reasoning with mental and external diagrams: Computational modeling and spatial assistance, Stanford, CA, 21–23 March 2005*, pages 6–11.

Geerinck, T., Sahli, H., Henderickx, D., Vanhamel, I., and Enescu, V. (2009). Modeling Attention and Perceptual Grouping to Salient Objects. In *Attention in Cognitive Systems: International Workshop on Attention in Cognitive Systems, Wapcv 2008 Fira, Santorini, Greece, May 12, 2008 Revised Selected Papers*, page 166. Springer-Verlag New York Inc.

Goldsberry, K. and Battersby, S. (2009). Issues of Change Detection in Animated Choropleth Maps. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 44(3):201–215.

Harrower, M. (2002). Visualizing change: Using cartographic animation to explore remotely-sensed data. *Cartographic Perspectives*, 39:30–42.

Harrower, M. (2007). The cognitive limits of animated maps. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 42(4):349–357.

Harrower, M. and Fabrikant, S. (2008). The role of map animation for geographic visualization. *Geographic Visualisation: Concepts, Tools and Applications, Wiley, Chichester, UK*, pages 49–65.

Hayes, D. and Sader, S. (2001). Comparison of change-detection techniques for monitoring tropical forest clearing and vegetation regrowth in a time series. *Photogrammetric Engineering and Remote Sensing*, 67(9):1067–1075.

Hornbæk, K. (2006). Current practice in measuring usability: Challenges to usability studies and research. *International journal of human-computer studies*, 64(2):79–102.

Jaspers, M., Steen, T., Van Den Bos, C., and Geenen, M. (2004). The think aloud method: a guide to user interface design. *International journal of medical informatics*, 73(11-12):781.

Kosara, R., Miksch, S., and Hauser, H. (2001). Semantic depth of field. In *Proceedings of the IEEE Symposium on Information Visualization 2001 (INFOVIS'01)*, pages 97 – 104. IEEE Computer Society.

Kosara, R., Miksch, S., and Hauser, H. (2002). Focus+context taken literally. *Computer Graphics and Applications, IEEE*, 22(1):22 –29.

Koussoulakou, A. and Kraak, M. (1992). Spatio - temporal maps and cartographic communication. *The cartographic journal*, 29(2):101–108.

Kraak, M. (2000). Visualisation of the time dimension. *Time in GIS: Issues in spatio-temporal modelling*, 47:27–35.

Kraak, M. (2007). Cartography and the Use of Animation. *Multimedia cartography. ed. by W. Cartwright, M. Peterson and G. Gartner. Second edition. Berlin : Springer*, pages 317–326.

Kraak, M. and Brown, A. (2001). *Web cartography : developments and prospects*. Taylor and Francis, London.

Kraak, M. and Klomp, A. (1995). classification of cartographic animations : towards a tool for the design of dynamic maps in a gis environment. *In: Proceedings of the seminar on teaching animated cartography : Madrid, Spain August 30 - September 1, 1995. pp. 29-35*.

Kraak, M. and Ormeling, F. (2010). *Cartography: visualization of geospatial data*. Harlow: Pearson Education.

Kreuseler, M., Lopez, N., and Schumann, H. (2000). A scalable framework for information visualization. In *Information Visualization, 2000. InfoVis 2000. IEEE Symposium on*, pages 27 –36.

Lobben, A. (2003). Classification and application of cartographic animation. *The Professional Geographer*, 55(3):318–328.

Luna-Reyes, L. and Andersen, D. (2003). Collecting and analyzing qualitative data for system dynamics: methods and models. *System Dynamics Review*, 19(4):271–296.

MacEachren, A. (1995). *How maps work: representation, visualization, and design*. New York: The Guilford Press.

MacEachren, A. and Kraak, M. (1997). Exploratory cartographic visualization: advancing the agenda. *Computers & Geosciences*, 23(4):335–343.

Mwakisunga, H. A. (2010). Gestalt theory for remote sensing image analysis. Master's thesis, University of Twente Faculty of Geo-Information and Earth Observation, ITC, Enschede.

Nielsen, J. (1992). The usability engineering life cycle. *Computer*, 25(3):12–22.

Nielsen, J. (1993). *Usability engineering*. Morgan Kaufmann, Amsterdam.

Nielsen, J. and Molich, R. (1990). Heuristic evaluation of user interfaces. In *Proceedings of the SIGCHI conference on Human factors in computing systems: Empowering people*, pages 249–256. ACM.

Nowell, L., Hetzler, E., and Tanasse, T. (2001). Change blindness in information visualization: A case study. In *Proceedings of the IEEE Symposium on Information Visualization 2001 (INFOVIS'01)*, page 15. IEEE Computer Society.

Ogao, P. (2002). *Exploratory visualization of temporal geospatial data using animation.* . PhD thesis, Universiteit Utrecht, ITC, Utrecht, Enschede. ITC Dissertation 89.

Paas, F., Renkl, A., and Sweller, J. (2003). Cognitive load theory and instructional design: Recent developments. *Educational Psychologist*, 38(1):1–4.

