Dynamic visualization variables in animation to support monitoring of spatial phenomena

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Dynamic visualization variables in animation to support monitoring of spatial phenomena

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To my parents, Janneke and Jos

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This thesis is the most important product of my PhD research work. The work has been a challenge that has enriched my life, but also a task that turned out to be tedious, long, demanding and often hard to combine with other important things in life. It would not have been completed without the support of many people and that of ITC. I wish to express here my sincere thanks to them all.

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1 INTRODUCTION

1.1 General background

Our world is dynamic. Changes occur constantly in all the components of the earth's system: its lithosphere, hydrosphere, biosphere and atmosphere. Although human interest in the world's dynamics is not new, in the past major factors that inhibited the study and understanding of these changes were the limited availability of large temporal data sets and a lack of suitable methods and techniques to discover patterns, relationships and trends in such data.

In the past few decades, this situation has changed. Temporal-spatial data are gaining in importance. Periodic earth observations – in particular – provide a wealth of data, to such an extent that these data are not even fully exploited yet. However, new methods and techniques to extract useful information from rich data have been developed, and are still being investigated. Data mining, KDD (Knowledge Discovery in Databases), scientific visualization in general and geovisualization in particular (see Chapter 2) can all be viewed in this light.

An important application dealing with spatial dynamics is monitoring. Monitoring is, for example, an integral part of many sustainable development, disaster prevention, early warning and emergency response programmes. Spatial dynamics results from changes in the characteristics of spatial phenomena over time (see Chapter 3). Therefore, no matter to what domain monitoring is applied, its aim is always to keep track of the various changes in the phenomena under investigation through exploration and analysis of the data. These activities yield information about changes needed to discover patterns, relationships and trends, which in turn can be used to warn of /interfere in possibly undesired developments, to model the dynamics, or to extrapolate them to the future.

Although specialists in monitoring make use of (static) maps and images, they rely heavily on computational methods to reveal information about changes reflected in spatio-temporal data sets. The human ability to quickly 'see' shapes, patterns, relationships, trends and movement, however, is very powerful. Therefore, additional options to *visually explore* graphic representations (or to use geovisualization) can perhaps complement computational methods in processes involved in the extraction of relevant information. Particularly if more qualitative, visually based methods are integrated with computationally based functions in one environment (e.g. directly linked to or embedded in a GIS), a rich range of exploration and analysis methods and tools are provided to support users in decision-making (see e.g. Takatsuka & Gahegan, 2002).

Within the framework of computer-supported visualization methods, animation seems pre-eminently suitable for the visual detection of spatial dynamics, because it not only enables a viewer to see the data in a spatial but also in a temporal context. Therefore, dynamic aspects of world phenomena can be observed and spatio-temporal patterns, trend and relationships may be discovered that would be less apparent from numerical data or static maps alone (Openshaw et al., 1994; Peterson, 1995; MacEachren & Boscoe et al., 1998).

Animations of spatial data have been used for some time. Campbell & Egbert (1990) provide an overview of early developments; references to more recent research can be found in Chapters 2 and 4. Recently, their dissemination has increased with the World Wide Web as an important medium. The technology required to produce animations is available and affordable. Also, animations are often received with enthusiasm by users (e.g. Antin et al., 1990; Slocum et al., 1990): they attract attention and meet the expectations of current generations of users. Other main reasons for their increase in use are the ability of animations to mimic real-world dynamics (as mentioned above), to represent processes and track changes, and to support search operations by means of quick browsing through large amounts of data (e.g. remotely sensed imagery).

Although animations are widely believed to be useful for the representation of spatial dynamics, an important question is whether they are also an *effective* medium for visualization. Effectiveness should be considered here in terms of the possibility to extract relevant information from animated representations and to acquire or discover knowledge from them. Various authors claim that animations are 'fugitive' and difficult to perceive, that they overload users with sequences of rapid changes (e.g. Monmonier, 1992b). Morrison et al. (2000) reviewed literature in which static and dynamic graphics were compared to determine their relative effectiveness in supporting learning. They concluded that static graphics usually give better results and *if* animations are effective, then it is because they better display the micro steps between more important changes than static graphics can.

Does this mean that displaying micro steps is the main strength of animations? Can they can be effective if they are used for applications in which detailed sequential information about changes is important (Slocum et al., 2001), for example for monitoring spatial dynamics? These questions have not been answered yet. Morrison et al. (2000) refer to studies that are almost entirely outside the geoinformation sciences. Research undertaken in the 1990s, when the interest in animation within the geoinformation sciences grew, yielded mixed results. There is evidence that animation facilitates the processing of spatial data (e.g. Koussoulakou, 1990; Koussoulakou & Kraak, 1992; Gershon, 1992; Openshaw et al., 1994; Patton & Cammack, 1996), but other studies report either mixed results or favour static maps (e.g. Slocum et al., 1990; Slocum & Egbert, 1993; Johnson & Nelson, 1998). The effectiveness of an animation obviously depends on many factors. These factors are related to characteristics of the data represented (e.g. complexity, spatial and temporal resolution), to the design of the animation (e.g. use of the representation variables, controls provided, multiple views on the data) and to various aspects of use (such as overall goal and purpose of use, characteristics of the user and of the use environment). Complex interactions among these factors preclude straightforward conclusions, but one reason for the mixed results is that the full potential of animations has often not yet been utilized. For example, interactive control of the animation by the user has to be considered.

Morrison et al. (2000) assumed that the effectiveness of an animation must be evaluated without interaction. But, among the geoinformation sciences some evidence exists that animations are more effective when users have control and can interact. MacEachren & Boscoe et al. (1998), for example, found that epidemiologists effectively detected spatio-temporal patterns in interactive animations. Ogao (2002) discovered that in visual exploration both view-only and interactive animations can play a role, although the view-only types just contribute to early stages of the process. The number of empirical investigations of interactive animation is still limited and the results are not wholly positive. For example, Harrower et al. (2000) found that interactions with a temporal legend, intended to assist students in learning about global weather, were not particularly effective. On the other hand, students with a modest knowledge of weather phenomena benefited most. Dorling (1992) argues that animation *needs* to be interactive in order to be successful; other authors claim that *users* like and/or express a need for interactivity (e.g. Slocum et al., 2001; Ogao, 2002). A number of interactive animation tools have been provided since the 1990s (e.g. Dykes, 1996, 1997; Andrienko & Andrienko, 1999; Peterson, 1999, Kraak, 2003), but often we know little about the way users work with them and whether they influence understanding or not (Slocum et al., 2001).

From the above description, it is clear that more research is required to gain understanding of the factors affecting the effectiveness of animations. Examples of key research areas are animation design – particularly on representation variables – and the nature and degree of user control. Slocum et al. (2001) mention that there is a need to evaluate animations *with* and *without* interactivity, in various problem contexts.

1.2 Focus of this research

This research focuses on particular design and use aspects of animations of spatial data used for monitoring. The perspective used is that of the domain specialist, who uses 2-D animations of time series to visually explore spatial data sets and gain information about their dynamics. Animation seems suitable for monitoring, not only because it can represent spatial dynamics, but also because all changes in the data, including those typically displayed in the micro steps of an animation, as mentioned by Morrison et al. (2000), can be relevant. In addition, in an animation "... *users are drawn to patterns that look odd such as with outliers"* (Ogao, 2002, p. 112), and searching for outliers or anomalies is an important task in monitoring applications dealing with disaster prevention, early warnings and emergency response programmes.

For the representation of spatial data in an animation, graphic variables (form, colour, value, size, etc.) are applied in the spatial dimensions of individual maps or images. The use of these variables has been studied extensively. The particular design aspects investigated in this thesis are the dynamic visualization variables originally distinguished by DiBiase et al. (1992) and MacEachren (1994b). These variables can be observed in the temporal dimension, where the dynamics in an animated representation are manifested. They mark, for example, the moment in time, the order, the duration and the frequency in which elements in the animated representation are visible (see Chapter 4). Many current GIS and image processing environments enable observation of spatial dynamics by offering simple sequential displays of a series of maps or georeferenced images as frames in an animation. Although design and interaction functionality is usually limited, this option offers one way to visually explore the dynamics. But the maps or images may be complex, with many changes occurring all over the display area. If this is the case, then the fugitive character of an animation can be a serious limitation, which calls for interactivity. It seems reasonable to assume that both the quality and quantity of the information extracted increases if the user is able to interactively control the representation. In my research, animation control by the use of dynamic visualization variables is investigated.

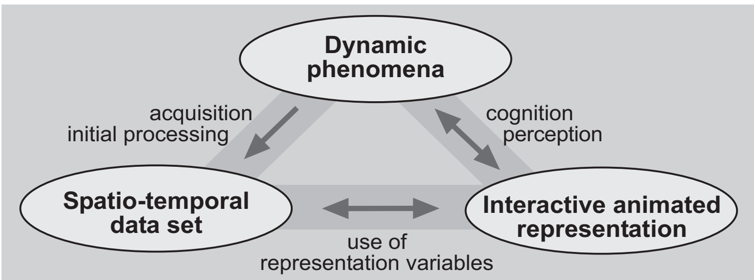

Figure 1.1 General processes involved in the use of an animated representation of spatial data to gain information about dynamic phenomena

This research does not directly address the stages and processes involved in data acquisition and initial processing that lead to spatial data sets (see Figure 1.1). It starts with existing data sets and studies the use of the dynamic visualization variables in a monitoring context in basically two ways. Firstly, ways to incorporate the variables in animation design to depict spatial data and to interact with these data will be explored. This will result in an animated representation of a sample data set with a dedicated interface. Secondly, the strategies and reasoning applied during the use of the animated representation and its interface by domain experts to gain information will be investigated. *Data* are defined in this context as representations of spatial phenomena acquired, for example, by remote sensing; they are pre-processed for further application by domain specialists, who use computational and/or visualization techniques to gain information about reality. *Information* is data interpreted to derive the semantics; it is a product of perception and cognitive processing that affect the internal representation of the real world.

More specifically, the main research objectives are:

- To develop methods by which the dynamic visualization variables can be used to acquire or discover information from time series in a monitoring context.
- To gain knowledge of strategies and related cognitive processes applied by domain experts during the use of the dynamic visualization variables in a monitoring context.

I hope that this knowledge can be used to extend conceptual and theoretical frameworks designed for the graphical representation of spatial data by the *graphic* variables for the *dynamic* visualization variables. Furthermore, I expect that more knowledge of user strategies and their related cognitive processes will shed light on the methods required to use an animation effectively, and that design recommendations can be derived from it. These are the ultimate goals of this research.

Cognitive aspects, i.e. trying to understand the interaction between dynamic visualization variables and users of an animation, will play a main role in this research (see also Ogao & Blok, 2001; Blok, 1998b). Cognition stands for the higher mental processes on which man draws to acquire, store and use information. Interest in cognitive abilities of map users started with work by Robinson (1952), but all early studies applied psychophysical testing. The focus of this popular testing was on a description of the (quantitative) relationship between visual stimuli and user response, without an attempt to explain the processes involved. This 'black box' approach was common practice until the late 1970s, early 1980s. From then on, a few cognitive or mixed perceptual and cognitive studies were started (Gilmartin, 1981; Lloyd, 2000). Nowadays, a cognitive approach is considered to provide insights into how map users process and determine the meaning of information during the complex interaction with all kinds of spatial data representations and interfaces. For example, Slocum et al. (2001) argue that cognitive research is needed because spatial data representations may guide, constrain or even determine cognitive behaviour. The authors advocate a dual approach: an attempt to understand how man creates and utilizes representations of spatial data; and the evaluation of use of tools according to usability engineering principles. Cognition of dynamic phenomena and their representations is also one of the priority research topics distinguished by the North American National Centre for Geographic Information and Analysis, NCGIA (see e.g. Hirtle & MacEachren, 1998).

My research focuses on data of remotely sensed time series. An important reason for their selection is that these data provide good opportunities for monitoring, and they are commonly used for this purpose, particularly in developing countries, where spatio-temporal data are often not available from other than remote-sensing sources. Another reason for their selection is that remote-sensing data, even large time series, are available from a variety of sources.

The main questions that guide my research and for which answers were sought are:

1. To what questions about dynamic spatial phenomena do experts involved in monitoring seek answers?

2. What dynamic aspects of spatial phenomena can be visually perceived in an animated representation?
3. How can dynamic visualization variables be *applied* to support the finding of answers to these questions in animated representations?
4. How are dynamic visualization variables *used* to find answers to these questions and what strategies do experts use to explore an animated representation for monitoring purposes?
5. Is it possible to establish a theoretical framework to guide application of the dynamic visualization variables in animated representations of spatial data?
6. Can design recommendations for effective use of animations be derived from the results?

1.3 Methodological approach

The main aspects of the methodological approach are explained below. Briefly, there are four phases (see Figure 1.2).

1. *User task analysis*

In this phase, answers are provided to the first research question: *To what questions about dynamic spatial phenomena do experts involved in monitoring seek answers?* The main approaches are a literature study to identify the goals, objectives and questions that are relevant for experts involved in monitoring in general, and – more specifically – for the application selected as the case, as well as interviews with domain experts to verify the results.

2. *Creation of an environment in which answers to questions can be sought by visually exploring animations*

The second research question, i.e. *What dynamic aspects of spatial phenomena can be visually perceived in an animated representation?*, and the third research question, i.e. *How can dynamic visualization variables be applied to support the finding of answers to these questions in animated representations?*, are dealt with in this phase. Answers are necessary to establish how animation can, in theory, support experts seeking to find answers to their monitoring questions. Literature is studied to identify important concepts and principles related to visualization, geovisualization and animation. The main cognitive tasks that can be used to visually explore animated representations are derived. Since monitoring is about change, important perceptual and cognitive problems related to 'seeing change' are investigated. Next, literature is reviewed to discover what characteristics of change relevant for answering monitoring questions can actually be seen in animated representations. This leads to a generic classification of visually perceptible change. Different temporal reading levels at which answers can be found are also distinguished.

Literature is then reviewed to learn what animation design variables have been distinguished to build on it and to place these variables in a broader context of representation variables for spatial data. Further investigation into the dynamic visualization variables leads to definitions, identification of characteristics, relationships and possibilities for using those variables to support monitoring experts. The anticipated effects of the use of the dynamic visualization variables are worked out in a conceptual model. The model attempts to predict which effects will be used by the experts in their search for answers to a number of generic monitoring questions with the animated representation. Finally, all the findings in this phase are used to design and implement a prototype containing an animated representation of a large sample data set and an interface dedicated to interactions with the dynamic visualization variables by the user.

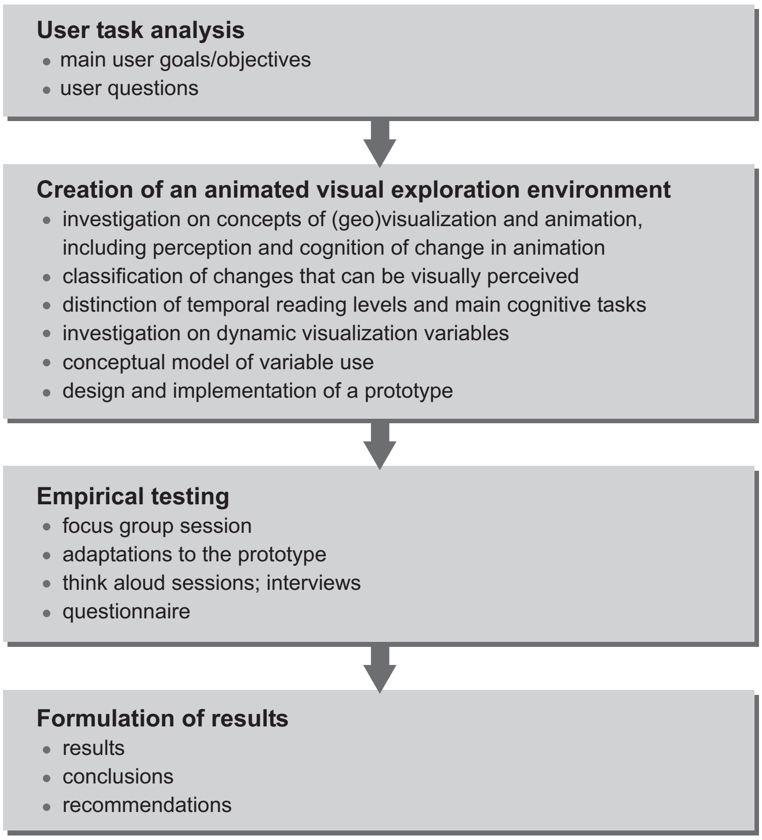

Figure 1.2 Main research phases

3. *Empirical testing*

In the third phase, a focus group session with a small number of domain experts is to be organized (Morgan, 1998a). The main goals of this session are to obtain opinions and reactions on a first version of the prototype and to minimize potential use problems in the later evaluation, needed to gain insights in the cognitive aspects of animation use. Feedback from the focus group is used to improve the application. Then, in order to answer the remaining research questions (*How are dynamic visualization variables used to find answers to these questions and what strategies do experts use to explore an animated representation for* *monitoring purposes? Is it possible to establish a theoretical framework to guide application of the dynamic visualization variables in animated representations of spatial data? Can design recommendations for effective use of animations be derived from the results?)*, empirical testing of the improved prototype is required. Empirical testing is conducted in individual sessions. The main aim is to discover what strategies and reasoning users apply during execution of a monitoring task with the prototype, and whether answers are provided or not. Knowing how users look at the animation, work with the prototype and conceptualize the contents, why some things work, or do not work is important for the further development of effective animated representations. The main method used in my research is the think aloud method, a very suitable method to unravel cognitive processes (Ericsson & Simon, 1993; van Someren et al., 1994; van Elzakker, 2004). Participants are requested to execute a problem-solving task while thinking aloud. All actions and verbalizations are recorded on video tapes. After the think aloud test, participants are interviewed by the experimenter to clarify some aspects of the execution of the task; interviews are also recorded. The test is concluded by the participants filling in a questionnaire.

4. *Formulation of results*

The last phase consists of analysis of the verbal and action protocols and video recordings generated during the test and during the interview after the test. Analysis is directed to the strategies used during task execution, the reasoning applied and the answers provided. Reactions to the application are noted as well. In addition, the questionnaires are analysed. An attempt is made to establish a theoretical framework for the use of dynamic visualization variables in animations for monitoring purposes. Conclusions are formulated by providing answers to the research questions 4, 5 and 6 above, and suggestions for further research on animation design are given.

1.4 Organization of the thesis

The thesis is organized in seven chapters. The contents of the chapters following this introduction chapter are briefly described below.

Chapter 2 is about the visualization of spatial data. It starts with a description of important developments leading to a shift in emphasis from communication-oriented cartography to exploration-oriented geovisualization. Next, basic geovisualization concepts are described. This is followed by a section on the complementary role of geovisualization with respect to computational techniques for the handling of spatial data. Then it narrows down to animation as a geovisualization method to visually explore large time series. Main perceptual and cognitive aspects related to 'seeing change' are also discussed in this chapter.

Chapter 3 deals with monitoring of dynamic spatial phenomena. It gives an overview of the objectives and generic user questions in monitoring applications based on literature reviews and expert interviews. The focus is on vegetation monitoring, since NDVI data are used as a case study. NDVI stands for Normalized Difference Vegetation Index. Application-specific matters are highlighted. If questions are to be answered by visual exploration, then experts have to perform certain cognitive tasks at various temporal levels. The relations between monitoring questions, tasks and temporal levels are explained. Furthermore, results of an investigation into aspects of change that can be visually perceived from an animated representation to trigger domain knowledge are described. A conceptual classification of spatial dynamics is proposed.

Chapter 4 first provides the context in which dynamic visualization variables can be considered by giving a brief overview of all kinds of variables that can be used for the representation of spatial data. It also describes existing and proposed frameworks for *application* of the variables. Then it focuses on the dynamic visualization variables. Types, characteristics and relationships are described, followed by ways to enable user control over the variables in animated representations of spatio-temporal data sets. Next, (anticipated) effects of the dynamic visualization variables are introduced, together with the assumption that these effects connect the use of the dynamic visualization variables to monitoring tasks or questions.

Chapter 5 outlines the design and implementation of *aNimVis* (Animated Image Visualization), the prototype developed for testing. It also provides details about the satellite data used for the case study and about the area used for testing. In addition to the satellite data, some base map layers are produced. Details about the focus group session, organized to be able to improve a first version of the prototype, are then described. Finally, the adjustments made are summarized.

Chapter 6 describes the evaluation methods applied and the results. First, a conceptual model of the use of the variables is introduced, which is subsequently tested empirically. Justification for the selected research methods is given. Details of the procedure for the selected think aloud test, the post-test interviews and the questionnaire follow. The main part of this chapter, however, is devoted to description of the results. The chapter ends with a discussion on the findings.

Chapter 7 outlines the main contributions and conclusions of this research, with an emphasis on results regarding a theoretical framework and animation design and use. Recommendations for further research on animation, in general, and for monitoring in particular are provided.

2 VISUALIZATION OF GEODATA AND MAIN COGNITIVE ASPECTS

2.1 Introduction

As described in Chapter 1, the possibilities to obtain information about the world's dynamics are growing. Abundant data are provided by periodic earth observations, and methods and techniques to deal with these data are developing. Data as well as methods and techniques are prerequisites for the current approach of geo-information scientists studying aspects of the real world. The earlier status-oriented attitude has changed into a process-oriented approach, and studying single phenomena is often replaced by interdisciplinary attempts to incorporate interrelations between subsystems of the social and the physical environment.