Peuquet, D. (1994). It's about time: A conceptual framework for the representation of temporal dynamics in geographic information systems. *Annals of the Association of American Geographers*, 84(3):441–461.

Rensink, R. (2002a). Change detection. *Annual Review of Psychology*, 53:245–278.

Rensink, R. (2002b). Internal vs. external information in visual perception. In *Proceedings of the 2nd international symposium on Smart graphics*, pages 63–70. ACM.

Rensink, R. (2007). The modeling and control of visual perception. *Integrated models of cognition systems*, page 132.

Rensink, R. (Forthcoming). *Human Attention in Digital Environments*, chapter The Management of Visual Attention in Graphic Displays, pages 63 – 92. The American University of Paris, France. Retrieved from http://www2.psych.ubc.ca/rensink/publications/index.html, last accessed on November 4, 2010.

Rensink, R., O'Regan, J., and Clark, J. (1997). To see or not to see: The need for attention to perceive changes in scenes. *Psychological Science*, 8(5):368.

Robinson, A. (2006). Highlighting techniques to support geovisualization. In *Proceedings of the ICA Workshop on Geovisualization and Visual Analytics*. Retrieved from http://www.geovista.psu.edu; last accessed, July 15, 2010.

Robinson, A. (2009). Visual highlighting methods for geovisualization. In *24th International Cartographic Conference, November*, pages 15–21; Retrieved from http://www.geovista.psu.edu; date accessed, July 15, 2010.

Sarkar, M., Snibbe, S., Tversky, O., and Reiss, S. (1993). Stretching the rubber sheet: a metaphor for viewing large layouts on small screens. In *Proceedings of the 6th annual ACM symposium on User interface software and technology*, pages 81–91. ACM.

Shadaram, S. (2010). Evaluation of focus + context techniques applied to network data visualizations. Master's thesis, University of Twente Faculty of Geo-Information and Earth Observation, ITC, Enschede.

Shneiderman, B. (1996). The eyes have it: a task by data type taxonomy for information visualizations. In *Visual Languages, 1996. Proceedings., IEEE Symposium on*, pages 336 –343.

Simons, D. (2000). Current approaches to change blindness. *Visual Cognition*, 7(1):1–15.

Simons, D. and Ambinder, M. (2005). Change blindness. *Current Directions in Psychological Science*, 14(1):44.

Simons, D. and Chabris, C. (1999). Gorillas in our midst: Sustained inattentional blindness for dynamic events. *Perceotion*, 28:1059–1074.

Simons, D. and Rensink, R. (2005). Change blindness: Past, present, and future. *Trends in Cognitive Sciences*, 9(1):16–20.

Simons, D. J. and Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences*, 1(7):261 – 267.

Slocum, T., Blok, C., Jiang, B., Koussoulakou, A., Montello, D., Fuhrmann, S., and Hedley, N. (2001). Cognitive and usability issues in geovisualization. *Cartography and Geographic Information Science*, 28(1):61–75.

Slocum, T., McMaster, R., Kessler, F., and Howard, H. (2009). *Thematic cartography and geovisualization*. Pearson Prentice Hall, Upper Saddle River.

Sweller, J. (2002). Visualisation and instructional design. In *Proceedings of the International Workshop on Dynamic Visualizations and Learning*, pages 1501–1510.

Sweller, J., Van Merrienboer, J., and Paas, F. (1998). Cognitive architecture and instructional design. *Educational psychology review*, 10(3):251–296.

Turdukulov, U. (2007). *Visualizing the evolution of image features in time-series: supporting the exploration of sensor data.* PhD thesis, Universiteit Utrecht, ITC, Utrecht, Enschede. ITC Dissertation 149.

Van Elzakker, C. and Wealands, K. (2007). Use and users of Multimedia Cartography. *Multimedia Cartography*, pages 487–504.

Van Merrienboer, J. and Sweller, J. (2005). Cognitive load theory and complex learning: Recent developments and future directions. *Educational Psychology Review*, 17(2):147–177.

Ware, C. (2004). *Information visualization: perception for design*. Elsevier, Morgan Kaufmann, Amsterdam.

Ware, C. (2008). *Visual thinking for design*. Morgan Kaufmann Pub, Amsterdam.

Wood, J., Dykes, J., Slingsby, A., and Clarke, K. (2007). Interactive visual exploration of a large spatio-temporal dataset: reflections on a geovisualization mashup. *Visualization and Computer Graphics, IEEE Transactions on*, 13(6):1176–1183.

WWW-1 (The invisible gorilla, <http://www.theinvisiblegorilla.com/videos.html> . Last accessed on October 25, 2010).

WWW-2 (ILWIS 3.5 help document, Last update: November 18, 2008. <http://spatial-analyst.net/ILWIS/help.html> . Last accessed on December 05, 2010).

WWW-3 (INTERNATIONAL ISO DIS 9241-11 STANDARD, Part 11: Guidance on Usability, <http://www.usability.ru/sources/iso9241-11.htm>. Last accessed on December 18, 2010).

WWW-4 (Web–based survey solution provider. <http://nl.surveymonkey.com>. last accessed on January 12, 2011).