Monitoring of geospatial dynamics is highly process-oriented. Although it is possible to monitor single phenomena (e.g. pollution, certain hazards, like floods), the issues related to those phenomena are usually considered in a broader perspective (e.g. environmental protection, food security). The focus of this research is on visual (animated) methods and techniques to extract information from remotely sensed data in a monitoring context. Therefore, in this chapter the role of visualization with respect to geospatial dynamics are highlighted.

Section 2.2 describes the origin of, and current attention paid to, visualization of geospatial data, also called *geovisualization*. Visualization goals, particularly *exploration* and related concepts, are briefly discussed. Next, visual exploration is described in the context of abductive reasoning. Section 2.3 describes concepts of geovisualization and introduces a model to emphasize that (from a human point of view) graphic, or *external*, and cognitive, or *internal*, representations of phenomena in the real world interact during visual exploration. Main exploratory tasks with the external representations and tools that can be used to facilitate interaction between the two types of representations are briefly presented. In Section 2.4 the role of geovisualization in relation to computational approaches is considered. Next, the discussion is narrowed down to animation as a visualization method to represent geospatial dynamics in order to support monitoring (Section 2.5). Also described here are aspects related to the perception and cognition of change in animation. Finally, Section 2.6 provides a summary.

2.2 The context

Cartography has a long-standing experience in graphic representation of the real world. The discipline has no doubt evolved in many ways over the course of time, but a fundamental change that started in the late 1980s is worth mentioning in this context, namely the gradual integration of ideas stemming from Exploratory Data Analysis (EDA), scientific visualization and information visualization. The term EDA stems from Tukey (1977), who emphasized the importance of data *exploration* by graphic representation and statistical analysis as opposed to searching for confirmation of a priori models. Ten years later, the report on Visualization in Scientific Computing (ViSC) appeared (McCormick et al., 1987). It called attention to the use of interactive and dynamic computer visualizations to facilitate 'visual thinking' by domain specialists. Examples are techniques to enable multivariate data analysis and exploration of (physical) objects in ways that are normally not possible, for example by representing opaque objects transparently, or by slicing parts of the human body as in tomography. Although multivariate data visualization and scientific discoveries through visualization are older than 1987 (e.g. see the permutation matrices of Bertin, 1981, originally published in French in 1977), the influential ViSC report marked the start of what is formally called *scientific visualization* in many disciplines (Wood & Brodlie, 1994). Cartography is one of these disciplines. DiBiase (1990) was among the first to recognize the need for cartographers to focus on the role of maps in scientific visualization (Figure 2.1).

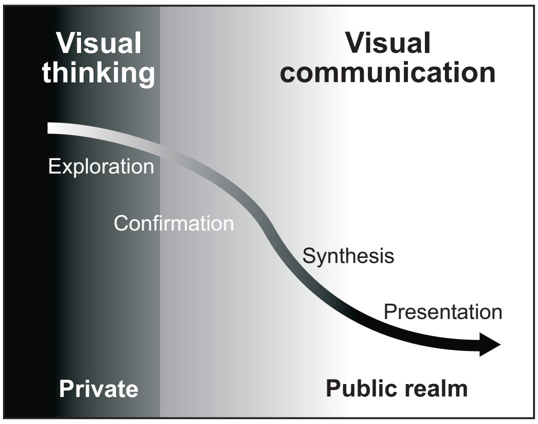

Figure 2.1 Scientific tasks in which maps or other visual aids can be used (after DiBiase, 1990)

The graphic representations in the private realm in Figure 2.1 facilitate visual thinking during exploration when hypotheses are generated and confirmation when hypotheses are tested. A synthesis of the results found may lead to presentation in the public realm. Later, the term *geovisualization* was introduced for scientific visualization applied to geodata (MacEachren & Kraak, 2001). Recently, cross-fertilization has been taking place with information visualization, which deals with the visualization of abstract, non-geographic data like business information and collections of documents (e.g. Card et al., 1999; Fabrikant, 2000; Dykes, Kraak & MacEachren, 2004).

These developments, together with the integration of GIS and image analysis techniques, extent cartographic theories, methods and tools (see for the relationship to GIS: Hearnshaw & Unwin, 1994; MacEachren & Taylor, 1994). They cause a shift in focus from static, view-only and usually single 'optimal' presentations of geodata to representations that facilitate visual exploration. The latter representations are likely to offer interactive, dynamic, personalized views on the data, which are often represented in multiple dimensions and sometimes in ways that require multiple perception channels, like in fully immersive Virtual Environments, or if sound is added (Visvalingam, 1994; MacEachren & Kraak, 2001). These developments also resulted in the establishment of the ICA Commission on Visualization in the mid-1990s (later on 'and Virtual Environments' was added to the commission's name) and in the publication of several special journal issues on geovisualization (e.g. in *Computers and Geosciences*, *International Journal of Geographic Information Science*, and *Cartography and Geographic Information Science*).

The shift towards visual exploration of geodata representations can also be viewed from a map use perspective. From this point of view, reference is often made to the map-use cube, originally developed by MacEachren (1994c) and later adapted by MacEachren and Kraak (1997). The cube is based on three orthogonal axes representing different categories of users (from private to public), different purposes of use (from revealing unknown to showing known data relationships) and different degrees of interaction with the data (ranging from high to low). Depending on the goal of map use, a position can be determined in the cube. If the main goal is *exploration,* map use can be located in the private, unknown relationships and high interactivity corner. If the main goal is *presentation*, map use is located in the diagonally opposite corner. *Analysis* and *synthesis* occupy intermediate positions in the cube (Figure 2.2).

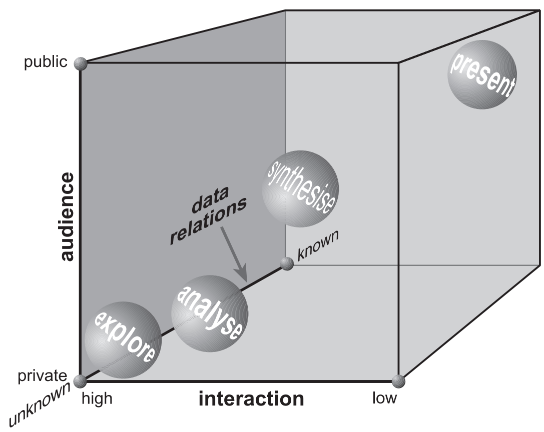

Figure 2.2 Perspective on map use (MacEachren & Kraak, 1997)

Because of technological advancements, however, the position of particularly *presentation* in the cube currently varies. The Web has not only enlarged the map user community, it has also changed expectations of users, who nowadays prefer dynamic, interactive and real-time visualizations. From a technological point of view, delivering such visualizations is no longer a problem. Furthermore, the Web has extended the role of the map from merely a representation medium to an interface to distributed geospatial data resources (MacEachren & Kraak, 2001). Together with other recent developments, such as the possibility to use maps displayed on mobile devices, *presentation* may also be positioned further away from low interaction and known data relationships than currently displayed in the cube. Nevertheless, relative differences will remain, particularly between the extreme goals of presentation and exploration. The focus of this research is on visual exploration.

Visual exploration is a process in which abductive reasoning is followed. *Abduction* – a concept introduced by Charles Peirce about a century ago – is a process of reasoning to the best explanation. It starts without hypotheses about the data. The user explores (a representation of) data to prompt hypotheses about patterns, relationships, trends, etc. These hypotheses are evaluated to judge if they make sense or fit into a coherent pattern of cognitive representations. Often not all the data are explained, and explanations may be probabilistic in nature. Abduction may be followed by other types of reasoning: deduction and/or induction. For example, from an abductive suggestion deduction may build a theory and draw a prediction that can be tested. Observations during testing may inductively lead to adaptations in the theory (Thagard & Shelley, 1997; URL 2.1).

Gahegan and Brodaric (2002) describe a slightly different sequence to illustrate a *possible* path through their model of stages and relationships in geographic knowledge discovery. In their example, abductive reasoning may first lead to the building of concepts or categories (where induction plays a major role). These concepts or categories can be used to build models of the data (an activity comparable to building theories mentioned above). This is a mainly deductive process, which is usually followed by evaluation of the models' usefulness. In general, abduction is commonly applied in new environments or situations. We then try to match the current situation to what we have experienced in the past (Armstrong, 1998), which may or may not change our cognitive representations.

Vision can play an important role in abductive reasoning. Both internal (mental) and external (physical) images can be involved. People often form a mental picture or vision of something not actually present to the sight and some major scientific breakthroughs have been achieved after mentally visualizing potential solutions to a problem. In scientific visualization external images are used to trigger the abductive reasoning process. Use of visual aids reduces memory load and increases resources since perception is also involved in information processing. Human vision is powerful in information extraction from graphic representations such as maps or diagrams. Together with domain expertise, vision is assumed to be able to turn large, complex, heterogeneous data volumes into information and to integrate it with other information (Card et al., 1999). This is partly the case because such displays are somehow structured spatially (instead of alphanumerically), which facilitates recognition of patterns in the data, and partly because the visual perceptual system uses mechanisms that enable quick recognition of certain visual stimuli (Larkin & Simon, 1987). Bertin (1974) seems to have taken this characteristic of the visual system into account when he developed his theory of graphic semiology. There are, however, also some potential pitfalls with this approach. Abductive reasoning based on observations is not completely foolproof, and we are all familiar with ambiguous figures and visual illusion. It is good to be aware of those potential dangers during the reasoning process, to take the context in which patterns are seen into account and to use, if possible, feedback mechanisms to alter abductive inferences (Armstrong, 1998).

Visvalingam (1994) uses the term *visualisation* (with an *s*) for the mental process during which an internal representation is formed, consulted or adapted, while *visualization* (with a *z*) refers to the representation of data in the form of an image, understandable for the human perceptual system. For convenience, the most common term, i.e. *visualization*, is used in this thesis to cover both aspects.

2.3 Geovisualization: basic concepts

Geovisualization can be considered to mean 'making visible' in two ways. Firstly, it refers to making geodata visible by creating *graphic* or – from a human perspective – *external* representations in a particular context of use: visual exploration. As explained above, visual exploration is characterized by highly interactive, private use of representations of mainly unknown data (MacEachren, 1994c). The external representations are used to prompt thinking. Secondly, therefore, visualization can also be considered as the process of 'making visible' in terms of *cognitive* or *internal* representations (MacEachren, 1995). Maps play a dominant role in these processes.

Patterns in a map are important. Most definitions of the concept *pattern* in relation to geodata refer to spatial patterns, not to spatio-temporal ones (see, for example, Johnston, 1981; Mayhew & Penny, 1992). Blok et al. (1999) therefore define a pattern in a graphic representation of geodata as: (a constellation of) perceptual units (symbols, pixels) in space and/or in time that form(s) a figure or entity. Users of (carto)graphic representations from various backgrounds who want to explore geodata are generally interested in:

- the existence of patterns in the data, and the characteristics of those patterns;
- relationships and differences or correspondences in patterns;
- trends in pattern development.

Basic pattern-related tasks are *identification* and *comparison*. These tasks apply to the locational, thematic attribute and temporal components of geodata. Others have proposed more detailed classifications (e.g. Fabrikant, 2000; Ogao, 2002), but it seems that in many cases these tasks are not independent, or they can be hierarchically ordered. For example, *recognize* is similar to *identify* and *locate* can be considered as *identify* in space; *associate*, *relate* and *differentiate* seem to be functions of *compare*. Therefore, identification and comparison are here considered as *main* cognitive pattern-related tasks.

MacEachren (1995) makes a distinction in pattern (or feature)-related tasks at increasing levels of complexity:

- pattern identification (in a location and/or attribute space);
- pattern comparison (in a location and/or attribute space);
- Space–time analysis: involves the former tasks, but includes the temporal domain.

MacEachren uses the term *feature* instead of *pattern*, because he feels that patterns are usually considered to have a global extent, while features may either be local or global. In this report the term *pattern* refers to (constellations of) both local and global (individual) features.

Pattern comparison is more complex than identification since several patterns are involved in the task. In general, patterns can just be identified or first be identified and then compared. Alternatively, comparisons may trigger identification. Thus, pattern comparison is always accompanied, but not always preceded by identification. Pattern comparison in the spatio-temporal domain is also more complex than identification. Therefore, Blok et al. (1999) suggest to extend MacEachren's three-level classification to four levels, where the third and fourth levels refer to pattern identification and pattern comparison, respectively, in the spatio-temporal domain.

Patterns on the map interact with cognitive representations of the geographic environment. These cognitive representations encode spatial information that results from direct experience with the environment and from secondary sources of geoinformation, such as small-scale models like maps, but also films, stories by others, etc. (Lloyd, 1997). They are constructed from features like landmarks, roads, cities and land masses, the spatial relations between them and the relations to other, larger units. What cognitive representations actually look like is not yet fully clear. Basically, it is a network of connections established in a neural network, but beyond those connections is the meaning that spatial knowledge has for man (Lloyd, 2000). There is strong evidence that cognitive representations are not coherent, detailed picture-like representations of reality (Rensink, 2000). Several metaphors have been suggested. Tolman (1948) introduced the term *cognitive map*. To emphasize that it is not a single-scale map, but a collection of cognitive maps, perhaps at different scales and with gaps, Kuipers (1982) preferred *cognitive atlas*. There is evidence that the representations are organized by administrative areas or in other (functional) groupings, which are in many cases hierarchically ordered into larger encompassing units. The representations need not be visual in form (blind people also construct cognitive maps), but help us to understand the spatial part of our environment (Downs & Stea, 1977). They are simplified and contain distortions, which is evident from judgements of distances and directions (Mark et al., 1999). Tversky (1993) therefore prefers the term *cognitive collage* to emphasize that the representations are constructed and fragmented, and include multi-media. Mark et al. (1999, p. 756) summarize:

"... because different knowledge is retrieved for different tasks, knowledge representations of space are probably not best conceived of as coherent, unchanging wholes, but rather as conglomerations of information drawn from different sources and modalities and pulled together for a particular purpose."

This suggests that cognitive representations of the geographic environment are not fixed entities, and enables incorporation of spatial dynamics, which can be acquired from various sources. However, more research is required to obtain a clear picture of ways in which knowledge of the geographic environment is represented in the brain, how it is recalled, how people derive new knowledge, and about the roles of different sources of geoinformation (Mark et al., 1999).

In order to explain how patterns on maps interact with cognitive representations – or how vision interacts with cognition – a pattern identification model was introduced by MacEachren and Ganter (1990) and later extended by MacEachren (1995). A slightly simplified version of the more recent model is used here to explain the complex information processing cycle (in Figure 2.3 'propositional, image, event schemata' have been generalized to 'knowledge structures or schemata'; and 'propositional, image and procedural representations' to 'cognitive representations').

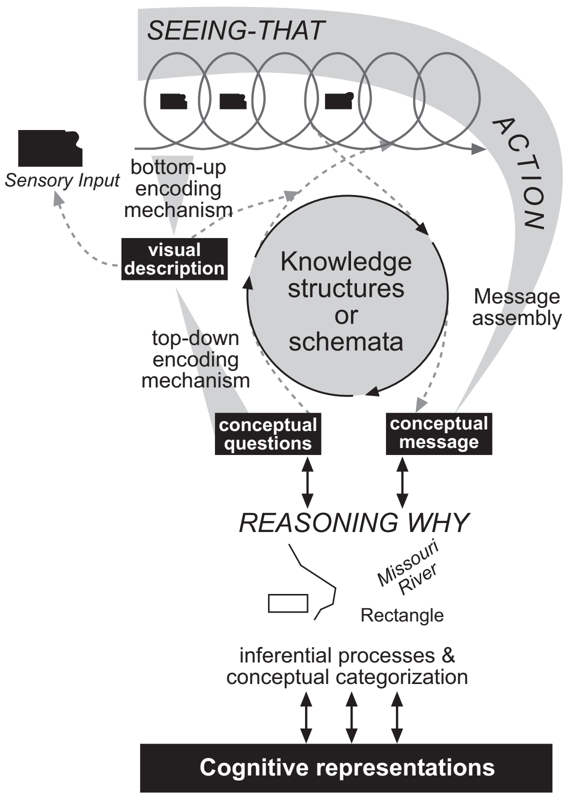

Figure 2.3 Pattern identification model (after MacEachren, 1995)

Vision and cognition together attempt to match sensory input to schemata. Schemata are rather abstract and general internal representations of arrangements of objects; they are available to mentally organize the input. They guide perception and also assist storage and retrieval of information (see also Lloyd, 2000). Availability of schemata is influenced by experience and knowledge stored in more specific cognitive representations. The matching process consists of a phase in which vision tries to recognize patterns: the *seeing that* phase. This gives a quick, perhaps partly unconscious, bottom-up reaction (a visual description). The usually correct reaction is then interrogated by more conceptual, top-down processes, the *reasoning why* phase, which is guided by prior knowledge and experience. It may result in acceptance or adaptation of the meaning derived in the *seeing that* phase. Next to their function in the *recognition* of patterns, vision and cognition can also act together to categorize sensory input and infer patterns that *become noticed*. This may lead to the development of new schemata and new or altered cognitive representations. Although information processing is described here in a sequential way, it is at least partly parallel and often cyclic: if no pattern match can be made, more fixations or iterations are required.

The model refers to the processes involved in the identification of patterns in the spatial domain, a task at the lowest level of complexity. Although not explicitly stated by MacEachren, it seems, however, that the mechanisms at work in pattern-related tasks for identification also play a role at higher levels of complexity. A difference might be that external representations are more frequently consulted during comparison than with identification. In addition, other schemata and cognitive representations might be involved in data processing.

Table 2.1 Main cognitive processes in exploratory tasks in different sources

Source	**Main cognitive processes**	
Abductive reasoning after Thagard & Shelley (1997)	Exploration to prompt hypotheses	Evaluation to judge if the hypotheses make sense
Research sequence model DiBiase (1990)	Exploration or generation of hypotheses	Confirmation or testing of hypotheses
Pattern identification model MacEachren & Ganter (1990) MacEachen (1995)	Seeing that: noticing patterns	Reasoning why: interrogating the meaning of the patterns
Geneplore model Finke et al. (1992)	Generation of 'pre-inventive structures' (mental representations)	Exploration and interpretation of the 'pre-inventive structures'

MacEachren (1995) indicates that the model, which is based on research by others but adapted to patterns on maps, provides a 'rough sketch' of the manner in which the interaction between graphic and cognitive representations might proceed. It is not necessarily the only or the best model. It is clear, however, that at least the two phases correspond to cognitive processes employed in exploratory tasks mentioned in other sources (see Table 2.1): starting with activities to derive meaning by constructing some kind of mental representation (e.g. a hypothesis, a pattern, an object), followed by interrogation of the representation to evaluate whether it makes sense. In addition, all sources emphasize that this whole creative process is not linear, but rather cyclic or iterative: after interrogation, a representation might be modified and regenerated until it is finally accepted or rejected. If it is rejected, the process may start again to derive other meaning.

The pattern identification model sheds light on the way in which graphic representations are likely to interact with cognitive representations. It means that the creative processes used to derive meaning and ultimately to construct knowledge can be enhanced by skilfully designed graphic representations. Design is certainly one of the contributing factors in successful application of visual exploration. Although confirmation is clearly necessary after exploration, it is common practice to refer to both processes by the single term (visual) exploration. The main goals of visual exploration are discovery, explanation, knowledge acquisition and decision-making. Slocum et al. (2001) list publications in which applications of *geovisualization* are described that appear to facilitate achievement of these goals. Although the list is not based on a complete literature analysis, it is important to note that little is known about whether users truly benefited from geovisualization, since user studies are lacking in almost all cases. Further research is clearly needed in this area.

Success in visual exploration depends on many factors. Among them are the goals of the domain expert and his or her motivation, ability and expertise. Next, the application domain and the phenomenon under investigation play a role, as well as the data, scale and time frame considered. The role of graphic representations has already been mentioned. Visual exploration seems to be facilitated by multiple views on the data. Several authors point to the advantage of including unusual views, or representations, that 'spark' the imagination (Finke et al., 1992; Keller & Keller, 1992; Peuquet & Kraak, 2002). It may yield unexpected discoveries because it helps to avoid conventional ways of thinking. Major characteristics of representations that facilitate patterns to 'emerge' and that contribute to creative discovery include novelty, ambiguity, emergence and incongruity as discussed by Finke et al. (1992); MacEachren (1995) describes Gestalt and other principles to guide vision, and Bertin (1974) explains how patterns emerge from '*images*'.

The availability of visualization tools – a last factor mentioned here – also influences the success of visual exploration. *Visualization tools* in an exploratory context can be defined as controls that enable a user to build and/or manipulate graphic representations of (geo)data in a computer environment. Interaction is an important key word here. Several authors have attempted to classify visualization tools (e.g. Keller & Keller, 1992; Kraak 1998; Gahegan, 1999; Crampton 2002). In the context of this research, a classification that refers to the pattern-related tasks, as mentioned above, would be desirable (see also MacEachren, 1995; Blok et al., 1999). Andrienko et al. (2003) take a broader (and more complicated) view. They try to relate all kinds of exploratory representation methods and techniques to exploratory tasks. Since the interest here is confined to animation as an exploratory representation method, a narrower view, focusing on types of interaction linked to animation, would be more suitable.