Appendix A
INVITATION FOR USABILITY TESTING

A.1 INVITATION LETTER

Dear Sir/Madam,

I am a GFM (geoinformatics) MSc student. Right now, I am doing my MSc research supervised by Ms. Dr. C.A. Blok and Dr. R. Zurita-Milla, assistant professors in the GIP department. My research focuses on supporting users to visually explore animated time series of imagery, using NDVI data as case. To this end, an interactive tool is being developed and integrated in ILWIS. I hereby would like to kindly invite you to take part in the usability testing of the prototype that will be held in the second and third weeks of January, 2011. The test will be carried out in the usability laboratory (Room 1-066) of the GIP department and may take approximately 45 minutes. Your names and individual results of the test will be kept in private. If you are willing to help me, please fill in the questions below and your preference date and time order 1 to 3 in the given table (1 for best suitable time and date) in your reply, this will help me to organize participants in two hopefully homogeneous groups. Your response is kindly appreciated before 5th of January, 2011. You will be informed about the final schedule in advance.

Thanks in advance, and best regards,

A.2 PRE–TASK QUESTIONNAIRE

1. Sex
   - ❐ M
   - ❐ F
2. Educational qualification
   - ❐ PhD
   - ❐ MSc
   - ❐ PhD student
   - ❐ MSc student
   - ❐ Other, please specify

3. Have you ever worked with NDVI data before?
   - ❒ Yes, How frequent ______________________________
   - ❒ No
4. Are you familiar with Ethiopia (the case study area)?
   - ❒ Highly familiar
   - ❒ Moderately familiar
   - ❒ Slightly familiar
   - ❒ Not at all
5. Do you have experience of working with ILWIS?
   - ❒ Yes, How frequent ______________________________
   - ❒ Not at all
6. Are you familiar with visual exploration of animated time-series?
   - ❒ Yes, In which circumstances have you used animations? ______________________________
   - ❒ No
7. Please, label your preference date and time in order 1 to 3 in the table below (1 for best suitable time and date)

Time Date	09:00 - 10:00	10:00 - 11:00	11:00 - 12:00	12:00 - 13:00	13:00 - 14:00	14:00 - 15:00	15:00 - 16:00	16:00 - 17:00
Wednesday, January 12								
Thursday, January 13								
Friday, January 14								
Monday, January 17								
Tuesday, January 18								
Wednesday, January 19								

Thank you for your kind support

Appendix B
TEST PROCEDURE

B.1 CHECK LIST

- **Before the test:**
  - ❍ Test room arrangement
    - ✓ Checking the camera
    - ✓ Check for sufficient room light, ventilation, etc.
    - ✓ Preparing the computer for the test, running ILWIS
  - ❍ Availability of required materials
    - ✓ Task description and procedure
    - ✓ Check for sufficient room light, ventilation, etc.
    - ✓ Guide lines for self familiarization of the prototype/tool
    - ✓ Questionnaire papers
- **During the test:**
  - ❍ Welcoming test participants
  - ❍ Introduction to the test:
    - ✓ Purpose of the test
    - ✓ How to perform the test (explanation about think aloud method)
    - ✓ Describing the case study data set and the tasks to be performed
    - ✓ Handing over required materials and let him/her pass through it
  - ❍ Familiarizing with the prototype
    - ✓ The ILWIS environment and the tools to use (short demonstration of the prototype with training data)
    - ✓ Running the animation for self familiarization based on the a step–by–step guideline
    - ✓ Describing the case study data set and the tasks to be performed
  - ❍ Performing the task
    - ✓ Start the video camera and the webcam
    - ✓ Start the test with the test data
    - ✓ Encouraging participants to think aloud
    - ✓ Clarifying the tasks for inconveniences, if any
    - ✓ Reminding the questionnaires

- **After the test:**
  - ❍ Asking participants suggestions, remarks, etc., for improvement
  - ❍ Downloading and saving the recorded data, switching off video and webcam
  - ❍ Thanking the participant

B.2 TEST SCHEDULE

January 12 – 19 / 2011

Table B.1 Usablity testing time table

Time / Date	09:00 - 10:00	10:00 - 11:00	11:00 - 12:00	12:00 - 13:00	13:00 - 14:00	14:00 - 15:00	15:00 - 16:00	16:00 - 17:00
Wednesday, January 12		**Expert**	**TP-09**				**TP-12**	
Thursday, January 13	**TP-01**	**TP-15**					**TP-14**	
Friday, January 14			**TP-06**		**TP-11**	**TP-07**	**TP-08**	**TP-05**
Monday, January 17		**TP-04**				**TP-13**		**TP-02**
Tuesday, January 18			**TP-16**					
Wednesday, January 19		**TP-03**	**TP-10**					