Table 2.2 shows an attempt to approach the classification of tools by first giving a general description of user activities that support the various pattern-related tasks, followed by related controls at an operational level. Tools at an operational level may change with technological advancements; the higher-level description is likely to be more stable.

Table 2.2 Tools to support main tasks with graphic representations of geodata: some examples

Pattern-related tasks	**General description of user activities to support the tasks** (*examples*)	**Tools to support the tasks at an operational level** (*examples*)
To identify locational and attribute patterns	- choose or generate alternative views of the same spatial data, switch between them, link them - change emphasis from local to global spatial pattern processing and vice versa	- choice of spatial data representations - geographic and attribute brushing - zooming, scaling - spatial filtering, highlighting - dynamic classification
To compare locational and attribute patterns	- select multiple subsets of spatial data and generate simultaneous displays - transform spatial data to make them comparable	- multiple-window display - overlay - zooming, scaling - spatial filtering, highlighting - dynamic classification
To identify patterns in the spatio-temporal domain	- choose or generate alternative views on spatio-temporal data - control the display of patterns in display time - switch between short- and long-term spatio-temporal pattern processing	- choice of spatio-temporal data representations - geographic, attribute and temporal brushing - stop and rehearse the display, control display speed and order - interactive temporal legends - change spatial and temporal scale or resolution - spatio-temporal filtering, highlighting - dynamic classification
To compare patterns in the spatio-temporal domain	- select multiple subsets of spatio-temporal data and generate simultaneous displays - control the display of patterns in display time - synchronize spatio-temporal data representations - transform spatio-temporal data sets to make them comparable	- multiple window display - stop and rehearse the display, control display speed and order - interactive temporal legends - tuning - change spatial and temporal scale or resolution - spatio-temporal filtering, highlighting - dynamic classification

A problem in such a pattern-related classification is that although some tools may be specific for one task (e.g. synchronization), many tools can be applied for several tasks. Furthermore, classification depends on the type of environment in which they are used. For example, in a fully immersive virtual environment or in an augmented reality application, other types of interaction can certainly be added. Therefore, Table 2.2 shows just some representative examples, and no attempt is made to propose a comprehensive classification of pattern-related visualization tools.

The question of what tools are *appropriate* for exploration of geospatial data is not fully answered yet. A number of tools have been suggested (e.g. Andrienko & Andrienko, 1999; DiBiase et al., 1992; Dykes, 1997; Kraak et al, 1997; Fuhrmann, 2002; Hedley, 2003; Harrower et al., 2000; Monmonier, 1990, 1992b). A growing number of studies include user evaluations of tools, showing that the typical supply-driven way of thinking, by which geodata representations and tools have been offered in the past, evolves into a more demand-driven or mixed approach. This change corresponds with a general trend in our digitally and technologically oriented society: a functional approach with attention to users and to the usability of all kinds of products, ranging from domestic appliances, forms and web sites for a general audience to highly specific application programmes. Finding out *why* things work or don't work is clearly important. It explains the growing attention being paid – also in cartography – to cognition in usability research.

Answers to the question about the effectiveness of geovisualization tools can partly be expected from research on cognitive questions like *when, why* and *how* maps are actually used (e.g. van Elzakker, 2004). Another fruitful approach seems to be to investigate how man creates and utilizes (internal and external) representation of geospatial data *and* to apply a user-centred approach in tool development (see also Slocum et al. (2001) for a dual approach). User-centred development of products forms the core of *usability engineering*. Usability has been defined as "the effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments" (ISO 9241-11; after Dix et al., 1998; see also URL 2.2). Key elements of usability engineering are: knowing the users at an early stage, iterative product design and product evaluation with representative users (e.g. Nielsen, 1993; Dix et al., 1998; Shneiderman, 1997).

To fully explain how reasoning processes are influenced by external graphical representations, a multidisciplinary approach that covers all aspects of visual information processing, including neurophysiological and neuropsychological sensory and perceptual aspects, would ideally be required. Within the cartographic discipline, MacEachren has attempted to include many aspects in *How maps work* (1995). However, trying to unravel cognitive processes and to discover patterns in the reasoning and use of graphic representations and associated tools in the evaluation phase of user-centred development may already lead to useful answers to the question of why things work or do not work in geovisualization, although it would be an illusion to think that the whole process of transformation and passing on of sensory input can be fully explained in that way.

2. 4 Geovisualization and computational approaches

GISs and image processing software are currently the most commonly used environments to handle geodata. They offer a variety of tools, among which are possibilities to visualize the data and interact with the resulting maps or images and the data behind these representations. Sometimes there is even an option to animate data (e.g. a time series), but controls are generally limited to a simple viewing option. Current systems, however, have some weaknesses. Knowledge in the geosciences is progressively constructed and refined through a number of processing and interpretative stages (MacEachren et al., 1999; Gahegan & Brodaric, 2002). It usually begins with exploration, which (as described above) is a creative process that starts without hypotheses about the data to discover emergent patterns. Openshaw et al. (1994) indicate that visualization in general, and animation in particular, offers a creative way to answer vague questions like: *What is going on? Is there anything interesting? What is happening: when and where? Are there any discernible patterns?* Current GISs and image processing systems, however, are more oriented towards supporting geodata *analysis* than *exploration*. Analysis is the (usually subsequent) phase where confirmation is sought for hypotheses or answers are sought to predefined queries in order to develop theories about the data, build models or support spatial decisions (Langran, 1992; Yuan, 1996).

Another weakness of current systems used in geosciences is the way in which temporal data can be used. Time is essential to understand processes. Applications like monitoring require temporal data, but current GIS data models do not sufficiently support analysis of the temporal dimension, since temporal queries are limited to relationships like 'less than' or 'equal to' a given time (Peuquet, 2002). A lot of research related to temporal GIS exists. Proposed are, for instance, temporal data models and Data Base Management Systems (DBMSs), a change description language (Hornsby & Egenhofer, 2000), extended query languages and prototypes, like Apoala (see Peuquet, 2002 for an overview). Nevertheless, temporal GISs and the use of temporal databases are not common practice yet, but some dedicated software is available (e.g. WinDisp for time series analysis of imagery, (URL 2.3)).

Visualization methods and tools can be employed to support knowledge discovery in geodata (see also Blok, 1996). Graphical representations (of temporal and non-temporal data) offer compact stimulus spaces in which large numbers of variables can be represented together. Predetermined queries are not required, as the whole range can be freely explored in the visual domain (after Gahegan, 1999). This enables a quick qualitative impression. Based on pattern recognition capabilities, rich cognitive structures and mental models, patterns may emerge and hypotheses may be prompted. Visual support in knowledge discovery is not confined to exploration; it also facilitates subsequent stages in the process (see Gahegan & Brodaric, 2002; Gahegan, 2004). However, visualization alone is often not enough: it relies on impressions of the data, created in the mind of the observer (MacEachren & Kraak, 2001). These impressions might be right but might, as indicated before, also include illusions and probably need to be tested anyway. On the other hand, fully relying on computational approaches, for example by automating the whole process, is also difficult. The human observer has to play an important role in imbuing results with meaning, building knowledge structures and decision-making, even with extended computational facilities to better support exploration (e.g. data mining and pattern recognition techniques). The best approach, therefore, seems to alternate (computer-supported) visual, qualitative approaches with man-controlled computational methods to enable statistical and other quantitative analyses of the data. The real power is in the integration of approaches. This is also the current trend in systems development, which is at least partly caused by the need to work more and more with large, heterogeneous and complex data sets. Rhyne's (2000) forecast of a merger of GIS and geovisualization systems, including the use of software agents and data mining tools in high-speed networking and mobile environments in 2–5 years' time has not fully materialized yet, but steps towards a better integration have definitively been taken (e.g. CommonGIS (URL 2.4); GeoVISTA *Studio* (URL 2.5)). Gahegan (2004) is among the researchers who plead for (and apply) an open-system approach to ease integration (see also Takatsuka & Gahegan, 2002). Tools developed in closed systems are not portable, so they cannot easily be modified, shared or integrated. Developments initiated or supported by the Open Geospatial Consortium (URL 2.6) make clear that open approaches are becoming the state of the art.

2.5 Animated visualization of geodata

2.5.1 Definition and dimensions

This research focuses on visual exploration of animated representations of geodata for monitoring. Animated maps are also called *dynamic* maps. In some cases this is done to emphasize their difference from static maps (e.g. Kraak & Brown, 2000), but the term 'dynamic map' has a broader meaning as well, for example, a map that changes continuously because of user interaction, with or without animated contents (e.g. Slocum et al., 2001), or a map that is generated and updated 'on-the-fly'. To avoid confusion, preference is here given to the terms *animated map* or *animated representation*.

An *animated* map represents the characteristics of geodata in a map that changes dynamically or in a sequence of static maps, which, if shown in a quick succession, will give the viewer an illusion of change. The limited temporal resolution of the human visual system is responsible for this impression of continuity (McKee & Watamaniuk, 1994). In addition to two or three spatial dimensions, a temporal dimension is used in which the changes can be observed. An obvious choice is to use the spatial dimensions for geographic space, and the temporal dimension to establish a direct link between changes in world time and in display time (Kraak & MacEachren, 1994). World time is the time at which changes take place in the real world, and display time refers to the time during which an animation is running and can be viewed. However, in order to discover patterns, relationships, trends, etc., in temporal or non-temporal data, it can also be helpful to make alternative use of the representation dimensions, for example, by displaying geodata in *attribute space* instead of geographic space. Some examples are cartograms (Dorling, 1992) or bivariate scatter plots (Monmonier, 1990). Alternatives for a time-based order in the temporal dimension are *attribute* order, for instance through the sequential representation of different classes of attribute values (e.g. DiBiase et al., 1992; Slocum & Egbert, 1993), or *geographic* order through offering sequential viewpoints, for example in a fly-by of a 3-D scene (Dransch, 1997). Based on the ways in which this temporal dimension can be used, several classifications of animated representations of geodata have been proposed (e.g. Dransch, 1997; Kraak & Klomp, 1996). In an interactive environment, however, these classifications may become less relevant if options are provided to manipulate the use of the different dimensions, for example to change the chronological sequence of temporal data into an attribute sequence based on values.

2.5.2. Brief history

Animated cartoons have been produced since the early 1900s, but Thrower was in 1959 the first geographer to investigate the possibilities of animated representations of geographic data. A few years later he also reviewed a number of short films that had been produced since the 1930s and contained cartographic sequences. The 1960s mark the start of what Kraak & Ormeling (2003) call the first wave in cartographic animation from a technical point of view: a manual, cartoon-like approach, with animations stored on video or film. Ideas to produce computer animations of geographic data were first expressed by Tobler in the 1960s. Moellering started investigations in the 1970s and produced the first 3-D animations of geographic data in the 1980s. The first computer animations (from about 1980) belong to Kraak & Ormeling's (2003) second wave. Although the 'early adopters' were positive about the prospects, there were few other researchers involved until the 1990s. Campbell & Egbert (1990) produced an overview of the early developments.

Slocum (1999) described more recent applications of animation. Continued interest since the 1990s has mainly been in the USA (e.g. MacEachren, DiBiase and colleagues at Penn State; Monmonnier; Slocum; Peterson), in the UK (e.g. Dykes; Dorling), the Netherlands (Kraak; Ogao), Greece (Koussoulakou) and Germany (Dransch; Andrienko and colleagues). Kraak & Ormeling's (2003) third and current wave is created and enabled by GIS technology. Virtual and web technology can be added here.

Research trends in the application of animation have been described by Peterson (1995), Ormeling (1996) and Dransch (1997). A research agenda has been prepared by the ICA commission on Visualization and Virtual Environments; it was published as a special issue of the journal *Cartography and Geographic Information Science* (see e.g. Slocum et al., 2001).

2.5.3 Seeing change

One of the reasons for the focus of this research on animation is given in Chapter 1: in their literature review on the effectiveness of static and animated graphics to support learning, Morrison et al. (2000) concluded that *if* an animation is more effective, it is so because it includes information about the micro steps between major changes. For monitoring, this seems to be an asset since even minor changes can be relevant. However, an animation can also overload or bombard the user with rapid sequences of changes that need to be tracked and compared (Monmonier, 1992b). The human visual system has limited bandwidth, images fade quickly and it needs effort to maintain them (Kosslyn & Osherson, 1995; Gahegan, 1999). But, even if one tries to maintain the images, changes may go unnoticed (Rensink, 2002). Two general visual perception phenomena are responsible for this and they are also applicable to changing graphical representations: change blindness and inattentional blindness.

Change blindness occurs when one fails to detect change in the visual field (Rensink et al., 1997; Simons & Levin, 1997). This may happen when view is interrupted (e.g. during eye movements or other viewing interruptions, such as the temporary masking of a target) or when extremely slow changes occur. Various demonstrations of materials used in change blindness experiments can be viewed at URL 2.7, 2.8 and 2.9. *Inattentional blindness* refers to the inability to detect unexpected changes – even if they are in the centre of the visual field – when observers are actively engaged in a task, focusing on particular objects. Changes to other objects or parts of a scene go unnoticed, but if attention is not diverted, these changes are easily seen. Inattentional blindness, a term introduced by Mack and Rock in 1998 (Mack & Rock, 1999), nowadays receives much attention in psychological research. Many experiments have been conducted, among others by Simons and his colleagues. One famous example is an experiment in which a video tape of two basketball teams was used; one wearing white and the other one black shirts. Test subjects had to count how many times the ball was passed between members of one team and to ignore the other team. During the play, a person in a gorilla suit walked into the scene, stopped in the centre, thumped his chest and walked off. About 25% of the subjects did not notice the gorilla. In other experiments, about the same or higher percentages were reached (Simons & Chabris, 1999). The 'gorilla movie' and other examples causing inattentional blindness can be found at URL 2.8. Change blindness and inattentional blindness research have demonstrated convincingly that human perception (here considered as explicit conscious awareness) of change is far from complete. We often do not see changes, even if they are big, made repeatedly or anticipated by the observer (Rensink et al., 1997).

How do we see changes? It all starts with vision. An image received by the lens of the eye is projected on the retina, a light-sensitive layer of interconnected nerve cells at the back of the eyeball. In addition to photoreceptors (rods and cones), the retina contains (amongst other elements) two types of specialized nerve or ganglion cells: X cells concentrated in a small centrally located area called fovea are specialized in early detection of pattern; the more widely distributed Y cells are responsible for motion detection (Gregory, 1998; Dix et al., 1998). There are various specialized motion detector cells, such as *directionally* selective motion detector cells, originally discovered in the late 1950s/1960s by Hubel & Wiesel, who mainly worked with cats. Later, other researchers found similar cells in primate and human brains (Smith & Snowden, 1994, Nakayama et al., 1995).

The nerve cells in the retina send electrical pulses to the brain for further processing. Usually, a distinction is made between low-level and high-level processes (see e.g. Smith and Snowden, 1994; Tse et al., 1998; Rensink, 2002). Any change in the visual field causes motion: a local and temporal variation in intensity or colour energy, among other factors. *Low-level* processes are involved in the detection of motion: the visual field is scanned by an array of motion detectors sensitive to a number of spatio-temporal variations of stimuli (Cavanagh & Mather, 1989; Cavanagh, 1993). Processes at this level are passive, i.e. without conscious control. It is possible that there are two low-level, energy-based motion detection pathways. A first-order system is sensitive to variations in the luminance (brightness) and wavelength (hue) of stimuli, all other variations in properties (e.g. contrast, texture and direction) are derived from luminance or wavelength by a second-order system. Both systems seem to be based on filtering to reveal motion, defined in different ways (Smith, 1994). Several models have been developed for both types of systems (for an overview, see Smith & Snowden, 1994), but many questions about low-level processes remain unanswered. There is evidence, however, that the detectors operate locally and in parallel for all points in the image.

The motion detectors do not enable us to group motion at points into (what the Gestalt psychologists call) 'figures': objects and spatio-temporal patterns. They also do not enable us to perceive change (Mack & Rock, 1999). Rensink (2002) describes the difference between motion detection and the perception of change. *Motion* (variation pertaining to location) is detected locally and is always visible when there is a change. Perception of *change* (transformation or modification of a single structure over time) is a higher-level process because it requires the observer to see a structure and its variations, and to maintain spatio-temporal continuity. Both the detection of change and the perception of spatio-temporal patterns are important in monitoring.

In order to see patterns and compare object states and locations over time, attention is required. Rensink (2000) calls this *focused* attention. *Attention* can generally be defined as a process that brings a stimulus into consciousness (Mack & Rock, 1999) or, more specifically, as enhanced processing over a limited subset of sensory information that can be selected for monitoring or tracking over time (Tse, 2004). Attention seems to temporarily bind sequences of spatially indexed points to objects that can be tracked in space and time. Without attention, the contents of memory will be overwritten or displaced, but when attention is focused on it, the object can be further processed. This processing, underlying perceptual constancy, is a *higher-level* interpretation of motion based on low-level processes. It is active, serial and therefore less rapid than low-level parallel processing (see e.g. Smith & Snowden, 1994; Rensink et al., 1997; Tse et al., 1998; Mack & Rock, 1999; Tse, 2004).

Rensink's *coherence theory* attempts to integrate low- and high-level processes (Rensink, 2000; 2002). It comprises three stages:

- Early processing: described as low-level processing above. It results in *proto-objects* that have limited coherence in space and time. In the absence of focused attention, proto-objects will be replaced by any new stimuli at their location. The output of this phase can be seen as volatile, quick-and-dirty local interpretations (proto-objects) that may not always be correct.

- Focused attention: attention acts as '… *a hand that grasps a small number of proto-objects from this constantly regenerated flux'* (Rensink, 2000, p. 20). While held, they are part of a *coherence field*, which represents an individual object with bi-directional links to the proto-objects. Information about the properties of the proto-objects is transmitted up the links, and information about the object, making the properties coherent in space and time because of focused attention, is transmitted down. Coherence means establishing consistency and interconnections so that several proto-objects belong to the same spatio-temporal entity, thus enabling perception of larger-scale objects/patterns and of change.
- Release of focused attention: when the feedback loop stops, coherence is no longer maintained and the object representation dissolves again into volatile proto-objects.

Coherence fields have a similar function as the *object files* described by Lloyd (2000) and first mentioned by Kahneman & Treisman in 1984. Object files are temporary episodic internal representations of objects. If attention is focused on a changing object, the current properties are noticed and one has to decide whether the change is related to an existing object file or whether a new object file has to be opened. The perceptual system can usually maintain only one single object file at a time. The decision is based on correspondence, in which spatial and temporal proximity are important. If an existing object file is opened, the recent history is reviewed. Reviewing maintains the continuity by relating current to previous states.

A key point in all theories is that attention can only be directed to a small number of items at any one time. Although it is possible to *detect* change by attending to several objects (4–5) at a time, perceiving the *identity* of a change is better if one focuses on a single object (Smith & Snowden, 1994; Rensink, 2002). This is an efficient way of our visual system to deal with the constant flux of stimuli. For most tasks in everyday life it is enough to stabilize only one or a few objects at a time, as long as the refresh rate is fast enough. We thus seem to have a sparse, 'just-in-time' system that provides the right object at the right moment instead of internal representations that are detailed and coherent everywhere (Rensink, 2002). The internal representation mentioned here is an immediate product of dynamic sensory input that is constructed and temporarily kept in working memory. The schemata and cognitive representations (e.g. the cognitive collage) mentioned in Section 2.3, on the other hand, refer to more permanently stored structures in long-term memory

What directs attention (and thus the perception of change) then? First of all, low-level motion signals, caused by any change; if they exceed background signals, or noise, attention is drawn to their location (Klein et al., 1992, cited by for example Smith, 1994; Rensink et al., 1997). Changes to moving objects seem easier to detect than changes to stationary objects (Rensink et al., 1997). Attention can also be directed by the gist (meaning) and the layout (spatial arrangement) of a scene (Figure 2.4). Rensink's triadic architecture consists of three interacting systems. Volatile proto-objects are formed in the early system. Attention generates a coherence field in which a small number of proto-objects are stabilized as a spatio-temporal entity in the object system. Gist and layout are rapid and rough estimates of a scene in which details are neglected, based on properties obtained from the constantly regenerating set of proto-objects. These rough estimates may be used to verify whether the original impression was correct and to gather additional detail by directing attention to objects that are most important in a particular use context. As long as the gist does not alter, efforts to discover changes are not efficient, and therefore unlikely (see e.g. Simons & Levin, 1997; Rensink 2000). Finally, attention may be directed by the higher-level knowledge, experience and ability of observers to detect change, their intentions, interests, expectations or the task at hand (Rensink et al., 1997; Tse, 2004). Known objects may be rapidly identified (Mack & Rock, 1999) and changes to parts of a scene that are somehow significant or of interest are usually quickly perceived.

Rensink indicates that his coherence theory and ideas of the direction of attention by gist and layout are plausible explanations, but further testing is still needed and many questions still remain. Mack & Rock (1999) also indicate that many questions about change perception remain to be answered. Nevertheless, there is broad agreement about the importance of attention in higher-level processes (see above), for example to see change, and about the fact that attention is limited to 4–5 items (see e.g. Cavanagh & Mather, 1989; Smith & Snowden, 1994, Mack & Rock, 1999; Tse, 2004).