Appendix C
HANDS–ON PRACTICE

C.1 MAIN INTERACTION STEPS: GROUP–1

1. Start ILWIS from the desk top shortcut ( ) icon.

   ☞ ILWIS starts directly from where it was last closed

2. Browse to the demonstration data (if not directly accessed) (refer Fig. C.1)

   ☞ C:\Usability_test\Kenya_ndvi → double click on ( ) kenya

   ➢ a Map List window containing all the individual frames will be displayed

3. To popup the animation window (refer Figure C.1)

   ☞ Click Open As Slide Show( ) button on the Map List window toolbar

4. To overlay the regional boundary map of the country (refer Figure C.1)

   ☞ Click Add Layer ( ) button on the animation window toolbar → Select( ) Boundary_map from the Add Data Layer dialog box → Ok

5. Navigate through the **Layer Management** pane along the left hand side of the animation window by clicking the + sign and get more familiarized with ILWIS. For example to change the color of the boundary line (refer Figure 1)

   ☞ Click the + sign in front of ( ) Boundary_map, → Display option → Portrayal → double click the Single color check box → Select color from Single Draw Color... dialog box → Apply → Close

   ➢ Maximize the window for better display

6. To run the animation (refer Figure C.1)

   6.1 Under the Display option → Double click the **Run** button

   - The Time dialog box pops up and the animation automatically starts...
   - The default display speed is one map frame per second;

   ☞ Enter another value (e.g. `0.5`) in place of the default value to change the display speed.

   ➢ *As it might be needed for further interaction* **Do not click Ok**, *and keep the dialog box aside.*

   6.2 Select the Use Time check box in the Time dialog window to read the time (in year–month–date format) for the observed changes in the animation;

- The default display speed is 40 days (P1M10D) per second

☞ Enter another value (e.g. **20D** for 20 days per second) in place of the default value (P1M10D) to change the display speed

✍ **Remark:** if required, it is also possible to interact with:

✓ The media player buttons of the Time dialog: Pause, Forward,Backward…
✓ Zooming in/out from the animation window tool bar.

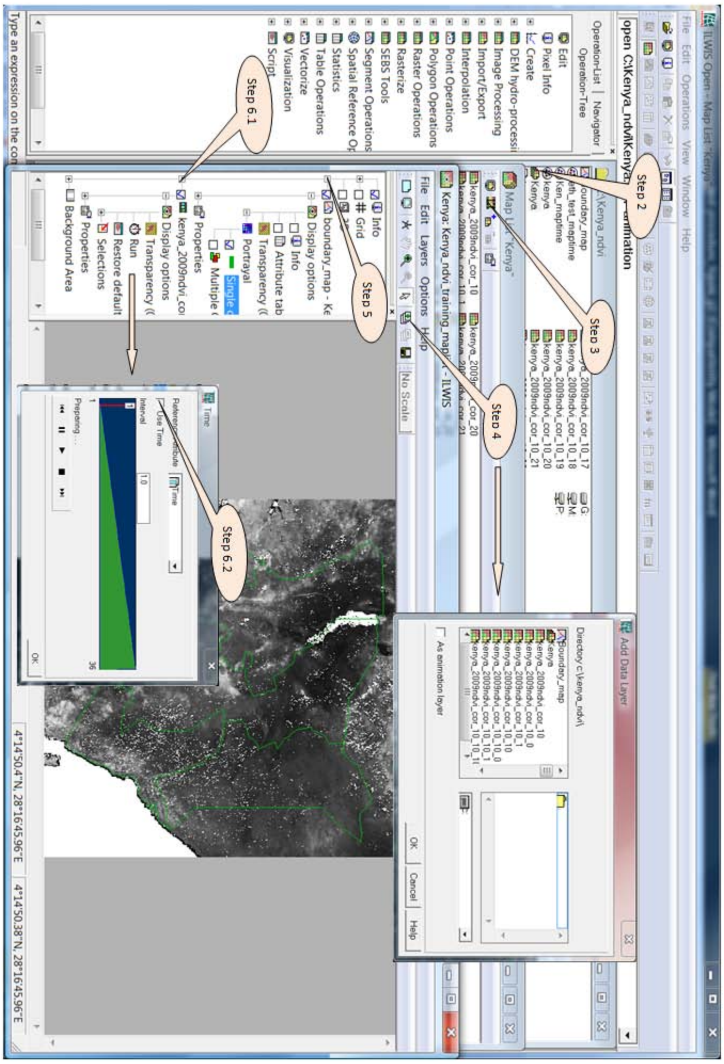


Figure C.1: Main interaction steps for getting familiarized (Group–1)

C.2 MAIN INTERACTION STEPS: GROUP–2

1. Start ILWIS from the desk top shortcut ( ) icon.

   ☞ ILWIS starts directly from where it was last closed

2. Browse to the demonstration data (if not directly accessed) (refer Fig. C.1)

   ☞ C:\Usability_test\Kenya_ndvi → double click on ( ) kenya

   ➢ a Map List window containing all the individual frames will be displayed

3. To popup the animation window (refer Figure C.1)

   ☞ Click Open As Slide Show( ) button on the Map List window toolbar

4. To overlay the regional boundary map of the country (refer Figure C.1)

   ☞ Click Add Layer ( ) button on the animation window toolbar → Select( ) Boundary_map from the Add Data Layer dialog box → Ok

5. Navigate through the **Layer Management** pane along the left hand side of the animation window by clicking the + sign and get more familiarized with ILWIS. For example to change the color of the boundary line (refer Figure 1)

   ☞ Click the + sign in front of ( ) Boundary_map, → Display option → Portrayal → double click the Single color check box → Select color from Single Draw Color... dialog box → Apply → Close

   ➢ Maximize the window for better display

   ✍ **Remark:**

   The following two steps help to select range of attribute values of interest and/or a specific area of interest (AoI). In both cases the unselected range of (NDVI) values and/or the surrounding context area (area outside the selected AoI) will be subdued while the selected ones remain with the original presentation.