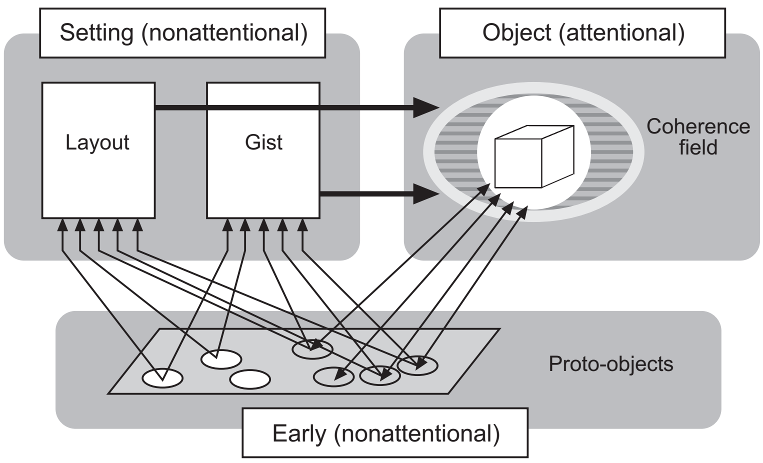

Figure 2.4 Model of visual information processing: Rensink's triadic architecture (after Rensink, 2000, 2002)

Research efforts summarized here help us to explain why phenomena like change blindness and inattentional blindness occur frequently. These problems can partly be attributed to low-level and partly to higher-level processes. If change perception starts with motion energy signals and attention can only be directed to a few objects, it will first of all be difficult to perceive change if the motion signals are very weak (e.g. too slow). Weak signals may be below the thresholds for motion energy detectors or may not be distinguishable from background signals and noise. Secondly, local motion signals may also be masked by saccades or other interruptions. Alternatively, attention may be overwhelmed if local signals are swamped by global signals when changes are occuring simultaneously all over the visual field. In all these cases, change blindness may occur because a slow item-by-item scan of the whole image will be needed to detect change (Rensink et al., 1997; Rensink, 2002; Tse, 2004). Inattentional blindness can be explained by the fact that only a few changes can be given focused attention at any one time. The likelihood of noticing unexpected objects if human beings are actively engaged in a task with other objects seems to be related to the similarity to those other objects and to depend on the difficulty of the task (Simons & Chabris, 1999).

Although there are limitations to our ability to perceive change, there seem to be ways to (partially) overcome some of the problems mentioned above. I am not aware of any psychological study in which observers had control over a scene representation, but if one can interact with an animated representation – of geodata, for example – the perception of change can be facilitated. Some examples of useful controls are options to stop and rewind, enabling the user to view individual images and to review the sequence. Other examples are options to control the display speed (e.g. to detect very slow changes) and zooming (to better focus on local instead of global changes), options to make sub-selections to reduce the content and to facilitate focused attention, etc. When designing animated representations, problems caused by visually overloading users have to be taken into account, for example by facilitating options to focus attention on specific aspects.

An additional foundation for the focus on (interactive) animation in this research can be found in the fact that animation is suitable for the representation of processes and in the finding that users are attracted to outliers in an animated representation of geodata (Ogao, 2002). Peuquet (2002) mentions that the possibility to note abrupt versus gradual change is important for many applications. Animation certainly enables this kind of observation. And, finally, also Peterson's (1995, p. 48) statement that '*The most important aspect of animation is that it depicts something that would not be evident if the frames were viewed individually*' stimulates even more. All these aspects seem to be relevant for monitoring.

2.6 Summary

The roles of (geo)visualization in general, and of animation in particular, to visually extract information about geospatial dynamics are discussed in this chapter. First, the developments that have led to the current attention being paid to exploration and geovisualization are described. These developments caused a transition from a focus on static, view-only, single optimal presentations to interactive, dynamic, personalized, multiple (dimensional) views that facilitate visual exploration. Visual exploration in general is described as a process that uses abductive reasoning: reasoning to the best explanation that starts without hypotheses, then generates and finally evaluates them. Advantages and potential dangers of the use of vision to gain knowledge are also briefly discussed.

Next, basic concepts of geovisualization are highlighted. Maps are important here, particularly patterns on maps. Identification and comparison are introduced as main pattern-related tasks that can be executed at different levels of complexity. Since patterns on the map interact with cognitive representations, questions that come to mind like *What is a cognitive representation? What does it look like?* and *How do patterns on a map interact with cognitive representations?* are discussed. A pattern identification model was introduced that tries to explain the interaction between graphical and cognitive representations. It resembles other abductive models.

Success in geovisualization depends on many factors, including tools. Classification of tools is discussed. The question as to what makes tools appropriate cannot be fully answered yet, but some possible ways to get more clarity are described. A description of the advantages and weaknesses of geovisualization versus analytical, computational approaches leads to the conclusion that the approaches are complementary, and can best be integrated, preferably in an open environment.

Finally, the chapter narrows down to animated representations. After a definition and brief history, the reasons to focus on animation in this study are explained. Potential problems that may limit their use, such as phenomena like change blindness and inattentional blindness, are also discussed. These phenomena raise the question of how changes are seen. A coherence theory has been described as one attempt to integrate those processes. The importance of *attention* in seeing change is highlighted. Discussion of those processes helps us to understand why phenomena like change blindness and inattentional blindness occur. It can be concluded that there are definitely limitations to our ability to see change, but there also seem to be ways to partly overcome those limitations. Interaction with the animated representation is considered important in this respect.

3 MONITORING AND GEOSPATIAL DYNAMICS EMPHASIS ON NDVI DATA AS A CASE STUDY

3.1 Introduction

The point of view taken in Chapter 2 is that visual exploration of geospatial data can fulfil a complementary role with respect to a more analytically oriented computational approach. Animated representations, in particular, seem to be promising for visual exploration of geospatial dynamics, although psychological research shows that 'seeing change' in dynamic representations has its limitations as well. Monitoring is about change, but in what kind of changes are experts in monitoring interested? What are the underlying monitoring goals, objectives and questions? And what aspects of the changes of interest can be visually perceived? These are some of the questions that I will address in this chapter. Section 3.2 starts with a description of some general characteristics of monitoring and then narrows down to aspects that are related to vegetation monitoring with NDVI data (Normalized Difference Vegetation Index data, the case study used in this research). Next, Section 3.3 describes the overall goal, main objectives and generic user questions of monitoring experts. Section 3.4 reports on characteristics of dynamic phenomena that can be *visually* explored. A framework of concepts will be proposed to describe a variety of phenomena, mainly in the physical environment. Finally, Section 3.5 provides a brief summary.

3.2 Monitoring of geodata

3.2.1 General characteristics

Almost all geographic phenomena are dynamic. Some dynamics are caused by variation in natural circumstances (e.g. atmospheric conditions, pests and diseases, endogenous activities in the earth crust), but many changes are at least partly man-induced (e.g. erosion, deforestation, forest fires). Since some changes can really affect our lives and our environment, there is a need to monitor these changes. A general definition of *monitoring* is: to watch, to track, usually for a specific purpose. In the context of geodata, it can be described as: keeping track of changes that are directly or indirectly visible in the landscape to gain insights into the behaviour of dynamic phenomena. Monitoring enables us to anticipate and to react to change and to investigate the effects of our actions on the surface of the earth (Walker, 1989). *Change* indicates ongoing developments. In the current context, change is defined as: variations in the spatial and/or thematic characteristics of geographic phenomena over time.

Remotely sensed data play an important role in many monitoring applications, and are particularly relevant for the study of phenomena in developing countries and otherwise ‘data-poor’ environments. Publications in journals like *Environmental Monitoring and Assessment* and *International Journal of Remote Sensing* show that there is a broad variety of application areas ranging from, for example, monitoring of atmospheric processes, plate shifting and ground deformation, hydrological and ecological phenomena, desertification, crop and rangeland dynamics through to risk assessment and disaster management (focusing, for example, on earthquakes, volcanic eruptions, landslides, hurricanes, floods, wildfires and droughts). In terms of data requirements, the spectral, spatial and temporal scopes – as well as the update needs of these applications – may vary. In the case of disasters, for example, frequent updates are often required to estimate the speed or evolution of the event, the area affected, the damage, etc. Recent developments are a better pointability of sensors (allowing faster revisits), and dedicated satellite systems are planned to quickly obtain information for hazard and disaster applications (e.g. the ASTER sensor onboard the Terra spacecraft is an on-demand system (URL 3.1); see also the overview that is provided by the University of Freiburg (URL 3.2)of activities undertaken with respect to vegetation fires). The need for and type of ancillary data to support exploration and analysis also varies among applications, from other satellite data (e.g. a colour composite of the area of interest, cloud or estimated rainfall images), framework data or topographic maps and DEMs, to field and other data or maps (earthquake or hurricane history, details about weather and evapotranspiration, crop tables, data to calibrate classifications, socio-economic data, etc.).

Satellite data are often pre-processed by the supplier before they are made available to users. Users can import the data into image processing and GIS environments or use dedicated software for time series analysis and integration with ancillary data. In most cases, one works with static images, although there may be a film mode available in the application software, but interaction possibilities in this mode are limited. Users commonly start with visual inspection to determine the fitness for use (e.g. completeness, cloud contamination), then make corrections and georeference the data if it has not been done by the supplier. For exploration and analysis purposes, the data are further processed, for example segmented or stratified (to delineate objects or relatively homogeneous areas), statistically analysed, classified and sometimes mapped during, or even before, an attempt is made to detect and interpret changes (de Bie, 2002; Groten & Ilboudo, 1996). In most cases, data analysis is based on a limited number of snapshots.

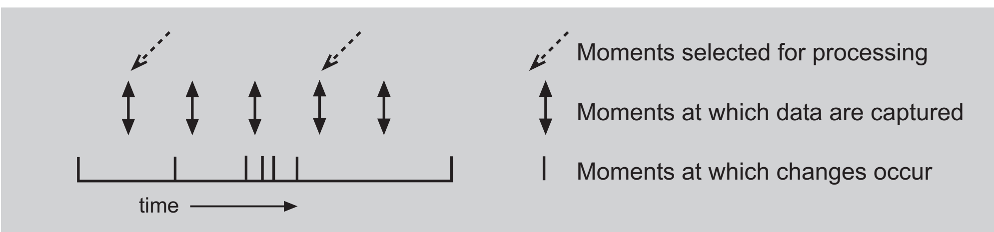

Figure 3.1 Data acquisition and selection of snapshots for further analysis influence how well spatial dynamics are rendered

How well spatial dynamics are actually rendered depends, among other things, on factors related to data acquisition, such as the period considered and the temporal resolution within that period, and on spatial extent and resolution – because seeing patterns, trends, cycles and so on are related to these aspects (MacEachren, 1995). Data acquisition decisions are usually not based on the occurrence of change but on other (e.g. economic) grounds (see Figure 3.1), although increased temporal resolution, pointability of sensors and systems dedicated to disaster management help to improve change detection.

The results of interpretations of the data are commonly graphically represented in change maps, anomaly maps (showing the deviations from long-term average values) or multi-temporal colour composites. This approach emphasizes spatial reasoning, while the common practice to also select some pixels or objects and view their values over time in a graph at higher temporal frequencies – if available – emphasizes temporal reasoning. Combined spatio-temporal reasoning (Figure 3.2), taking the behaviour of a phenomenon in its spatial and temporal context into account, will be easier in the near future in a TGIS (Temporal GIS) environment (see Section 2.4). Animated representation might also facilitate spatio-temporal reasoning, particularly when it is linked to a GIS or image processing environment, because in a running animation one can actually 'see', for example, whether an area with low NDVI values shrinks or expands, in which direction it develops, when the area starts to break up into smaller parts, how fast the process is and how often it is repeated over time.

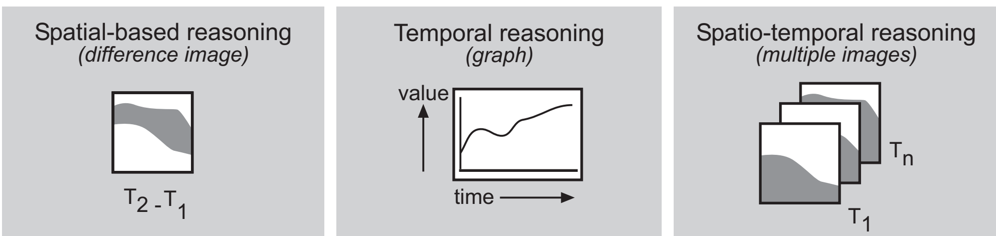

Figure 3.2 Types of reasoning with dynamic geodata

3.2.2 Monitoring with NDVI data

Many satellites carry sensors that detect radiation reflected from the surface of the earth in the visible (0.4–0.7 µm) and near-infrared (NIR, 0.7–1.3 µm) bands of the electromagnetic spectrum. These radiation data can be used to quantify the amount of green vegetation on the surface by a vegetation index. Such quantification is based on the principle that pigment in the leaves of green plants (chlorophyll) strongly absorbs visible light for photosynthesis. The more leaves and the higher the level of photosynthetic activity in a vegetation, the lower the values detected in the visible bands. Unhealthy or sparse vegetation reflects more visible light. At the same time, the cell structure of leaves is reflected in the NIR bands: strongly for healthy vegetation and weakly for unhealthy and sparse vegetation. The proportions of radiation in the RED and NIR bands can be expressed in a vegetation index, sometimes also referred to as a 'green-ness' index. Various indices exist. To some extent, it matters which one has been selected (see, for example, van der Meer et al., 2001) but a commonly used one is the NDVI (Normalized Difference Vegetation Index). The index is calculated as:

$$NDVI = (NIR - RED) / (NIR + RED).$$

To avoid that overall brightness of sunlight or shadow strongly influence the difference between the NIR and RED values, the index is normalized by dividing the difference by the sum, which represents the total brightness (intensity) of the image. Theoretically, values are between –1 and 1, but actually the range is smaller, from slightly negative (excluding noise) to 0.8–0.9. Values below zero represent water and noise, while very low positive values correspond to barren areas (snow, ice, rock or soil). Different soils have different spectral properties, which may influence the reflectance in areas with sparse vegetation. The highest NDVI values represent lush vegetation and dense forest, but in large highly vegetated areas, such as tropical rainforests, values tend to approach the saturation level. Other distortions may be caused by cloud contamination, water vapour, aerosols (tiny particles suspended in the air), glare from the sun, or temporal malfunctioning of the sensors. NDVI values may vary considerably, and daily images are rather patchy at best. To reduce the effects of clouds and other disturbances in the atmosphere in single-date images, the best daily indices (maximum NDVI per pixel) are usually selected for a composite image of, for example, 8, 10, 16 or 30 days (Groten & Immerzeel, 1999; URL 3.3). Thus, although the temporal resolution is important for monitoring, experts usually do not use single-date images.

NDVI data are widely used for the monitoring of vegetation dynamics. It started with NOAA or Landsat data. NOAA-AVHRR (Advanced Very High Resolution Radiometer) images with a spatial resolution of 1.1 × 1.1 km are as NDVI product usually reduced to approximately 8 × 8 km (URL 3.4). Composites are freely downloadable from the Internet. Landsat data have been around since the 1970s, but they are not free. The most recent Landsat 7 satellite provides TM (Thematic Mapper) and more expensive ETM+ (Enhanced Thematic Mapper Plus) data. Both have more detail than NOAA (30 m resolution; (URL 3.5)). SPOT VEGETATION data (available since 1998) have a spatial resolution of 1 km (URL 3.6); geometrically well-corrected 10-day composites are freely downloadable (URL 3.7). The wide field-of-view sensor does not have the drawback of variable pixel sizes towards the edge of an image (Han et al., 2004). On board the Terra spacecraft of NASA's Earth Observing System Agency, launched in 1999, are the MODIS and the ASTER sensors. MODIS (Moderate Resolution Imaging Spectrometer) offers free but huge files with a spatial resolution up to 250 m. The Enhanced Vegetation Index (EVI) applied corrects for more distortions than the NDVI does in backscatter from soil and aerosols and it is not as early saturated as NDVI in areas with high values (URL 3.8). ASTER (Advanced Spaceborn Thermal Emission and Reflection Radiometer) data offer a spatial resolution of 15 m; it is an on-demand system, but already the collected data are relatively cheap (URL 3.1).

There are many applications of NDVI data. One example is monitoring of vegetation cover. Vegetation is a primary indicator of land degradation. Land degradation is often the result of pressure on resources, for example because population growth leads to an extension of activities into marginal areas. Together with other events, including flooding, droughts, pests and diseases, it endangers food security. Timely information and, if necessary, early warnings are important for sustainable programmes (de Bie, 2002). In some areas (e.g. the Mediterranean region) wildfires are also an important cause of land degradation. Risk of wildfires can be estimated with NDVI data because of the sensitivity of the index for vegetation dryness – and dryness is a major contributing factor in the occurrence of wildfires (Maselli et al., 2003). Monitoring of the vegetation cover may, of course, also reveal stability or regeneration after drought or overgrazing (Hostert et al., 2003). Other applications of NDVI are land use/cover classification and monitoring for planning purposes (Han et al., 2004; Skelsey et al., 2003), as well as forest monitoring (cutting and burning of large areas can easily be detected). Also biomass, often used as an indication of the amount of CO_2 stored in vegetation, can be derived from NDVI data.

Crop and rangeland monitoring are very common applications of NDVI data. Seasonal and annual changes are tracked to predict yields, drought risks, crop or pasture failures and to initiate early warnings. Pests (e.g. locusts) and diseases can be detected and monitored to prevent spreading and to mitigate their effects. The context for interpretation is provided by field data and some of the other ancillary data mentioned in the previous section. Of particular importance for crop and rangeland monitoring is also information on farming systems and the sequence of operations as applied to agricultural areas (e.g. grazing, fallowing, rainfed cropping), crop calendars, providing details *within* the sequence of operations (e.g. time of ploughing, seeding, weeding and harvesting for each crop) and data about grazing practices, fertilizer use, pests, storms, erosion, etc. (de Bie, 2002).

For *all* NDVI applications, rainfall data are important because there is a strong relationship between rainfall and vegetation. The response of the vegetation to rain can be almost immediate (visible within about 10 days), but it can also take longer or there may be no response at all, depending on several factors including type of vegetation (e.g. woody), soil characteristics, amount of water still available in the soil and management practices (such as planting or sowing time, plant density and weed control) (Groten & Immerzeel, 1999). Also important in many of the applications mentioned above are anomalies. Anomalies are deviations from 'normal' growing conditions in a given area, often expressed as percentages. The normal is a long-term value, for example the mean over at least 10 years, but preferably longer because clusters of dry or wet years may occur (de Bie, 2002; Groten & Immerzeel, 1999; Maselli et al, 2003). Negative deviations indicate dryness and are represented in red. Grey, yellow or white are used for neutral values, and green is used for positive anomalies. Interpretation of anomalies, particularly if they occur over a longer period, may point to land degradation, fire risk, droughts and desertification. Field data are often acquired to confirm the status before warnings are given (Groten & Immerzeel, 1999; Walker, 1989).

In all these applications, NDVI data are mainly used in a relative sense. Absolute values are not very informative, but comparing values with the normal, with a previous growing season, some other moment or other areas can be very meaningful. An increase or decrease, an important aspect, can be checked by displaying a graph with the values of a selected pixel or object over time (Groten & Immerzeel, 1999). As already mentioned, NDVI values range from <0 to about 0.9. To maximize the range and display the values on a colour monitor, the values are usually scaled (stretched) to a maximum of 256 values (e.g. 0–200 or 0–255). The exact range and the equation used to convert the values, however, depend on the data source. For example, the formula used for SPOT 4 VEGETATION data is:

$$\text{NDVI} = (0.004 * \text{DN} - 0.1) \Rightarrow \text{DN} = (\text{NDVI} + 0.1)/0.004$$

where DN stands for Digital Number; here the values are stretched from 0 to 255.

3.3 Overall goal, objectives and generic user questions

Investigations of the goals, objectives and questions that are important in monitoring were partly based on the literature mentioned in this chapter and partly on interviews and oral communication (in June 1998, November 2002 and March/July 2003) with three experts in vegetation and ecological issues as one of the steps towards the development of animated methods and tools. At the time of the communication all these experts were employed at ITC, Enschede, the Netherlands, and all have broad experience in monitoring and use of large remotely sensed time series (while many experts still are working with a few selected images, as described in Subsection 3.2.1). Each of them pointed to the tutorial written to learn about monitoring with *WinDisp* software (Groten & Immerzeel, 1999) as an important information source. On the basis of all this information, an attempt is made here to describe the goals, objectives and user questions in a generic way. Although NDVI data are used as a case study, the animated methods and tools to be developed should not be confined to NDVI applications.

The overall *goal* of monitoring of spatial dynamics can be derived from the definition of monitoring given in Subsection 3.2.1 and can be described as: to gain insight into the behaviour of dynamic phenomena. Insight is needed to act (e.g. to give early warnings in case of undesired developments, or to optimize human activities), to generate models (e.g. to simulate processes, estimate the effects of external variables or of interference in a development), and to extrapolate trends and forecast future developments. To be more specific, the *objectives* of monitoring are:

- to detect changes that affect geographic phenomena of interest.
- to analyse both recent developments and longer-term dynamics.

Changes are important because they are indicators of ongoing developments; they enable experts to reason about what is happening. Analysis of recent developments enables quick action in case of undesired developments; information about longer-term dynamics is needed to gain insight into processes and relationships and to be able to distinguish trends and extrapolate them into the future.

Experts involved in monitoring are interested in the following *aspects* of geographic phenomena (Eastman et al., 1995; Groten & Ilboudo, 1996; Groten & Immerzeel, 1999; Yuan, 1996):

- The *location*, *type* and *time* of changes in phenomena of interest. As described above, changes are usually considered in a relative sense.
- The occurrence of *anomalies*. Anomalies may require immediate action and are important in many applications, for example in the case of hazards or disasters.
- Ongoing *processes*, such as atmospheric processes, degradation and erosion.
- Possible *causes* and *relationships*, for example between vegetation and rainfall, or between erosion, deforestation and relief.
- *Spatio-temporal patterns/trends*, for example the cyclic pattern of El Niño, gradual loss of biodiversity or continuous global warming.

From the objectives and the aspects of interest, a number of generic user *questions* can be derived. These questions, derived from interviews and literature, refer to all the components of geodata (location, thematic attributes and temporal aspects) and are ordered from less to more complex:

- Are there relevant changes?
- Are there relevant differences/correspondences?
- Are there anomalies or outliers?
- What processes can be distinguished?
- Is it possible to distinguish causes or relationships?
- Is it possible to distinguish overall spatio-temporal patterns (e.g. cycles, trends)?

Since generic monitoring questions have been formulated here, it depends on the application, phenomena of interest and area being studied as to what changes, differences or correspondence can be considered as *relevant*. Discovering processes, causes, relationships and overall spatio-temporal patterns will usually require examination of the dynamics over relatively long periods of time, while questions about relevant changes, differences or correspondences and anomalies can be addressed to both changes that happened recently and to longer time spans. In applications where tracking of changes in (near) real time is important (e.g. in case of disasters or hazards), 'recent' has another meaning than in applications where developments occur more slowly (e.g. plate shifting). 'Recent' should therefore be considered as a relative, application-dependent concept. For most applications in vegetation monitoring, developments within one growing season can be considered as recent, while longer-term dynamics span more than one growing season.

3.4 Finding answers to questions: characteristics of change that can be visually explored

3.4.1 Relating concepts

Answers to the above questions can be sought by applying computational methods, but visual approaches have also some advantages and can perhaps be used in a complementary way (see Section 2.4). One of the objectives of this research is to develop methods and tools to use dynamic visualization variables in animated representations in a monitoring context. The map-use goal of the experts then (as defined by the map-use cube, see Section 2.2) is exploration: the user is a domain specialist who wants to interact with the data to reveal unknowns. The focus in monitoring operations is on spatio-temporal change, since changes are indicators of ongoing developments. It is important, therefore, to investigate what aspects of change exhibited by geographic phenomena can be visually explored.

Firstly, monitoring questions and the time span to which these questions are addressed are related to the earlier distinguished main cognitive tasks in visual exploration: *identification* and *comparison* (see Section 2.3). It is postulated that the discovery of processes and overall spatio-temporal patterns mainly depends on identification of the geometric, thematic and temporal characteristics of change over relatively long periods of time. Relevant changes can be discovered by identification and by comparison, in both recent images and data over longer periods. Discovering differences, correspondences and anomalies in the recent past or over longer periods requires comparison, while the investigation of relationships and causes relies mainly on comparison over long periods (see Figure 3.3).

Next, in order to determine whether it is theoretically possible to find answers to monitoring questions by visual exploration, an investigation into characteristics of change that can be perceived *visually* in graphic representations of spatial data will been undertaken. Those characteristics need to trigger relevant domain knowledge. I will propose a framework of concepts that describe the characteristics of change in general terms. Those characteristics mainly refer to dynamic geospatial phenomena in the physical environment, such as vegetation, erosion and atmospheric processes. Dynamics related to social and economic phenomena, such as movement of people or goods, are not explicitly taken into account.

The framework needs to fulfil some requirements. The concepts should:

- be geared to changes that can be visually explored in dynamic representations;
- describe not only changes in the spatial domain, but also the temporal characteristics of those changes, to facilitate the conceptualization of dynamic phenomena;

- be applicable to a broad range of phenomena in the physical environment; concepts should not be confined to one particular application, so they need to be stated in common linguistic expressions;
- be able to trigger domain-specific knowledge about dynamic phenomena.

	Main cognitive task and temporal periods			
	Identification		Comparison	
	recent	longer	recent	longer
Concepts to describe characteristics of change:				
- In the spatial domain	●	●	●	●
- In the temporal domain	●	●	●	●
- As overall patterns		●		●
- In terms of similarity			●	●
Generic monitoring questions:				
- Changes	●	●	●	●
- Differences, correspondences			●	●
- Anomalies			●	●
- Processes		●		
- Causes, relationships				●
- Spatio-temporal patterns, trends		●		

Figure 3.3 Relationship between monitoring questions and other main concepts

Four main categories of concepts are distinguished. For any cognitive task and temporal period considered, concepts to describe change *in the spatial domain* (e.g. appearance or disappearance, changes in location and thematic attributes) and concepts to describe the *temporal characteristics* of change are important. In addition to these categories, concepts to describe *overall patterns* are needed for longer periods and concepts for *relative similarities* are needed for the cognitive task comparison. Figure 3.3 gives an overview of all the relationships.

Various existing categorizations of spatio-temporal phenomena have been investigated to assess their usefulness for the research described here (Blok, 2000). However, none of the classifications found meets all the prerequisites defined above. Some relevant examples are described below.

In some classifications, categories are distinguished that emphasize changes in the spatial domain; they do not explicitly take temporal aspects into account. Typical examples of concepts used are appearance/disappearance, movement, expansion/shrinkage, increase/decrease or change in internal/external morphology. An example is provided by Dransch (1995).

Hornsby and Egenhofer (1997) propose a *change description language* to characterize sequences of object changes. It consists of a detailed description of transition types that either preserve or change the identity of single and composite objects (e.g. create, generate, reincarnate, divide, merge, mix). Domain-specific knowledge will often be required to distinguish among transition types. The language is meant to build formal data models of change; it does not fully describe the changes in *graphic* models (e.g. animations) to be used for monitoring applications. For instance, movement, geometric changes such as boundary shifts and temporal characteristics are not (explicitly) incorporated.

Eschenbach (1998) attempted to classify movement based on the spatial structure of objects. The two main classes are movement along trajectories (complete shifts in position) and internal motion (changes in the position of parts of an object). Internal motion is further subdivided into growth/shrinkage, internal rotation, movement of parts and a category referring to movement of large bodies that might proceed along trajectories but are too short to result in a complete shift of position. The distinction between the last two subcategories is not very clear and is probably not relevant for monitoring. Eschenbach indicates that the categories are not exclusive; some movements are, for instance, trajectory-based with internal motion. This classification also emphasizes changes in the spatial domain.

Yattaw (1999) classified movement by taking the spatial characteristics point, line, area and volume and the temporal characteristics continuous, cyclical and intermittent into account. A matrix of these characteristics results in twelve classes of movement. She also mentioned the influence of spatial and temporal scale and of context for the assignment of a particular movement to one of the classes. An advantage of this classification is that temporal aspects are explicitly included, although the concepts continuous, cyclical and intermittent mainly describe patterns over longer periods. Characteristics like the length of time involved in a change, or the rate of change over time, which are relevant for recent (short) periods *and* longer periods of time, are not accommodated. Another drawback is that the spatial characteristics distinguished do not adequately describe changes in the spatial domain.

Building on the work of these authors and on parameters of display time in animations (DiBiase et al., 1992; MacEahren, 1994c), a framework of general linguistic expressions is presented below to characterize changes that are relevant for monitoring and that can (at least in theory) be discovered by visual exploration.

3.4.2 Change in the spatial domain

The basic concepts I propose to describe what is happening at locations where change can be observed in the spatial domain (see Figure 3.4) are:

- *Appearance/disappearance:* refers to existential changes, i.e. the emergence ('birth') of a new phenomenon or the vanishing ('death') of an existing one (e.g. a tornado, an earthquake, a wildfire, pollution). Changes in the nature of an existing phenomenon (such as an inactive volcano that becomes active or the change from a forest stand to arable land) are not characterized by appearance/disappearance, but by concepts from the next category, mutation.

- *Mutation:* refers to a transformation that affects the thematic attribute component of an existing phenomenon; it does not refer to changes in geometric characteristics. Two subtypes are distinguished.

    - *Mutation at the nominal level of measurement:* refers to a change in the nature or character of a phenomenon (e.g. change from rain to snow, from gully to sheet erosion, from forest to burnt area, from a dry to a water-containing intermittent river).
    - *Mutation at a higher than nominal level, mainly in terms of increase/decrease:* refers to a change at the ordinal, interval or ratio level of measurement (e.g. changes in the force of a tornado, the thickness of the cloud cover, the amount of precipitation, the vegetation index).

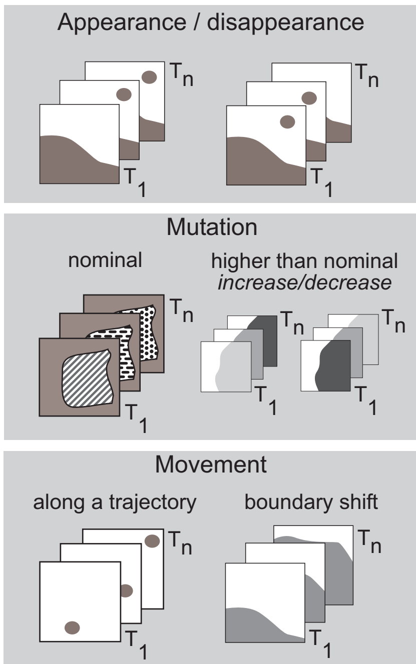

Figure 3.4 Basic characteristics of change in the spatial domain

- *Movement:* refers to a change in the spatial position and/or the geometry of a phenomenon. Again, two subtypes are distinguished.

    - *Movement along a trajectory:* refers to a movement by which the whole phenomenon changes its position. A kind of path is followed, hence it can be assumed that movement takes more than a single instant of time, some continuity is involved. Along the path, the geometric characteristics of the phenomenon may change (e.g. a tornado and pollution carried by running water exhibit movement along a trajectory).

- *Boundary shift*: refers to movement where at least part of the phenomenon maintains its location (e.g. the jet stream; expansion of an area occupied by an existing phenomenon, such as a deforested, an eroded or a polluted area, or an area with a high vegetation index). These types of movement may either happen at a single instant of time or take place over a longer period.

Some remarks can be made here. Firstly, most dynamic phenomena can be characterized by more than one of the proposed basic concepts for change in the spatial domain. For example, a tornado appears, increases in force while moving along a trajectory, decreases again, and finally disappears. In other words, to be able to describe the *behaviour* of a phenomenon in space, the concepts often have to be combined.

Secondly, the concepts used to characterise geospatial phenomena may vary: *"… the problem of putting a label on a geographic feature is much a matter of context"* (Ahlqvist & Arnberg, 1997, p. 73), which also applies to dynamic phenomena. A number of factors play a role, such as the perspective of the expert or the aspect of a phenomenon being studied (Yuan, 1997). If, for example, the *behaviour* of a wildfire is being investigated, relevant concepts to characterize it are appearance/disappearance, mutations (changes in intensity) and, most likely, movement along a trajectory. If, however, the wildfire *effect* is examined and the expert is interested in *burnt* surfaces, new areas appear and boundary shifts occur in existing areas. But if the effect is studied in terms of changes in *land use*, it is more like mutations and boundary shifts. Characterising change is further influenced by the phenomenon itself. Incidental pollution (e.g. carried by running water or moving air) is characterized as movement along a trajectory, but in the case of more or less continuous pollution of water, soil or the atmosphere from a fixed source, boundary shifts occur. Display scale or size of the area represented in a map or image also influence characterization. At a global scale the changes from cloudy to cloud-free skies can be conceived as mutations, but if a small area is extracted, clouds appear and disappear. A large-scale display of a volcanic eruption shows boundary shifts of lava streams. In a small-scale representation of the volcanic activity in a region, however, movement cannot be seen. The time frame considered is another factor influencing the way in which a phenomenon is characterized. If only recent changes are considered, clouds exhibit boundary shifts, but in longer periods movements along trajectories are more likely.

In short, some basic concepts to characterize change in the spatial domain have been proposed, but the context in which they are used and displayed influences what (combination of) concepts (is) are most appropriate to describe dynamic phenomena. Within a *particular* context, unambiguous assignments are of course required. Some refinements might be necessary for particular applications. For instance, it is not clear at this stage whether changes such as splitting and merging need to be distinguished separately, or whether they can be considered as combinations of appearance and disappearance. Also, many dynamic phenomena exhibit almost continuously change in their boundaries, in various directions (e.g. cloud cover, oil spills in water). For such 'movements' it is not easy to determine whether a phenomenon only changes in form, or in form and size, or perhaps even in direction. The category 'boundary shift' is not further subdivided here, but if useful for an application, another level (e.g. expansion/shrinkage and other geometric changes) can be added to the hierarchical categorization of basic changes.

3.4.3 Change in the temporal domain

To further characterize the behaviour of dynamic geospatial phenomena, concepts that describe change in the temporal domain are required. Proposed are (see Figure 3.5):

- *Moment in time:* refers to the date (the location in time) of a change in the spatial domain.
- *Sequence:* refers to the order of phases in a series of changes in the spatial domain.
- *Duration*: refers to the length of time involved in a change and/or the time between changes in the spatial domain. It can be expressed in absolute or in relative terms (number of time units or notions such as 'short/long' respectively).
- *Pace:* refers to the rate of change over time and can be expressed in terms like 'slow/fast'; or 'at increasing/decreasing/constant rate of change' (MacEachren, 1995).
- *Frequency:* refers to the number of times that a particular phase is repeated in a series of changes in the spatial domain.

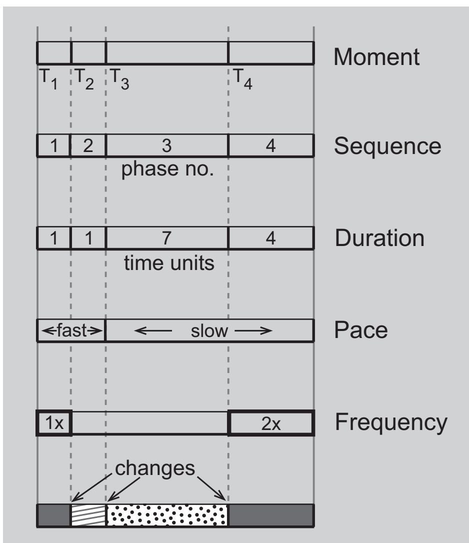

Figure 3.5 Characteristics of change in the temporal domain; changes are marked by orthogonal lines into the time bar

3.4.4 Overall spatio-temporal patterns for relatively long periods

Characterizing change over relatively long periods requires integration of individual changes into an overall spatio-temporal pattern of change. Hence, some additional concepts are introduced to enable the description of spatio-temporal patterns over longer series (although recognition of those patterns depends on the selected time frame and resolution). The patterns can, if required, be further characterized in more detail by concepts proposed for the spatial and temporal domains. The new concepts may refer to (combinations of) the locational, thematic and temporal data components. Proposed for monitoring applications are (see Figure 3.6):

- *Cycle*, which refers to a periodical return to a previous state/condition (Muehrcke & Muehrcke, 1992). Cycles are quite common in the physical environment; for example, daily or seasonal cycles in atmospheric processes and seasonal cycles in vegetation are quite common. But other phenomena, like erosion or insect infestations, may exhibit cyclic behaviours. If a cycle is discovered, developments can perhaps be predicted, although disturbance of usual patterns may always occur. The cycle in Figure 3.6 is the periodic return of a phenomenon that moves along a trajectory.
- *Trend:* refers to a structured but non-cyclical pattern (Muehrcke & Muehrcke, 1992). It is the general direction, or tendency, of a development over a period of time. Some examples are: developing spatial clustering, or a gradual shift to the north (locational and temporal components), decreased droughts (thematic and temporal components) and higher frequencies in the occurrence of cyclones (temporal and thematic/locational components). If a trend can be observed, extrapolation in time may be possible, although changes in the general direction of a development may, of course, always occur. The trend in Figure 3.6 is a gradual shift of a phenomenon to the northeast.

If no cycle or trend can be discovered, the pattern is unstructured. Characterizing unstructured patterns does not seem useful because they are generally too hard to interpret.

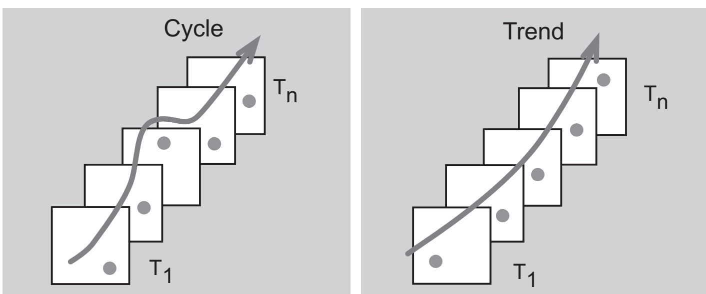

Figure 3.6 Overall spatio-temporal patterns over relatively long periods

3.4.5 Relative similarity in comparisons

Comparison of changes is an exploration task at a higher level of complexity than identification (see Section 2.3). Since comparisons can be made between locations or themes, or in time, the concepts described above for changes in the spatial and temporal domain, and sometimes those for overall patterns, are relevant for comparisons as well. In addition, I propose the following concepts to characterize the relative similarity.

Comparison of recent changes (relatively short periods). For these comparisons the following distinction will probably suffice (see Figure 3.7):

- *Same/different:* refers to changes that are comparable/incomparable, particularly in the locational and/or the thematic data components. Same/different observations may, for example, lead to the identification of anomalies by a domain expert.

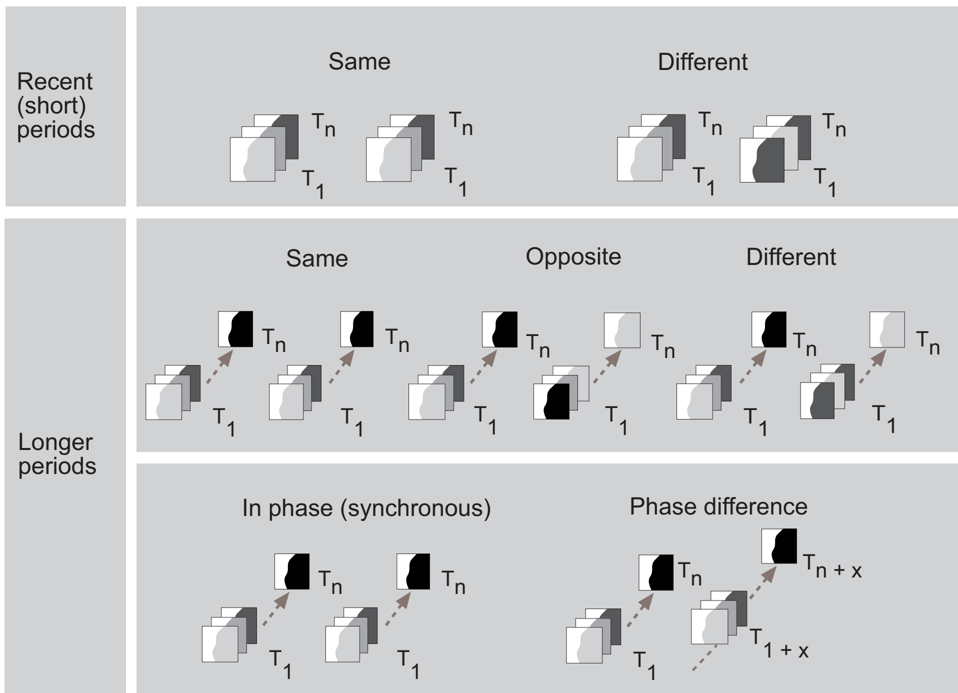

Figure 3.7 Comparing spatio-temporal patterns: relative similarity

Comparison of relatively long periods. Concepts here are:

- *Same/opposite/different:* refers to patterns that show comparable (proportionally or inversed) and incomparable changes. Similar patterns may point to a positive (cor)relation, opposite patterns to a negative one, and different patterns again to anomalies.

- *In-phase (synchronous)/phase difference:* refers to the simultaneousness of pattern developments, which may happen for same and opposite patterns. If pattern developments start and end at the same time, patterns are in phase and are perhaps somehow related. If same or opposite patterns are observed with a time lag, there is a phase difference. Exploration of those pattern developments can still be interesting, because that may point to a causal relationship. For instance, vegetation might develop similar patterns as precipitation, but later in time (Groten & Immerzeel, 1999).

3.5 Summary

In this chapter, monitoring goals, objectives and generic user questions are identified. As a first step to support finding answers to the monitoring questions by visual exploration of animated representations, main visual exploration tasks and relevant temporal periods to focus on are related to monitoring questions. Next, concepts to describe aspects of change that can be identified and compared during *visual* exploration have been distinguished. This has been done in order to determine whether it is theoretically possible to find answers to monitoring questions by visual exploration. Four main groups of concepts are recognized: for changes in the spatial domain, in the temporal domain, for overall patterns and concepts that characterize patterns that are compared in terms of relative similarity. In particular, concepts for change in the spatial domain seem to be influenced by the context in which they are used and represented.

The aspects of change described here should trigger the domain knowledge (of anomalies, processes, etc.) that is relevant in the search for answers of experts involved in monitoring. It may lead to further (perhaps computational) analysis of the data. In Chapter 4, I take a closer look at the dynamic visualization variables and their possible use to support monitoring tasks.