6. To activate Attribute threshold dialog and select NDVI values of interest (refer Figure C.2)

   6.1 Click the + signs (if not already expanded) in front of ( ) Kenya_22009ndvi... → Display option → Selections

   6.2 Double click the Attribute threshold button to activate the interface

   6.3 Select the number of categories you want to explore from the combo box

   6.4 Double click on the default color to activate the Step color dialog box ? Change the representation color as you like (the default is Red) and adjust the transparency level (if necessary) by dragging the horizontal slider bar or entering an integer value in between 0 (opaque) to 100 (full transparent)

   6.5 To select range of NDVI values of interest, drag either the top or the bottom horizontal margin of the default values if the selected number of categories is greater than 2, else drag only the bottom margin.

➢ *As it might be needed for further interaction* **Do not click Ok**, *and keep the dialog box aside.*

7. To activate Area of Interest dialog and select specific area of interest (refer Figure C.2)

   7.1 Double click the Area of Interest button under selections

   7.2 Click Select Area button, then delineate your specific Area of Interest (AoI)

   7.3 Select color for the context area (area outside the AoI) (if necessary)

   7.4 Adjust the transparency by dragging the horizontal slider bar or entering an integer value in between 0 (opaque) to 100 (full transparent).

   7.5 Make sure to click Apply to see the changes you made

➢ *As it might be needed for further interaction* **Do not click Ok**, *and keep the dialog box aside.*

8. To run the animation (refer Figure C.2)

   8.1 Under the Display option → Double click the **Run** button

- The Time dialog box pops up and the animation automatically starts…
- The default display speed is one map frame per second;

☞ Enter another value (e.g. 0.5) in place of the default value to change the display speed.

➢ *As it might be needed for further interaction* **Do not click Ok**, *and keep the dialog box aside.*

   8.2 Select the Use Time check box in the Time dialog window to read the time (in year–month–date format) for the observed changes in the animation;

- The default display speed is 40 days (P1M10D) per second

☞ Enter another value (e.g. **20D** for 20 days per second) in place of the default value (P1M10D) to change the display speed

✍ **Remark:**

✓ Interactions with the Attribute thresholds and Area of Interest dialogs may cause bugs if it is done while the animation is running. Please, Pause or Stop the animation before interacting with these dialogs.

✓ It is also possible to interact with Zooming in/out from the animation window tool bar, if required.

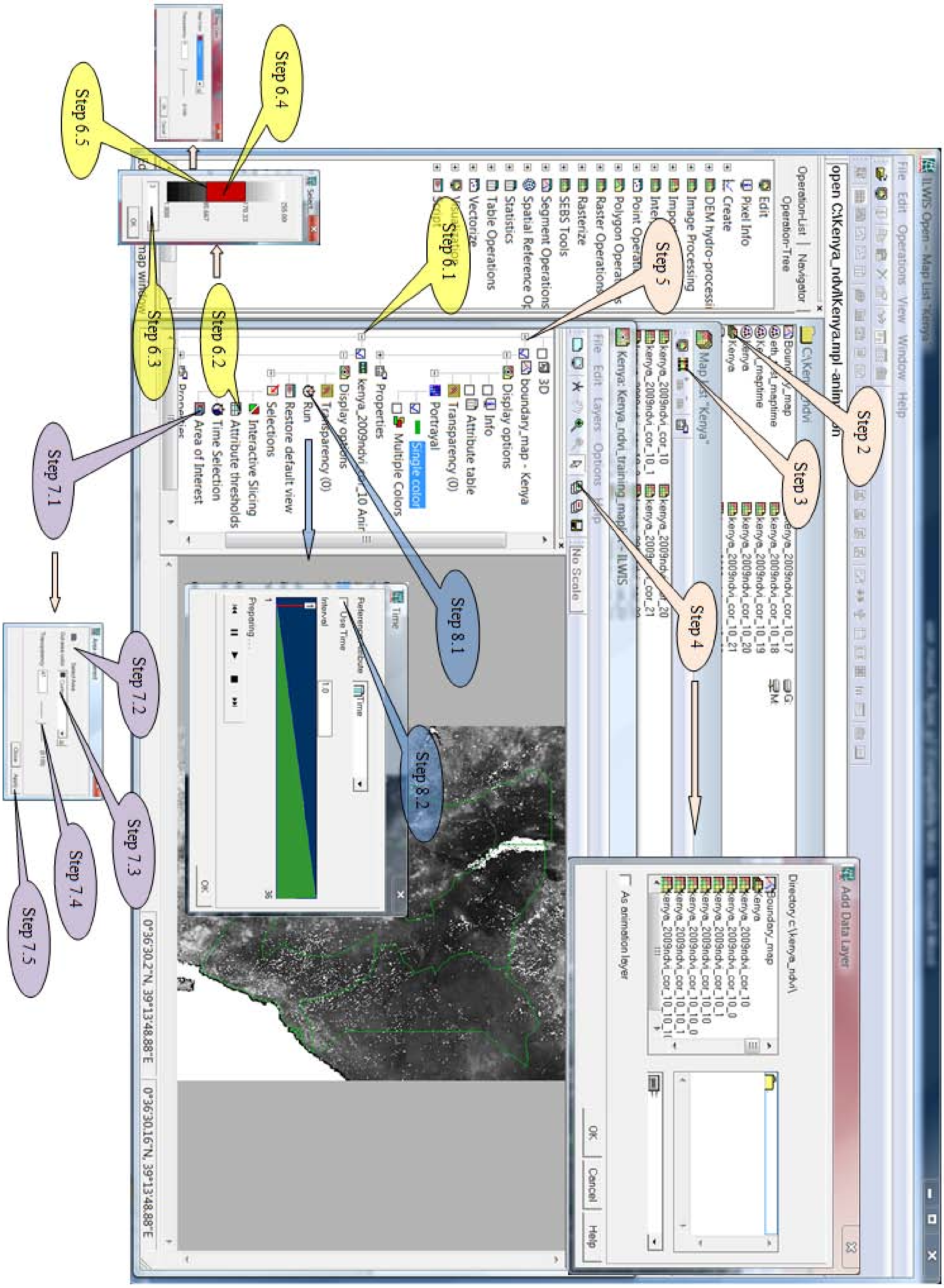


Figure C.2: Main interaction steps for getting familiarized (Group–2)

Appendix D
TEST SCENARIO AND TEST TASK

D.1 SCENARIO

A natural resource expert designs a project in order to plan and implement timely food security methods in Ethiopia. In most cases, vegetation variability is influenced by availability of water and analysis of variability might give a clue to drought susceptible areas. Drought susceptible areas can be concretized by further collection and analysis of relevant data, such as precipitation, land use, climate, soil type, etc. For this purpose, the project requires assessing parts of the country that show vegetation variability for an in situ sampling data collection, which can possibly be derived from animating time-series of NDVI data. To this end, the expert wants to perform a number of tasks by visual exploration of animated time-series of 2 years of NDVI data of the study area to decide on suitable sampling areas.

D.2 THE TASK

Now, put yourself in place of the expert. Use the skills acquired in the hands-on exercise and apply your knowledge about NDVI to visually explore the time series and address the following subset of questions. You are kindly requested to read the questions loudly and perform the tasks talking aloud about what you are doing in order to let the experimenter know what you are thinking during your visual exploration task. Keep in mind that the aim of the test is to evaluate the usability of the application you are working with, not the correctness of your approach. Your recorded activities are also used only for this research purpose and will be kept in private.

✍ **Remark:**

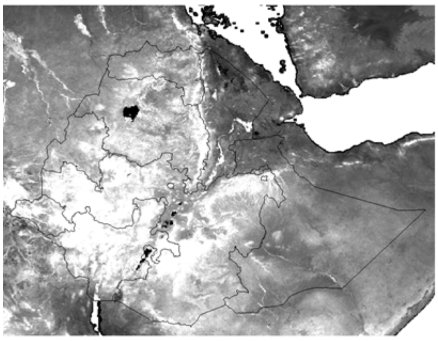
- You can refer to parts of the country as: eastern, western, east west, etc., in your answer; or point areas with the mouse
- The first year ranges from 1998–04–01 to 1999–03–24; or the first 36 (1 – 36) frames of the animation.
- The second year ranges from 1999–04–04 to 2000–03–26; or the second 36 (37 – 72) frames
- Follow the step–by–step guide used during the hands–on practice
  - Access the test data from C:\Usability_test\Eth_ndvi\()Eth
  - The administrative boundary map that should be added is named: ()Boundary_map
  - Activate any necessary dialog that you've used in the hands-on practice and keep aside until you finished the task
  - Read the questions aloud, and speak out your answers for each task and then:

  * Show areas of your answers on the screen and delineate them (by polygons) on the map given under the respective task.
  * Write your answers on the space provided, if it applies.
  * Write your answers on the space provided, if it applies.

- Please deal with the questions in the sequence indicated below and **don't forget to speak aloud each and every of your activities**.

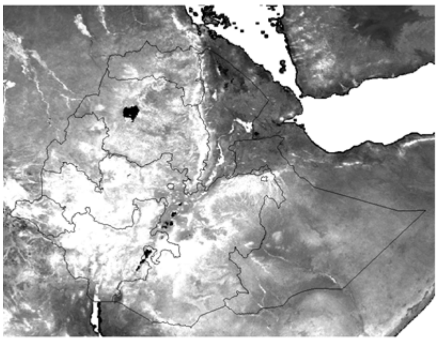
Task–1

✓ Where are constant NDVI values exhibited?