4 DYNAMIC VISUALIZATION VARIABLES

4.1 Introduction

After an investigation into aspects of change that can be visually explored to trigger domain knowledge of dynamic phenomena, I describe in this chapter how dynamics can be visually represented and how the user can manipulate the representation. Spatio-temporal data can be graphically represented in many ways. Vasiliev (1997) proposed a framework for graphic representation in static maps; Andrienko et al. (2003) attempted to do the same in an exploratory context, focusing on interactive and dynamic visualization of spatio-temporal data. The research described here is confined to animated representation, more particularly to the ways in which the dynamic visualization variables can be used to visually explore time series in order to find (partial) answers to monitoring questions. This chapter discusses various aspects of the dynamic visualization variables. In Section 4.2 I look at representation variables for geodata in general, and then in Section 4.3 I focus on the dynamic visualization variables. Types of variables and their relationships are defined. In Section 4.4 I describe aspects of use of these variables from a design perspective. After a short introduction on the influence of the representation medium (Subsection 4.4.1), I discuss ways to link the dynamic visualization variables to components of geodata and to interact with those data (Subsection 4.4.2). In Section 4.5 I discuss the variables from a user perspective. First, the levels of interest at which an animated representation can be explored in the temporal domain are described (Subsection 4.5.1). Users of animated representations and the interaction possibilities described in Subsection 4.4.2 will experience some effects. Possible effects and implication for application of the variables are discussed in Subsection 4.5.2. The chapter ends with a brief summary (Section 4.6).

4.2 Evolving framework of representation variables

Representation variables in a geodata context are changeable signs or signals that can be used to symbolize aspects of the data in perceptual form. Symbolization may vary from realistic to abstract; symbols may deliberately transform or exaggerate data characteristics, or exhibit special effects (e.g. blinking spots or symbols that change their characteristics upon mouse-overs). In principle, all variables that are perceptible through sensory perception can be used for geodata representation, not only the ones that can be visually perceived.

Apart from an early publication of Hettner in 1910 (see Hettner, 1962), attention for the 'language of representation' and the effectiveness of maps started with Robinson (1952), but the foundation for formalization was laid by Bertin in 1967 (see Bertin, 1974). Bertin not only distinguished basic *graphic* variables, but also suggested ways in which these variables can be matched to data (Bertin, 1974). His semiological framework has been further elaborated and extended. Among the main developments in the visual domain (see also Schlichtmann, 1999) is research on effects of combinations of variables (e.g. Spiess, 1970). Morrison (1974) and MacEachren (1994a, 1995) have argued that the variables colour (including saturation) and texture are composites rather than primitives, and they defined the different components. Wang & Ormeling made an attempt to extent Bertin's rules for the representation of absolute and relative quantitative data. Furthermore, new variables such as transparency and fuzziness or crispness of symbol edges have been distinguished and applied to represent characteristics of data and of metadata (MacEachren, 1994a; van der Wel et al., 1994). Adaptations to Bertin's way of linking the variables to data have been suggested as well (e.g. Geels, 1987; MacEachren, 1995; Morrison, 1974). Kraak (1988) investigated *depth cues*, i.e. variables that can be used to simulate the third dimension on a 2-D surface, while DiBiase et. al. (1992) and MacEachren (1994b) proposed *dynamic* variables for animated representations, together with suggestions for their use.

Characteristics of geographic data can also be represented by signs or signals for modes of perception other than sight. Vasconcellos (1993) made an attempt to define *tactile* equivalents of Bertin's graphic variables for visually disabled people. More recently, Griffin (1999) added *kinaesthetic* variables (e.g. resistance, friction) for application in fully immersive Virtual Environments. *Sound* variables are proposed by Krygier (1994), and Kimerling & Buckley (1997) even attempted to establish *taste* and *smell* variables.

These developments show that the framework for the representation of geodata by perceptual variables, originally founded by Bertin, is a dynamic construct that is still evolving (Blok, 1998, Fairbairn et al., 2001; MacEachren, 2001). Important reasons for ongoing developments are increasing insight and progress in technological advancements. All variables in the visual domain and sound variables can be produced and perceived with a standard PC. Application of smell variables might be possible in the near future. 'Scent printers' or other scent-producing peripherals that can be plugged into a computer are currently being investigated (see URL 4.1). Taste variables applied in a computer environment seem further away, but are certainly also less relevant for geodata representation. Tactile variables – used in the past mainly for visually disabled people – and kinaesthetic variables can be experienced in fully immersive virtual environments. Augmented reality applications are only beginning. It is clear that the representation framework is not a fixed construct; it will be further extended and adapted.

4.3 Definition and characteristics of dynamic visualization variables

The focus of this research is on animated representations, in which graphic and dynamic variables play a dominant role (Figure 4.1). *Graphic variables* (position, form, orientation, colour, size, etc.) are visible within the two or three spatial dimensions used to represent geographic data. They may change in successive maps or images, but in order to make the dynamic aspects of the changes visible (e.g. the speed of movement or the blinking frequency of a dot), dynamic variables, here further referred to as *dynamic visualization variables*, are needed as well (DiBiase et al. (1992) and MacEachren (1994b) introduced the term 'dynamic variables', but since variables are changeable (dynamic) by definition, preference is given here to 'dynamic visualization variables', where 'dynamic' refers to the representation method in which the variables are used). The dynamic visualization variables can only be observed in the temporal dimension (display time) of a running animation; although they rely on graphic elements in the spatial dimensions of an animation, they enrich the graphics with dynamism in the temporal dimension.

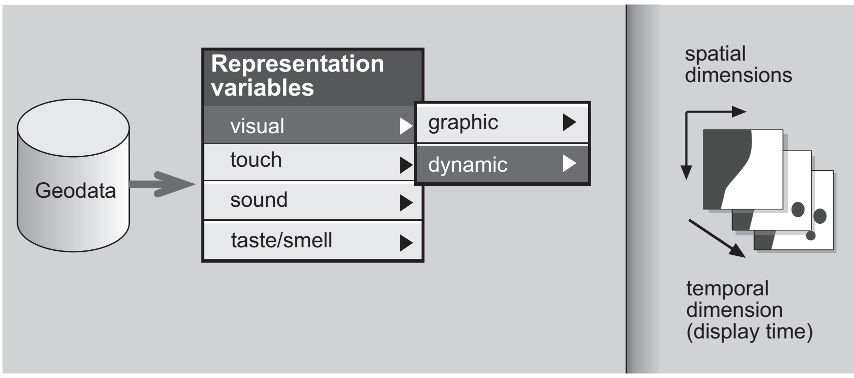

Figure 4.1 Variables perceptible through different sensory channels can be used for the representation of geodata; the graphic and dynamic variables of the visual domain are dominant in animated representations

Bertin was anxious that changing variables in maps would be too dominant for successful application, because of the sensitivity of the human visual perception system to changes in the visual field (see Section 2.5). Others, however, have demonstrated that this is not the case (e.g. DiBiase et al., 1992; Koussoulakou & Kraak, 1992). Since the 1980s several researchers have looked into animation variables. Hayward (1984) distinguished, in addition to graphic variables, viewpoint and distance, which refer to the position of the observer vis-à-vis 3-D objects. Furthermore, scene and speed of movement are mentioned. Scene refers to visual effects (mix, fade, wipe) that can be used to obtain smooth transitions in an animation, but these effects are created by manipulation of the graphic representation, followed by display in a particular order. So, *order* and *speed* are the only variables of the temporal dimension here. Magnenat-Thalmann & Thalmann (1990) distinguished animation objects, scenes and sequences. Animation objects consist of graphic objects (e.g. symbols in a map) that are characterized by variables comparable to Bertin's graphic set. In addition, there are a number of camera and light source variables relevant to 3-D animations. Scene refers to the positioning of animation objects in an image, and sequence refers to the structured presentation of images. *Sequence* is the only variable that is linked to the temporal dimension. DiBiase et al. (1992) distinguished the dynamic variables *order*, *duration* and *rate of change*. A few years later, MacEachren (1994b) added *moment of display*, *frequency* and *synchronization*. Shepard (1994) proposed variables to create maps with varying symbolism in display time ('time-varying symbol behaviour'). In addition to differences in graphic appearance, his variables of the temporal dimension are *timing* and *duration*, as well as *motion/positional change* (e.g. oscillating symbols) and *blinking*, which are both regularly repeating variations. Green (1999) mentioned the dynamic variables motion and flicker. Motion consists of *direction* and *velocity*; flicker entails *frequency* (on/off) and *phase* (the relative point in the on/off cycle). Finally, Wilkinson (1999) differentiated *direction*, *speed* and *acceleration* as attributes of motion.

Table 4.1 Variables of the temporal dimension in animated representations expressed in concepts introduced by DiBiase et al. (1992) and MacEachren (1994b)

Concepts introduced by DiBiase et al. (1992) and MacEachren (1994b)	**Concepts used by other authors:**				
	Hayward (1984)	**Magnenat-Thalmann & Thalmann (1990)**	**Shepard (1994)**	**Green (1999)**	**Wilkinson (1999)**
Moment of display	none	none	timing	none	none
Order	scene (effects)	sequence	none	motion direction	motion direction
Duration	speed of movement	none	duration	motion velocity	motion speed
Frequency	none	none	motion/ position change; blinking	frequency (flicker and phase)	none
Rate of change	none	none	none	none	motion acceleration
Synchronization	none	none	none	none	none

The dynamic variables just mentioned can all be expressed in terms of the concepts introduced by DiBiase et al. (1992) and MacEachren (1994b), as summarized in Table 4.1. Since the concepts in the first column of the table are most common in geovisualization literature, they will also be used in this research. Moment of display (also called display date) refers to the time at which some change is initiated, no matter what the type of change is, or how it is initiated. Order is the sequence of frames or scenes in an animation. It influences the animation narrative (Kraak & Ormeling, 2003). Duration refers to the length of time between two identifiable states or between the frames in an animation. Frequency is the number of identifiable states per time unit; '*… temporal frequency is a ratio between two durations … It is worth treating as a separate dynamic variable because … humans react to frequency as if it were an independent variable.*' (MacEachren, 1995, p. 285). Rate of change is the difference in magnitude of changes per unit of display time. Synchronization refers to the possibility to run two (or more) temporal animations simultaneously, and shift them in time so that patterns are *in phase* and relationships between data sets can be discovered. For example, the pattern between emission levels of pollution and the occurrence of certain diseases, or between rainfall and vegetation may show similarities that become clear if the time lag has been removed (see also Blok et al., 1999).

The question arises whether rate of change and synchronization can be seen as representation variables. Not only the characteristics of the underlying data and the design choices made for the animated representation lead to certain rates of change: *any* interaction with the animation affects rates of change that can be observed in a running animation. In order to observe synchronization of patterns, choices of different moments to start two animations of probably-related phenomena have to be made. Thus, interaction with *moment of display* is needed, but more might be required because in reality the match of the patterns will often not be perfect in time (or in space). For example, the spread of a disease may develop more slowly than pollution emission and some types of vegetation respond slower to rainfall than others (or not at all). Independent additional interaction with the animations might then be required, for example to run the animations at different speed. Thus, pattern correspondence has to be discovered during exploration and analysis of the representation, and various interactions may be required. Use of a representation variable seems a more elementary activity applied to data. Rate of change and synchronization will therefore not be considered as representation *variables* in this research, but as *effects* of changes in the data and/or of interaction with other dynamic visualization variables (as will be explained in Subsection 4.5.2).

Table 4.2 Definition of dynamic visualization variables for use in temporal animations

Dynamic visualization variable	**Definition**
Moment of display	Position of a state or a change in the representation in display time.
Order	Structured sequence of 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 the representation.
Frequency	Repetition or number of identical states or changes in the representation per unit of display time.

Not only change but also the lack of change is visible in display time from the behaviour of the dynamic visualization variables. Therefore, the descriptions given above of the four remaining variables need to be slightly adapted. Table 4.2 provides the definitions I use in this research; the concepts *change* and *state* are used here. A *change* can be the result of an alteration in the data underlying the representation, for example caused by some event. It can also be the result of an alteration in the representation itself, caused, for example, by user interaction. A *state* is a condition or mode of existence not being affected by change in the representation (see also Langran, 1992). Display date marks the position of changes and states in display time and is comparable to the variable *position* in space. Thus, the time at which a change is *initiated* (see MacEachren's 1994b description above) refers only to a moment of display time that is *marked by a change*, but the concept as it is used here is broader. Another difference with the descriptions of the variables given above is that in the case of frequency, repetition of *identical* or *similar* states or changes are emphasized.

The dynamic visualization variables listed in Table 4.2 are not independent of each other. Moment of display, as described above, is position in display time. Moments marked by the initiation of a change or a new state form the basis for perception of all other dynamic visualization variables. Duration – the distance between at least two marked moments of display – and order occupy the next level in the hierarchy. They can be considered as primary derived variables. Frequency is a function of order and duration; in addition, the underlying data play a role because it is not about any change or state but *identical* ones per unit of time. Hence, frequency is a secondary derived variable (see Figure 4.2).

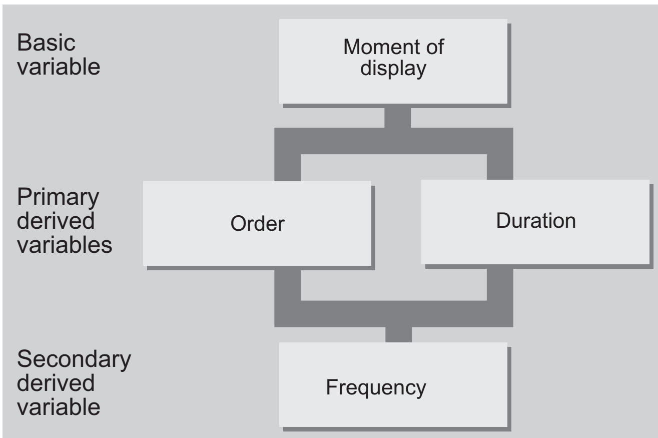

Figure 4.2 Relationships between the dynamic visualization variables used in this research

4.4 Use of the variables from a design perspective

4.4.1 Influence of the representation medium

The four dynamic visualization variables can only be observed in display time. Analogue media such as film or video are capable of displaying dynamics, but nowadays most animations for professional use are viewed in a digital environment, particularly on a PC. Factors such as processing capacity, network connections, bandwidth and varying traffic intensity influence the speed at which information can be displayed, particularly on the Web. A consequence is that dynamic visualization variables that are sensitive to differences in display speed cannot be precisely controlled, even though there are buffering techniques like streaming. The variables that may be affected are moment of display, duration and frequency. No problem, of course, occurs with order.

4.4.2 Providing interaction options

The dynamic visualization variables can be applied in several ways to represent characteristics of geodata in 2-D animations. The most obvious application for temporal data is to design a chronological representation in which the variables of *display time* are directly linked to characteristics of the data in *world time* (Kraak & MacEachren, 1994). The moments, order, duration and frequency at which elements in a running animation are visible mimic the dynamics in reality, albeit within the preconditions set by (temporal) scale and resolution of the data and by design choices. Examples of other links are, among others, provided by the original sources about dynamic variables (DiBiase et al., 1992; MacEachren, 1994b, 1995) and by Kraak & Ormeling (2003); more references are given in Subsection 2.5.1. As indicated in Subsection 2.5.1, however, classification of animations based on the link between the temporal dimension and one of the components of geodata is not very relevant in an interactive environment if options are provided to change the chronological sequence of temporal data. Linking the dynamic visualization variables chronologically in the default representation may, therefore, not be a limitation. The common format in which animations are still moulded today, however, is a representation with the standard options offered by media players (stop, play forward and backward, step forward and backward, to beginning and end). Although these options are limited, some are very important, particularly (in addition to play) stop and stepwise forward/backward, because these buttons enable the user to change a running animation into (a series of) static maps or images that can be used in conventional ways. Nevertheless, Fairbairn et al. (2001, p. 16) state: '*… we need to move well beyond the video-player metaphor for interacting with animations.*' Animations are difficult for users if not the position of features, but attributes change over time (Dorling, 1992). In complex representations in which changes are constantly happening over time and simultaneously at several locations of the display area, limitations in perceptual and cognitive information processing may hinder the understanding of a running animation. More controls over such a complex display are desired than the standard media-player type, particularly for exploration purposes, because interaction supports the for visual-exploration important activities of 'seeing that' and 'reasoning why', which encompass processes such as abstraction, combination, association and synthesis (see Section 2.3; see also Peuquet & Kraak (2002)).

Interaction can be defined as user-controlled manipulation of elements in the data representation or its interface that affects the map or image display. Dynamic visualization variables can be used as controls in several ways. Some types of interaction with these variables have been empirically tested in different applications (see some of the references below), but a systematic investigation into interaction with all these variables is still lacking. Also, we know little about how users actually work with such tools (Slocum et al., 2001).

The use of a variety of interactions with these variables for visual exploration of remotely sensed time series in a monitoring context will be tested in this research. Interaction with the dynamic visualization variables will be considered in four ways:

- in the temporal domain (with the data component time);
- in the spatial domain (with the data components location and thematic attributes);
- with the graphic representation or the view offered on the data;
- with general media player controls.

Figure 4.3 summarizes the interactions. No attempt has been made to incorporate all possible kinds of controls. In each of the categories mentioned, (variations on) a number of known map use activities in which the dynamic visualization variables are involved and that can be applied to a default chronological representation of the data will be tested. Interactions with, for example, alternative representations that can be dynamically *linked* to animations (e.g. scatter plots) or interactions which first require *re-calculation* of the data underlying the representation (e.g. temporal aggregation, calculation of contiguous areas, Harrower, 2002) are not included. Although re-calculations most likely influence the dynamic aspects of a running animation, these types of interaction are not considered to be interactions with the dynamic visualization variables.

Furthermore, only interactions that seem useful for monitoring are included. The table indicates which dynamic visualization variable is *primarily* involved in the interaction, but other variables may be affected as well. As explained in Section 4.3, the variables are not completely independent of each other. Interaction with a variable at a lower level in the hierarchy of types (see Figure 4.2) *always* affects display of the higher-level variables; alternatively, interaction with a higher-level variable *may* influence one or more lower-level variables. For example, the successive display of *selected* moments or intervals in time affects order and may affect duration or frequency as well.

Among the manipulations with MOMENT OF DISPLAY, selection of *time* will be implemented as an option to choose subsets (moments or periods) from the default chronological representation that can be sequentially displayed. Examples of moments that might be picked are the start of the growing season or, if an expert is interested in possible time lags, the same date to compare the patterns in successive years; periods might be the months of the growing season for a number of years, dry seasons, etc. Selection of a particular object or an irregular area of interest is useful and theoretically possible but cannot be easily implemented with raster data. In this research, selection of *location* will therefore only be included in a rudimentary way, as a zoom function that enables the isolation of the values in a rectangular part of the image from their surroundings. Other interactions with location will (for the same reason) not be implemented in the raster data used in this research. According to Dorling (1992), this falls under ‘animating space’. Selection of *thematic attributes* will enable the representation of certain pixels per frame only: an interval (e.g. one that represents bare soil or NDVI values between 0.2 and 0.4), values above/below one or two thresholds (e.g. all NDVI values <0.4, or all values <0.4 and those >0.7). Similar temporal and /or thematic selection functions (sometimes called focusing, brushing), but implemented and applied differently, can, for example, be found in Andrienko et al. (2000), Edsall et al. (1997), Harrower et al. (2000) and MacEachren & Boscoe et al. (1998). Selection of *representation/view on the data* will be offered by different colour and classification schemes. Options to *undo* the different selections mentioned above will also be included.

	Main dynamic visualization variable involved			
Type of interactions	Moment of display	Order	Duration	Frequency
Selection of:				
- time: moments, periods	●			
- location: zooming	●			
- thematic attributes: 1 or 2 thresholds, interval	●			
- graphic representation/view: base map, classification and colour schemes	●			
Deselection of choices	●			
Manipulation of start/end of the animation:				
- play forward; step forward/backward; to the beginning/end; stop	●			
- tuning	●			
Manipulation of the display sequence:				
- based on time: play backward, alternate moments		●		
- based on thematic attributes: alternate values		●		
- based on graphic representation/view: alternate classification and colour schemes		●		
Manipulation of the length of display time:				
- based on time: change of display speed			●	
- based on thematic attributes: value, interval			●	
Repetition:				
- based on time: blinking moments				●
- based on thematic attributes: blinking values, intervals				●
- looping				●

Figure 4.3 Examples of interaction with dynamic visualization variables in a chronologically ordered animation

One may question if the selections of thematic attributes and of representations/views mentioned above can truly be linked to moment of display. An argument for a positive answer to the question is that these interactions simply enable selected pixels to be on or off the display screen, or they use a different look-up table to display other class boundaries and colour schemes; they do not require computations on the underlying data. Since these selections alter the moments of display that are marked by changes in the default representation – the moments that are the basis for perception of all the dynamic visualization variables (see Section 4.3) – they are considered in this research as interactions with the dynamic visualization variable moment of display.