Task–2

✓ Where are the lowest (≈< 50) NDVI values exhibited during the first year of the study period?



Task–3

✓ What noticeable changes do you observe in the south-eastern part of the country (see Figure D.1) during the first year of the study periods?

✓ Are there any maximum (≈> 150) NDVI values exhibited in this particular area during this period?

Task–4

- ✓ How is the NDVI variability in the north-eastern part of Ethiopia (see Figure D.1) relative to its surroundings during the study period?

  ___

- ✓ In which of the two years the highest (≈> 150) NDVI values cover the largest part of this area of interest?

  ___

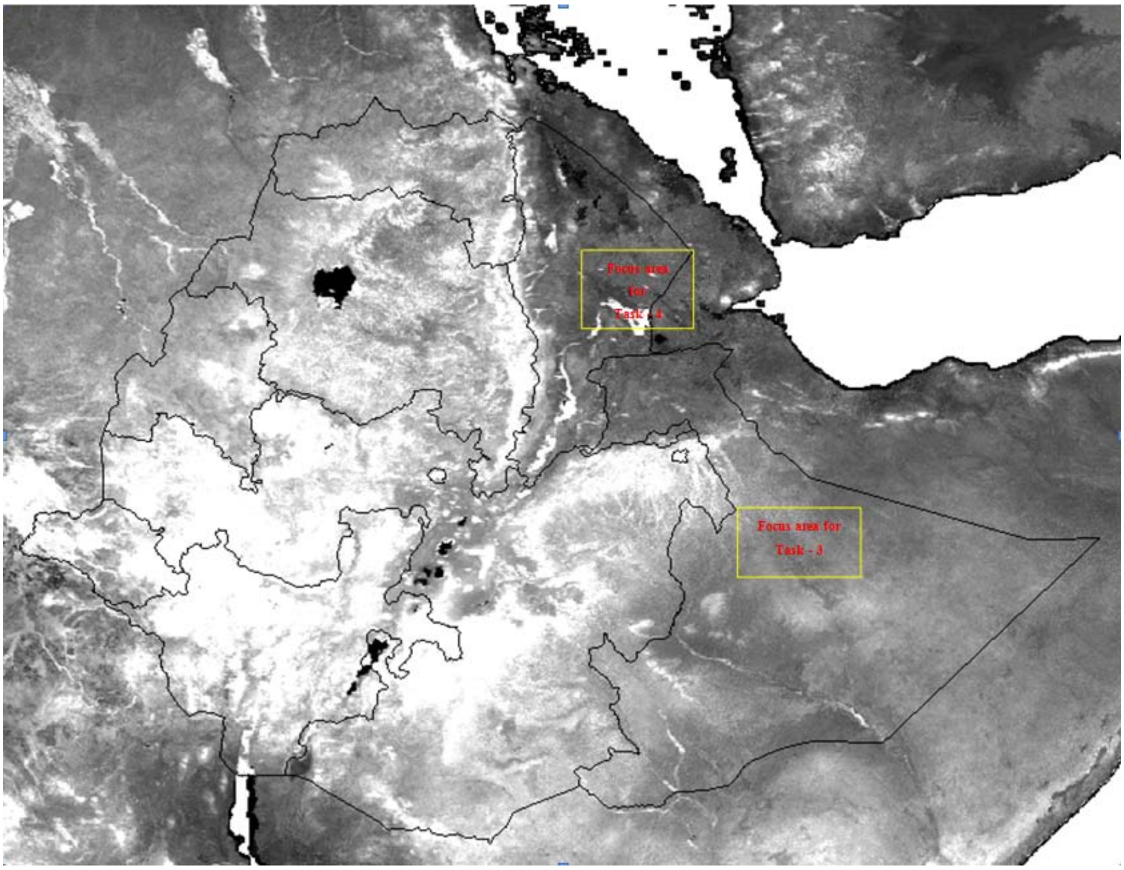


Figure D.1: Focus areas for tasks 3 & 4

D.3 POST–TASK QUESTIONNAIRE

1. How do you rate working with the prototype to perform the tasks?

   - ❒ Very good
   - ❒ Good
   - ❒ Satisfactory
   - ❒ Poor
   - ❒ Very poor

2. How do you rate the usefulness of the prototype in order to address the monitoring tasks? (Use the above rating for each task)

   - ❒ Task–1______________________________
   - ❒ Task–2______________________________
   - ❒ Task–3______________________________
   - ❒ Task–4______________________________