Manipulation of *start/end* of the animation will be possible with the media player buttons *play forward*, *step forward* and *stop*. In addition, buttons to *step backward* and to jump *to the beginning* or the *end* of the animation can be used to select another point on the time line to start observations, so they are considered as interactions with moment of display. In *tuning* it will be possible to manipulate individually the starting points of two simultaneously running, chronologically ordered animations. This is comparable to MacEachren's (1994b) separate dynamic visualization variable synchronization. The idea is that patterns of possibly related or comparable phenomena can be viewed together. If a (causal) relationship between the patterns of different data sets can be discovered and the time lag can be estimated, it might be possible to predict the patterns of the dependent variable. A comparison of rainfall and vegetation patterns might, for example, lead to predictions like: *if rainfall at location*$_{(x,\,y)}$ *at time*$_1 = x$*, then vegetation at time*$_2 = y$. Of course, deviations – for example, because of management practices – are always possible. An advantage of visual over computational methods (e.g. lag calculation) for the exploration of such a relationship is that actual patterns can be observed in a spatio-temporal context, so it is possible to see where, when and to what extent patterns match. Non-perfect matches (e.g. because of local anomalies) can be judged directly (Blok et al, 1999).

Interactions with ORDER refer to a release of the chronological sequence of the default representation, which may reveal different patterns. Under moment of display it will be possible to select subsets of time which, when displayed, appear in their original sequence. Interaction with order would enable deviations such as the display of a chronologically later period B before the earlier period A, but this does not seem to make sense. Playing the animation backward, however, seems to make most sense if applied to chronological time, so it can therefore be considered as interaction with *time*; it will be included in the prototype. Another interaction will be to select two moments in time and alternate them (see also Gershon, 1992). This option enables comparison between any two moments, particularly because the two frames will be repeated until the user decides to stop the sequence. Interactions with *location* will not be included. Options like displaying (in successive frames) the locations where a particular attribute value or value range occurs at a selected moment does not seem to contribute much to pattern identification. A better choice would be to select a value or value range and display it for all (selected) moments of time. This interaction with moment of display will be implemented (see above). Re-ordering of data based on *thematic attributes* has been applied before, for example by DiBiase et al. (1992), Peterson (1993) and Slocum et al. (1990). Most examples re-order the frames of an animation in such a way that quantitative values or classes are represented successively, for example from low/weak to high/strong (or the other way around). Generally, this is not very successful (Slocum, 1999) and it is less suitable for a time series of image data. The choice made here is to provide an alternate option that enables the detection and comparison of the distribution of pixels that correspond to two different single values for a selected moment in time. This method has been mentioned by Muehrcke & Muehrcke (1992) and has been applied to non-temporal data, for example by Monmonier (1992a), Fisher (1993) and Evans (1997). Interaction based in *representation/view on the data* will also be implemented as an alternation option between representations in different colour and/or classification schemes (see also Peterson, 1993 for non-temporal choropleth maps).

Two remarks have to be made about alternation. First, sometimes it has been implemented as a rapid switch between two variables to enable the detection of similarities or differences (in most cases for non-temporal data) and has been called 'blinking' of 'flickering' e.g. Evans, 1997; Monmonier, 1992a). In addition, it may be related to frequency instead of order. The fact that the dynamic visualization variables, and in particular frequency – as described in the previous section – are not independent of each other clearly shows here. In this research, alternating and blinking are not the same things. Alternating frames of *different* times, attributes or representations will primarily be considered as interaction with order. Since the frames are repeated, however, frequency is also involved. Blinking will be considered as repeated on/off cycles of the *same* time or attribute, which is indeed primarily related to frequency. My second remark is that application of alternation is not always successful. For example, Evans (1997) applied it to alternate between land use and a frame displaying land use together with reliability. Some test persons found the 'flickering' effect annoying, albeit helpful. Monmonier's (1992a) application to two thematic variables, tested by Monmonier and Gluck (1994), was not successful. Reasons might be the lack of interaction in Monmonier's example, high hue contrasts and a different application.

Interactions with the dynamic visualization variable DURATION influence the length of time during which elements in the animation are visible. Duration of the data component *time* can be influenced by control over the display speed, but it will also be possible to apply this very common type of interaction in all other situations. An option to mark single moments in time (e.g. by displaying the start of spring in successive years longer) will not be implemented under duration but under frequency (see below). Duration applied to *location* (e.g. by displaying a frame longer if low values occur in a vulnerable area) will not be implemented. Displaying frames longer if a particular (e.g. anomalous) value or interval occurs will be implemented as interaction linked to *thematic attributes* (see DiBiase et al. (1992) and Moellering (1976) for other examples). Linking duration to *representation/view on the data* will not be implemented since it does not seem to make sense.

There are many ways to apply the dynamic visualization variable FREQUENCY. Some well-known examples are blinking (on/off) symbols, symbols through which a colour sequence is cycled or symbols that are (apparently) moving (i.e. oscillating, jumping, morphing, shrinking, expanding, etc.) at a particular frequency (see MacEachren, 1995; Shepard, 1994). Manipulation of frequency can be applied to all data components. In this research it will be provided as an option to blink selected moments in *time*. In addition, it will be possible to display blinking values or intervals, examples of interaction with *thematic attributes*. Interactions with location (DiBiase et al., 1992) and with *representation/view on the data* will not be implemented. A different way in which frequency can be used is by providing possibilities to view (parts of) the animated representation more than once, for example as *loops*. This is a potentially very useful way for displaying complex time series of image data, where frequent changes appear all over the display area; it will be implemented in the prototype.

Many of the interactions mentioned above can be used in combination with each other. Examples of combinations that will be implemented are zooming into an area of interest and displaying a sequence in which a selected thematic interval is blinking within selected periods of time (e.g. to extract particular crops in the growing seasons); tuning of two animations in which values below a selected threshold are represented as a change of the display speed (e.g. to investigate a possible time lag between values for two growing seasons).

In Subsection 3.4.1 I have said that answers to monitoring questions are sought through identification and comparison of relatively short and longer temporal periods. Most types of interaction mentioned above support identification *and* comparison. Exceptions are blinking of moments, which is mainly meant to identify selected points in time in a running animation, and the tuning and alternate options, which primarily support comparison. Furthermore, alternation enables only comparisons within one moment or between two moments at any time. Although tuning can be used to compare two relatively short periods, it is more suitable for longer periods. All other types of interaction can be applied to temporal periods of any length.

4.5 Use of the variables from a user perspective

4.5.1 Temporal levels of interest

The dynamic visualization variables can be used for exploration and analysis purposes at different levels in the temporal domain. Koussoulakou and Kraak (1992) refer to temporal 'reading levels', analogous to Bertin's (1974) reading levels in the spatial domain. Here, I prefer temporal *levels of interest*: the (parts of) an animated sequence in which a user is interested during various stages of use. Distinguished are:

- Elementary level: usually single frames or individual views on geospatial data that are the building blocks of an animation.
- Intermediate level: a series of frames showing a more or less coherent sequence of states and changes.
- Overall level: a long series, the whole animation.

Interest of the user in a particular level may be guided by aspects that somehow attract attention during exploration of the animation (see Section 2.5), by previous knowledge of the area or the application, by expectations but also by task-related questions and hypotheses that arise. In Section 3.3, for example, a distinction is made between generic monitoring questions for which answers are sought in relatively short (recent) and in longer temporal periods (see Figure 3.3). With respect to *vegetation* applications, the remark was made that in most cases where answers are sought over relatively short, recent time spans, it actually means within one growing season.

In terms of temporal levels of interest this signifies that in general:

- *intermediate* levels will be needed to find answers to questions that address relatively short (recent) time spans (i.e. the questions about relevant changes, differences or correspondences and anomalies);
- *overall* levels will be more applicable for questions that address longer time spans (i.e. the questions mentioned above over longer periods of time and, in addition, questions about processes, causes/relationships and spatio-temporal patterns or trends).

In both cases, however, interest may temporarily switch to lower levels in order to concentrate on certain aspects that have to be integrated later. Particularly during exploratory use of an animated representation, it is expected that interest levels will frequently change.

4.5.2 Effects of use

Use of the dynamic visualization variables in the ways sketched above generates effects on the observer. Bertin's approach, that works fine on graphic variables, was to base design decisions on 'effects' (or perception properties) of these variables to *measurement levels* of data (Bertin, 1974). Several authors have attempted to extend Bertin's approach to the dynamic visualization variables. MacEachren (1995) indicated at which measurement levels the application of these variables might be good, marginally effective and poor, but mentioned that no empirical testing had been done. Köbben & Yaman (1996) reported on a small experiment in which the results differ to some extent from MacEachren's proposal. Green (1999) linked his dynamic variables (see Table 4.1) to selective, ordered and quantitative perception properties, probably with the idea that these properties can be linked to measurement levels of data, like Bertin did for the graphic variables.

In fact, there is little empirical evidence that shows whether and how a link with measurement levels influences *use* of an animated representation of geodata. More important, however, is that the four dynamic visualization variables distinguished above can basically be applied to data of *any* level of measurement. The location in time, the order, the duration and the frequency of changes and states in nominal data (e.g. vegetation types), ordinal data (such as bare soils, light, medium and heavy vegetation) and interval/ratio level data (such as NDVI indices, average rainfall and temperature) can all be represented in the temporal dimension of an animated representation. I postulate that there is another way to link the dynamic visualization variables: through a connection between effects of the use of these variables, with or without interaction, and monitoring tasks/questions (see Figure 4.4).

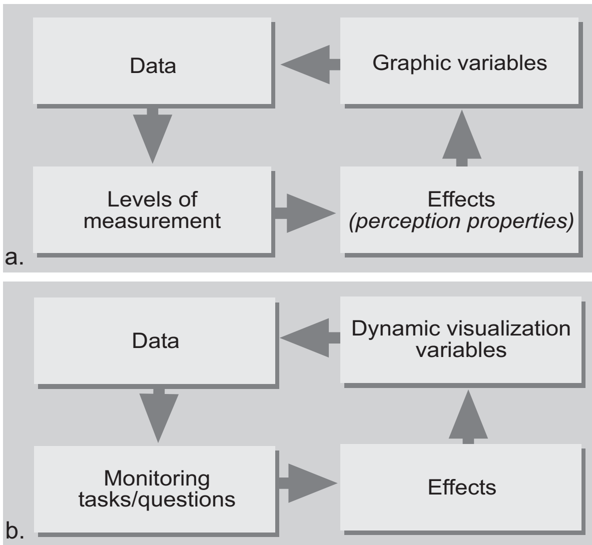

Figure 4.4 Bertin's method to use graphic variables for the representation of data (a) and the approach followed in this research (b)

The idea is that the variables are used because they generate certain effects. If we know what effects support users in their search for answers to (monitoring) questions, we might be able to recommend representation methods and tools that generate these effects. Even if a particular method or tool is not successful, it might be possible to find another one, because effects can often be created in various ways.

Figure 4.5 provides an overview of the effects of the animation-use activities in which the dynamic visualization variables are involved. Two main groups of effects are distinguished: *implicit* and *special* effects. If one plays an animated representation of geodata, it implicitly means that moments of display are marked in the temporal dimension of the animation. In addition, orders, durations and perhaps frequencies existing in the data or created by interactions with the animation become visible. An implicit effect of playing an animation, with or without interaction, is therefore that the *dynamic behaviour* of the data (influenced by choices made during the design of the animation) can be perceived. Another implicit effect is *rate of change*, i.e. the magnitude of change in an animation per unit of display time. As mentioned in Section 4.3, rate of change was originally proposed by DiBiase et al. (1992) as one of the dynamic variables but I consider it here as effect.

	Main dynamic visualization variables involved					
Animation use activities	Moment of display	Order	Duration	Frequency	Effects	
Play forward/play backward	●	●	●	●	Dynamic behaviour	**Implicit**
	●	●	●	●	Rate of change	
Selection of moments, periods	●				Visual isolation	**Special**
Zooming	●					
Selection of 1 or 2 thresholds, interval	●					
Step forward/backward, stop,	●					
Tuning	●				Synchronization	
Selection of classification and colour schemes	●				Re-expression	
Play backward		●				
Alternate moments		●			Swapping	
Alternate values		●				
Alternate classification and colour schemes		●				
Change of display speed			●		Rate of change	
			●		Pacing	
Change length of display time: value, interval			●		Emphasis	
Blinking moments				●		
Blinking values, intervals				●		
Looping				●	Review	

Figure 4.5 Effects of animation use activities in which the dynamic visualization variables are involved

Rate of change, however, can also be a special effect: an effect that is intentionally caused by interaction. The interaction that causes this type of effect is a change in the display speed. Increase or decrease of display speed directly influences the rate of change. *Synchronization* was originally proposed as a variable instead of an effect by MacEachren (1994b), as described above. *Re-expression* was mentioned earlier by Tukey (1977); Kraak & Klomp (1996) refer to 'relative' *emphasis* in relation to blinking. Other special effects that are intentionally caused by interactions with the representation are listed in Figure

4.5. Deselection of choices and use of the media player buttons 'to the beginning' and 'to the end' are missing in Figure 4.5. These interactions are considered as general controls of the animated representation; they do not create specific effects. Definitions of all effects are provided in Table 4.3.

Figure 4.5 shows that each of the dynamic visualization variables can be used to create a number of effects. Most special effects, on the other hand, can be generated by interactions with only one of the dynamic visualization variables; exceptions are re-expression and emphasis. *Re-expression* can be caused by interactions with the moment of display (selections of colour or classification schemes) and order (play backward); *emphasis* can be caused by interactions with duration (longer display time if particular values or intervals occur) and with frequency (blinking of moments, values or intervals).

Table 4.3 Definitions of the effects generated by interactions with the dynamic visualization variables

Effect	**Definition**
Dynamic behaviour	Succession of moments of display, orders, durations and frequencies in an animated representation.
Rate of change	Magnitude of change per unit of display time in an animated representation.
Visual isolation	Segregation of one or more selected times, locations and/or thematic attributes from the default representation of the data.
Re-expression	Alternative graphic representation of, or perspective on, the default representation of the data.
Synchronization	Correspondence between spatio-temporal patterns of two chronologically ordered representations of geodata in display time, irrespective of the time differences in reality (World Time).
Swapping	Interchanging two screen displays that show different times, locations, thematic attributes or representations.
Pacing	Adaptation of the speed at which moments of display, orders, durations and frequencies are represented.
Emphasis	Enhancement to stress selected elements in an animated representation.
Review	Multiple time views on (parts of) the animated representation.

The assumption made here is that the effects mentioned and defined in Table 4.3 support users in tasks with animated representations. One reason is that particularly the special effects may overcome some of the general problems with 'seeing change' (explained in Subsection 2.5.3). *Dynamic behaviour* is the most characteristic effect of any animated representation, generated by simply playing the animation. In a geodata context, it enables observation of the states and the changes of spatial phenomena over time. Section 2.5.3 indicates that playing an animation creates many low level motion signals. Attention of an observer may be drawn to *certain* movements in the animation, but many things will be missed as well, particularly when satellite imagery is animated, because pixel values change frequently and over the whole display area. There will be too many changes and they will occur too fast (and sometimes perhaps too slow) to be noticed, resulting in change blindness and inattentional blindness. It seems possible, however, to overcome at least part of the problems if we design interactive animated representations in which special effects can be created. Missing changes that are too fast (or too slow) may be avoided by interactions that result in adaptations of the *pacing* or the *rate of change*. The problems of being overwhelmed by too many changes, missing changes because of eye movements or other interruptions and not seeing changes because of involvement in another task can at least partly be tackled by interactions that create visual isolation, emphasis, swapping, synchronization and re-expression. *Visual isolation* means that part of the overwhelming signals can be excluded from the representation; it supports focused attention, which is necessary because attention can only be given to a few items at any time. *Emphasis* also supports focused attention by stressing selected aspects. *Swapping* enables quick comparison of a subset, and *synchronization* supports comparison by simultaneous display of two animations. *Re-expression* may help to overcome too narrow a focus on particular aspects, possibly leading to inattentional blindness. Finally, *review* seems a good way to tackle all these problems.

Another reason for assuming that effects may support user tasks is that some effects seem really useful to obtain answers to specific monitoring questions, while other ones are more broadly applicable. One example is emphasis. As described above, it can be created by displaying selected elements longer or by blinking. Blinking can be annoying but will certainly attract more attention (Evans, 1997). Therefore, it might be very suitable to display severe anomalies. This example illustrates that links can perhaps be made between monitoring tasks/questions and the effects of use of the dynamic visualization variables in an animated representation. One of the goals here is to establish and test those links. The idea, as described above, is that users *interact* because they aim at certain *effects*. Before testing, animation use scenarios have been developed for each of the monitoring questions (see Appendix 1). These scenarios predict the interactions that participants involved in an empirical test with a prototype will most likely apply. During the test, all the actions of participants with the prototype will be logged; in addition, participants will be asked to think aloud. User actions will be compared with the scenarios and verbal protocols will, among other things, reveal whether reasons for interaction can be found in attempts to create effects. The results will be described in Chapter 6. A potential problem is that the exploratory nature of the tasks may lead to interactions that are not really intentional and are difficult to foresee. This may lead to conclusions that are more tentative than definitive.

4.6 Summary

Four dynamic visualization variables are distinguished and defined in this chapter. These variables are part of a broader and developing framework of all kinds of variables to represent geodata. From a design perspective, the most important decisions to be made refer to ways to link the dynamic visualization variables to components of geodata and to ways to provide user control over the variables. Different options are described in this chapter. It is assumed that users who work with the controls apply them because they want to create certain effects. The types of effects that are desired are influenced by the task/question at hand. If this is indeed the case, then the effects of the variables can be linked to (monitoring) tasks/questions. This seems a more useful link than to measurement levels of data – a link that works well for the graphic variables (Bertin, 1974), but not necessarily also for the dynamic visualization variables. Two implicit and eight special effects are described. User tests will be performed to obtain proof of concepts, but before they can be described first the design and production of a prototype needed for those tests must be dealt with (see Chapter 5).

5 PROTOTYPE DESIGN AND IMPLEMENTATION

5.1 Introduction

This chapter describes the phases in the production of an application needed to test how the dynamic visualization variables and the controls (that are conceptually defined in Chapter 4) are used by domain experts to find answers to a number of generic monitoring questions (see Chapter 3). Evaluation is needed to gain insights in the cognitive aspects of variable use. The prototype is called 'Animated Image Visualization' (*aNimVis*). First, characteristics of the data set that was used as a case study in this research is highlighted (Section 5.2). Section 5.3 deals with the design of the first prototype that was evaluated in a focus group session. After some general design considerations (Subsection 5.3.1), aspects related to the main window (Subsection 5.3.2) and the tuning window of the application (Subsection 5.3.3) are described. In the next section (Section 5.4) I indicate how, and in what environment, the design was implemented. Details of the evaluation of the first prototype in a focus group session are then provided: Subsection 5.5.1 portrays the focus group method; procedures and participants of the session executed in this research are then described, followed by a section on the results (Subsections 5.5.2 and 5.5.3). Adaptations made to the prototype after the focus group evaluation are given in Section 5.6. The chapter concludes with a brief summary (Section 5.7).

5.2 Case study data

SPOT 4 VEGETATION data were used as a case study in this research. The SPOT 4 satellite, launched in March 1998, has been designed for monitoring of the landmasses of the earth. One of the sensors on board of the satellite is the VEGETATION instrument, a sensor with a wide field of view that operates in four spectral bands: blue (mainly used to perform atmospheric corrections), red and near infrared (sensitive to the photosynthetic activity and cell structure of the vegetation) and short-wave infrared (sensitive to soil and vegetation moisture content). The spectral characteristics of the sensor are very suitable for the detection of changes in vegetation. There is daily global coverage (see URL 3.6).

Various pre-processed products are offered, such as daily (S1) and ten-day (S10-NDVI) synthesis images. S1 products are particularly suitable for real-time applications like locust monitoring and for comparison with images from other sensors. For the monitoring of vegetation changes, they contain too much variation and there are also more cloud problems than S10 products. Furthermore, S1 products require much more downloading and processing time and they cannot be obtained free of charge, while the ten-day composites are downloadable for free (see URL 3.7). In this study, pre-processed S10- NDVI products are used. The images consist of mosaics that have been accurately georeferenced. This is important for animated representation: artificial shifts in the display of images of different times should be avoided. In addition to geometric corrections, radiometric and atmospheric corrections have been applied to enhance product quality. The reasonable spatial resolution (1 km × 1 km) and the high temporal resolution of S10- NDVI products make the data very suitable for a multi-sensor approach: users are able to obtain a quick overview of large areas to discover certain phenomena. If necessary, more detail can be obtained for selected areas and moments from a limited number of higher-resolution Landsat, MODIS, radar or other images.

NDVI values in the SPOT products are calculated from the red (0.61–0.68 μm) and near infrared (0.78–0.89 μm) spectral bands (see Subsection 3.2.2). For S10 images the maximum NDVI values per pixel are computed from all the passes acquired in each location during each ten-day period. Three images per month are produced: from the 1st to the10th, the 11th to the 20th and the 21st to the end of each month. Because of selection of maximum values for each pixel, cloud and no data problems are reduced. Nevertheless, the downloaded pre-processed data may still contain cloud cover. If the contamination is severe, additional processing such as (conditional) temporal interpolation or another operation is required to reduce the problem (Groten & Immerzeel, 1999).