3. How confident you are in your task performance?

   - ❒ Very good
   - ❒ Good
   - ❒ Satisfactory
   - ❒ Poor
   - ❒ Very poor

4. What, in your opinion, has to be improved in order to make the application more useful?

   ____

Appendix E
RESULTS

E.1 TASK CORRECTNESS

Table E.1 Participants respond to the tasks

Group	Code	Task -1	Task -2	Task -3		Task -4	
				a	b	a	b
1 (without the tools)	TP-01	Complete	Incomplete	Complete	Complete	Complete	Complete
	TP-02	Complete	Incomplete	Complete	Complete	Complete	Wrong
	TP-03	Incomplete	Incomplete	Incomplete	Wrong	Complete	Complete
	TP-04	Complete	Complete	Complete	Wrong	Complete	Wrong
	TP-05	Incomplete	Complete	Complete	Complete	Complete	Wrong
	TP-06	Complete	Complete	Complete	Complete	Complete	Wrong
	TP-07	Incomplete	Complete	Incomplete	Complete	Complete	Wrong
	TP-08	Complete	Complete	Complete	Complete	Complete	Wrong
	Overall Complete	62.50%	62.50%	75.00%	75.00%	100.00%	25.00%
2 (with the new tools)	TP-09	Complete	Complete	Complete	Wrong	Complete	Wrong
	TP-10	Complete	Complete	Complete	Complete	Complete	Complete
	TP-11	Complete	Complete	Complete	Complete	Complete	Wrong
	TP-12	Incomplete	Complete	Complete	Complete	Complete	Complete
	TP-13	Complete	Complete	Complete	Complete	Complete	Complete
	TP-14	Complete	Complete	Complete	Complete	Complete	Complete
	TP-15	Incomplete	Incomplete	Incomplete	Complete	Complete	Wrong
	TP-16	Incomplete	Incomplete	Wrong	Complete	Incomplete	Wrong
	Overall Complete	62.50%	75.00%	75.00%	87.50%	87.50%	50.00%

E.2 INDIVIDUAL AND AVERAGE TIME SPENT ON THE TASKS

Table E.2 Individual and average time (in minutes)

Group	Code	Task -1	Task -2	Task -3	Task -4	Indvidual Average
1 (without the tools)	TP-01	2.30	1.83	6.58	5.85	4.14
	TP-02	2.25	1.95	3.55	4.08	2.96
	TP-03	2.75	1.10	5.97	7.75	4.39
	TP-04	5.25	1.95	6.57	5.67	4.86
	TP-05	5.50	3.82	5.95	7.97	5.81
	TP-06	0.97	3.95	4.52	7.58	4.26
	TP-07	0.63	0.68	2.32	6.32	2.49
	TP-08	5.55	1.40	3.38	8.07	4.60
	Group Average	**3.15**	**2.09**	**4.86**	**6.66**	**4.19**
2 (with the new tools)	TP-09	2.42	1.75	4.32	4.43	3.23
	TP-10	2.18	2.88	6.50	5.67	4.31
	TP-11	1.30	2.53	3.90	4.48	3.05
	TP-12	2.63	1.97	3.82	5.40	3.46
	TP-13	4.70	2.78	5.60	9.28	5.59
	TP-14	4.95	1.42	2.88	4.55	3.45
	TP-15	2.55	1.67	4.92	4.75	3.47
	TP-16	3.15	2.17	6.28	5.33	4.23
	Group Average	**2.99**	**2.15**	**4.78**	**5.49**	**3.85**

E.3 TEST PARTICIPANTS' SATISFACTION RATING

Table E.3 Participants satisfaction rating

Group	Code	Overall satisfaction		Usefulness of the prototype for:								Performance confidence	
				T-1		T-2		T-3		T-4			
1	TP-01	Poor	2	Satisfactory	3	Poor	2	Poor	3	Poor	2	Satisfactory	3
	TP-02	Good	4	Satisfactory	3	Good	4	Good	4	Good	4	Good	4
	TP-03	Very good	5	Very good	5	Good	4	Very good	5	Very good	5	Good	4
	TP-04	Satisfactory	3	Good	4	Good	4	satisfactory	3	Poor	2	Good	4
	TP-05	Good	4	Very Good	5	Good	4	Good	4	Satisfactory	3	Satisfactory	3
	TP-06	Good	4	Good	4	Good	4	Good	4	Poor	2	Satisfactory	3
	TP-07	Very Good	5	Good	4	Poor	2	Good	4	Very good	5	Good	4
	TP-08	Good	4	Good	4	Very Good	5	Very Good	5	Good	4	Good	4
	Average		**3.88**		**4.00**		**3.63**		**4.00**		**3.38**		**3.63**
2	TP-09	Satisfactory	3	Satisfactory	3	Good	4	Good	4	Good	4	Good	4
	TP-10	Satisfactory	3	Poor	2	Satisfactory	3	Satisfactory	3	Good	4	Satisfactory	3
	TP-11	Very good	5	Good	4	Very good	5	Very good	5	Very good	5	Very good	5
	TP-12	Very good	5	Satisfactory	3	Very good	5	Very good	5	Very good	5	Satisfactory	3
	TP-13	Satisfactory	3	Good	4	Good	4	Good	4	Satisfactory	3	Satisfactory	3
	TP-14	Good	4	Very good	5	Very good	5	Very good	5	Poor	2	Very good	5
	TP-15	Very good	5	Very good	5	Very good	5	Very good	5	Good	4	Very good	5
	TP-16	Good	4	Poor	2	Satisfactory	3	Good	4	Good	4	Good	4
	Average		**4.00**		**3.50**		**4.25**		**4.38**		**3.88**		**4.00**