The case study data underwent some additional cloud removal by taking quality information from the Status Map, which is delivered with each image, into account. This processing was executed by one of the vegetation experts at ITC, who had also organized the 147 ten-day composite images (for the period from 1 April 1998 to 1 May 2002) as stacked layers in a single ERDAS IMAGINE file (59 Mb). The main area included in the case study images is South West Iran, but the lower left corner also shows South East Iraq and North Kuwait (see Figure 5.1). The area broadly consists of the lowlands and delta of the main rivers Euphrates and Tigris, including the ecologically important Shadegan wetland area in the southwest. A broad northeast to southwest band of mountain ranges and highlands with peaks of over 4000 m (the Zagros and Kuhrud Mountains) separates these lowlands from the desert area in the northeast. Overall, the whole area can be characterized as semi-arid, although autumn and winter rains in the Zagros Mountains cause frequent inundation in the delta area. The wet season usually starts in October and ends in March; the other months of the year are dry. It is, however, hard to relate processes to weather in the irrigated areas (oral communication with two experts; various atlases).

Another S10- NDVI data set of northern Iran, near the Caspian Sea, has also been obtained (see Figure 5.1). It is a data set of the same period, processed in the same way, and of roughly the same size, which will be used in the familiarizing phase of the empirical tests described in Chapter 6.

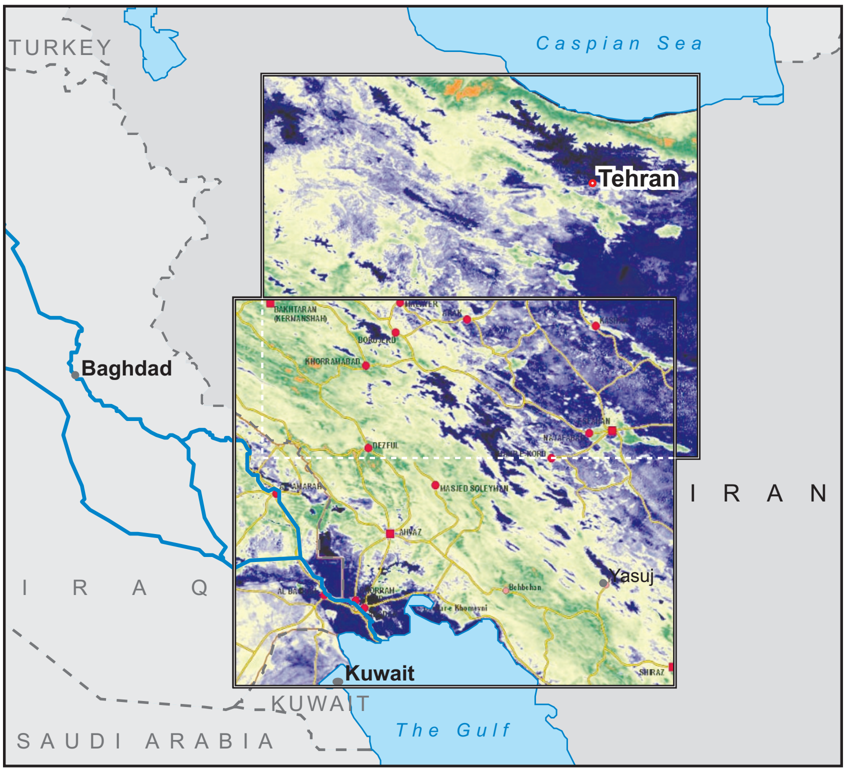

Figure 5.1 NDVI data sets of two areas in Iran: the set of northern Iran will only be used in the familiarizing phase of the evaluation sessions; the set of southwest Iran will be used as a case study

5.3 Initial prototype design

5.3.1 General considerations

The NDVI images described above consist of pixels (665 columns × 562 rows) in which values are represented that may remain stable for some time at particular locations. However, usually there is a lot of variation; changes that differ in magnitude and in speed are happening all over the display area of a running animation. Perception and cognition of users can easily be overwhelmed by such a representation. If there are too many stimuli that attract attention, change blindness and inattentional blindness (see Subsection 2.5.3) are very likely because attention, which is needed to see patterns and change, can only be focused an a few objects at any one time.

Another main potential problem with remotely sensed imagery –- even more if individual pixel values change frequently – is the figure-ground perception and grouping of pixels into spatial and spatio-temporal patterns. Figure-ground perception refers to the organization of the visual field into figures that stand out from their surroundings (the ground). The 'figures' in this context are patterns that have to be identified and compared in order to find answers to monitoring questions. Grouping means that some elements appear to belong together rather than remaining isolated and independent. Grouping principles have already been defined in the early 1920s by Gestalt psychologists. Examples of principles that are relevant to grouping in the context of my research are proximity (of locations), similarity (of attributes) and simplicity in the spatial domain. Additional principles in the spatio-temporal domain are objective set and common fate. Objective set refers to the tendency that perceptual units that are seen once as a group remain a group, even if the position of the units has changed over time. Common fate refers to the fact that objects or entities that are moving together tend to be seen as a group (MacEachren, 1995; Bruce et al., 1996). Both stimuli that attract attention, such as motion, and grouping principles influence figure-ground perception. Other major factors that influence pattern perception are contrast and the type of processing applied by the user: global, overall processing into an integrated whole; or more detailed, local processing. Finally, spatial and temporal scale or resolution are among the factors that influence pattern perception.

The potential animation-use problems sketched above of being overwhelmed and not being able to distinguish patterns have to be taken into account in the design, particularly because – in addition to a representation in which changes are happening simultaneously and sequentially – legends and options to interact with the display as described in Subsection 4.4.2 have to be incorporated in the interface. An interface is what the users see and work with to use a product (Hackos & Redish, 1998). According to the pattern identification model described in Section 2.3, map-based identification and comparison of patterns rely in the first phase on quick and largely unconscious bottom-up processing (*seeing that*). The reaction obtained in this phase is then further interrogated on the basis of prior knowledge and experience (*reasoning why*). The aim of the design phase, therefore, is to facilitate relatively quick identification and comparison of patterns in the first phase, so that the processing load of users will not be unnecessary burdened and overloading of the perceptual system is limited. In addition, interface heuristics (general principles that can be used to guide and evaluate interface design decisions) should be taken into account. Important heuristics are that user feedback should be provided (for example, if the system is busy) and errors should be prevented. Other heuristics are that users should understand the interface; conventions, a logical arrangement and order of elements, simple and natural dialogues, consistency and clearly marked exits all contribute to this (Nielsen, 1993; Dix et al., 1998).

The default appearance of the prototype used in the focus group session is represented in Figure 5.2. Opening of the application may take some time (depending on the processing power of the computer), but the user is kept informed of the progress by a status bar at the bottom of the window. The largest part of the window is reserved for the representation of the images. The display area is kept relatively small (approximately 9 cm × 11 cm) to be able to view the whole image (without scrolling or panning), together with the complete interface on standard computer monitors. Time bar, media player and display speed controls can be found under the display area and thematic legend and base map layers to the right of it. Menu and tool bars are located above the display area. Tuning can be considered as one of the menus of the prototype, but since the representation and the functionalities of tuning differ to some extent from the rest of the application, it is represented as a separate tab in the interface. All other functions belong to the main tab. These two tabs, or windows, are discussed separately in the remainder of this section.

5.3.2 Main window

Provision of *media player controls* is an absolute minimum requirement in terms of interaction possibilities. Most important for visual exploration (in addition to play) are stop and step forward/backward. Stop turns a running animation into a static image, which can be explored and analysed as long as users want without attention being directed by motion. The stepping buttons offer similar options in addition to enabling navigation in display time, like all the media player controls. Playing an animation backward may perhaps reveal other patterns than playing it forward. All common media players offer these standard controls. The image processing software used to generate the file for the case study data (ERDAS IMAGINE) also has a 'movie' function with media player controls, as well as options to move to a particular frame number and to change the display speed. Java applets, Flash or SVG interfaces found on the Web offer usually more functionalities. Although simple controls definitely play a role in visual exploration, we need to move beyond this level to facilitate quick identification and comparison of patterns.

Display speed control is essential for two reasons: adjusting the speed may prevent users from becoming overwhelmed by the animation sequence, and it may also reveal patterns that would otherwise not be visible. For example, changes that are too slow to be noticed, leading to change blindness, are illustrated on URL 2.7. However, the changes are *immediately* noticeable if the slider is dragged to increase the display speed. The speed of a running animation in the prototype can be changed 'on-the-fly'.

The *time bar* is an active temporal legend. Position in time is dynamically displayed and users can click in the time bar or drag the time indicator in conventional ways. One of the environmental scientists consulted during the development stage of *aNimVis* is interested in the response of vegetation (mainly reed) to inundations in wetlands. He suggested inclusion of one or more hydrographic graphs to explore relationships between the discharge of water by rivers into the delta area and the vegetation dynamics. He also provided data for one of the main rivers (the Jarrachi river), measured at the Shadegan hydrographic station. Although there was no complete temporal overlap with the NDVI time series, it was decided to experiment with these data by exposing the participants of the planned focus group session to a hydrographic graph embedded in the time bar. This results in a kind of dynamically linked graphics. Users can, for example, click on a discharge peak in the time bar, and then start the animation to explore the NDVI images from the moment of the discharge peak onwards. Actually, a graph of any related variable can be loaded into the time bar. Embedding one of the graphic representations in the time bar means that the amount of saccades (a major cause of change blindness, see Chapter 2) between image, graph and time indications can be reduced.

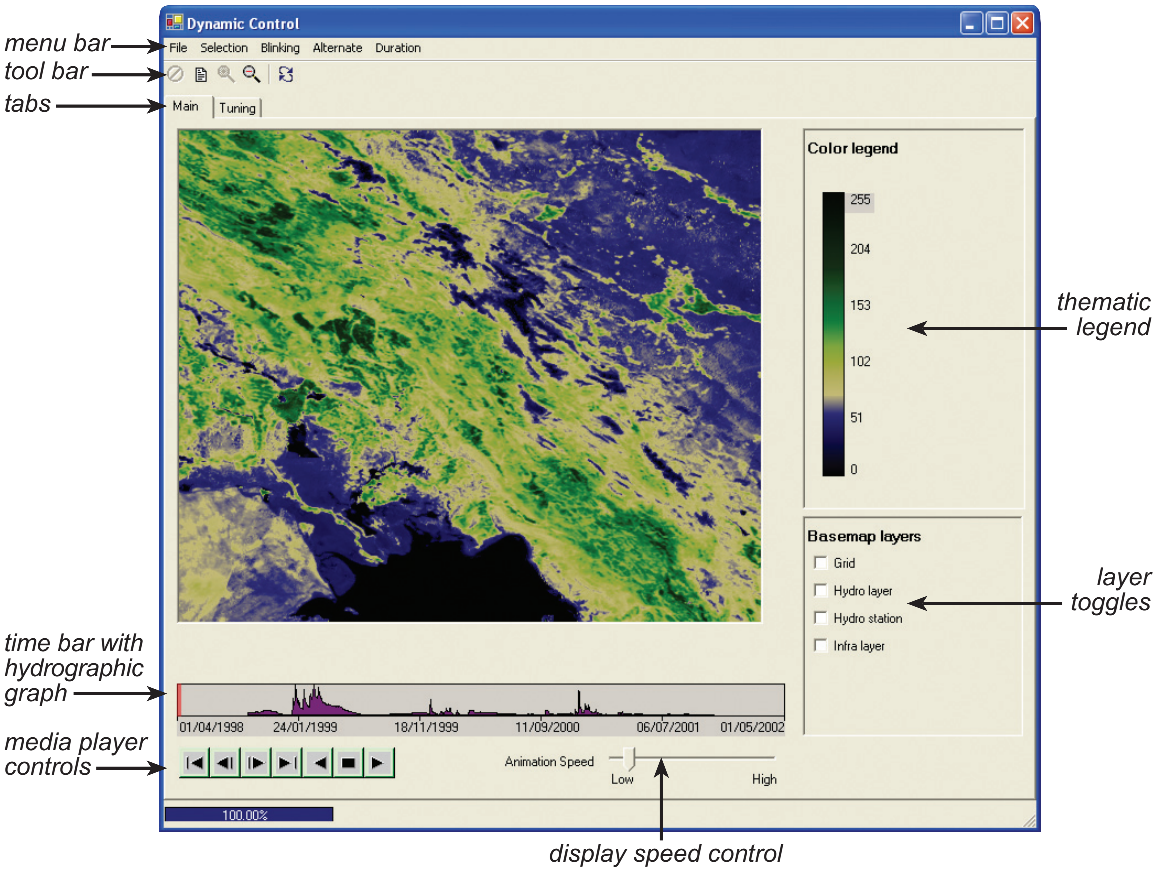

Figure 5.2 Main window of the first prototype

Base map information is indispensable. It gives structure to the changing NDVI patterns, which may help users to focus on particular locations. The grid, for example, may help to focus on particular grid cells. Base map information enables users to locate patterns in space and may provide valuable information to explain the patterns observed. On the other hand, it may also be distracting. In order to keep the images simple and help users to concentrate on the theme, several *base map layers* have been included that can be independently toggled (on or off). In addition to a grid, there are layers containing hydrographic information, main roads and cities and a layer on which the position of the Shadegan hydrographic station (see above) is indicated.

Buttons are provided to zoom in, zoom out or return to the full extent (view). Zooming is considered essential since the images in the display area are relatively too small to enable a quick overview. If interesting patterns are seen, however, or if a user wants to have a better view on a particular area, zoom is needed. A loop option is considered crucial to review (parts of) the complex representation as often as users want. Finally, there is a button to clear temporal selections (see below). Clear selection and back to the full extent are examples of 'exits' to which one of the heuristics refers.

The *file menu* on the menu bar has just two options: open and exit. The *selection menu* contains options to view temporal and thematic subsets of the data. These options seem useful because they reduce the amount of information presented, avoid perceptual and cognitive overload, and facilitate identification and comparison of patterns. Possible temporal selections are (one or more) moments or periods. So while the default animated representation offers a linear view on time, the temporal selection options add possibilities to view changes between distinct moments or selected periods in an animated way, or to compose cyclical views on time. Examples of moments are times at which the hydrographic graph shows peaks, the start of the growing seasons, etc. Periods could be periods with low discharge, or one or more growing seasons. Selections can be made in a pop-up window in three ways:

- typing in date fields;
- clicking in a calendar;
- clicking (moments) or clicking while holding the mouse and dragging in the time bar until the required period(s) is(are) selected. The hydrographic graph is also visible in this time bar.

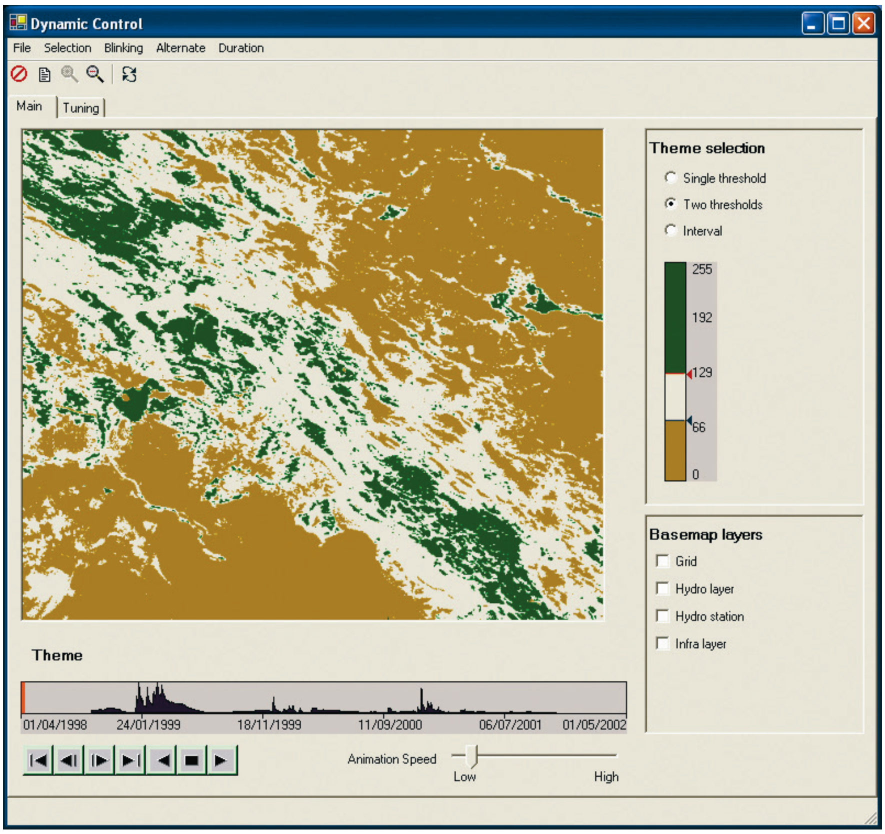

Figure 5.3 Two thresholds have been selected via the selection menu, thematic option; values below the lower threshold are represented in brown, values above the higher threshold in green

When temporal selections are made, the pop-up window disappears and the selections are marked in the time bar of the main window.

Thematic selections include options to define a single threshold, two thresholds, or an interval in the value range (Figure 5.3). Selections can be made by a single click in the legend or by clicking while holding the mouse and dragging until the desired value is reached. Only those pixels that have the selected value ranges will be displayed in the animation. In the case of a single threshold, all pixels with values above it are represented in green, the rest in brown. With two thresholds, green is used for values above the high threshold and brown for values below the lower one. The remaining pixels are transparent. Pixels belonging to a selected interval are green, while the rest of the image is transparent. Independent and dynamic change of the thresholds (slicing) is possible, even in a running animation. This filtering is important for exploration purposes, patterns may look different if thresholds are changed (van der Wel et al., 1994); it also provides contrast, improves figure-ground separation and facilitates global processing of patterns. The selection menu contains an option to clear temporal and thematic selections.

The default settings show a continuous representation of the NDVI values in digital numbers (DNs): values are stretched to the range 0–255, according to the SPOT formula, to improve the contrast (see Subsection 3.2.2). The colour scale selected for the values starts with black and blue for clouds, no data and water; it then uses a scale from brown to very dark green for bare soils and vegetated areas. The selection menu provides an option to choose other colour schemes and/or classified representations. I consulted two experts about this. With respect to classification, their advice was that grouping into equal classes (above approximately 50) could be added, and an opportunity for users to define their own class boundaries through one or two thresholds or intervals would be desirable. The latter option was provided in the thematic submenu of selection (see above). Colour was preferred over greyscales for the images because one can differentiate more with colour. There are no standard colour schemes, but a kind of natural pseudo colours are commonly used. This was applied in the NDVI option, where data are also classified into nine equal classes above 50. One of the experts pointed to some examples and also provided two colour tables that are used in the WinDisp environment to represent NDVI images (*256 color* and *Afr_ndvi*). When applied to the SPOT data in the application, these colours looked odd. At this stage I decided, however, to move on and to further discuss the colour issue in the focus group session.

The menu bar also contains a *blinking menu*. Blinking dominates perception and attracts attention. It should be used with care since it may annoy the viewer, because repeated retinal activity overloads the visual system; blinking is one of the causes of change blindness (see Subsection 2.5.3). On the other hand, blinking provides contrast with the appearance of other elements of the map and the Gestalt grouping principle of common fate seems particularly valid for symbols that blink together. In the prototype it is possible to highlight selected moments in time in the running animation (e.g. the start of a growing season, or the same date in successive years). Moments can be chosen in the same ways as in the temporal selection menu. A frame corresponding to a selected moment blinks twice (repetition of selected frame, highlighted frame) before the animation continues. Thematic blinking offers selection of a threshold or an interval in the legend. Frames in which pixels with values above the threshold occur blink in the same way as moments. In the case of an interval, pixels with values in the selected range are highlighted. Just as with the thematic selections, dynamic slicing is also possible here.

The *alternate menu* facilitates relatively quick comparisons. There is an option to alternate two moments in time. As soon as this or one of the other options is selected, the default media player buttons and speed control disappear, and an alternate/stop button appears. Moments can be selected in the time bar. The other options are to alternate two thematic values or two different representations for one moment in time. Values can be selected in the thematic legend and choices can again be dynamically changed. Pixels are represented in the colours of the two handles used to make the selections: blue for low values, red for high ones, the rest of the image remains transparent. Some doubt exists about the usefulness of this option because it can only be used for values in one frame each time. Empirical testing should shed light on this issue. Representations can be selected from the two lists that appear with this option. The stop button has to be pressed in all cases when a user wants to select different moments in time.

The *duration menu* enables the selection of a threshold or an interval in the thematic legend, just like thematic blinking. If pixels with selected values occur in a frame, the frame holds for a moment and a small red box appears under the frame to warn users who might otherwise think that a processing problem prevents smooth running of the animation. The slightly longer visibility of a 'frozen' frame gives more time to observe patterns formed by values of interest, while the thematic context is maintained. This is not the case with choices made in the selection menu, where selected values are isolated from the thematic context.

5.3.3 The tuning window

The tuning window is shown in Figure 5.4. In the literature, the possibility of using two simultaneously running animations to discover (causal) relations and possible time lags between *different* data sets is mentioned (MacEachren, 1995; Kraak & Ormeling, 2003). Only *one* data set is used in the prototype, but the principle remains the same: users are able to explore to what extent patterns are similar and whether there is a time lag in developments between different years, seasons or other periods of interest.

Patterns of different static maps can be mentally integrated (MacEachren & Brewer et al., 1998). However, to the best of my knowledge, there is no conclusive evidence about the human ability to pay attention to two simultaneously running animations. Detailed local comparison of two animations does not seem possible, but global processing of broad pattern similarities and differences might be carried out. This requires small display areas and also limits the number of saccades needed for comparison. The user is supposed to select different moments to start the first and the second animation in the two time bars. If the box 'link animations' is checked, the start will be simultaneous and the media player controls next to the second animation disappear. If *synchronize speed* is also checked, the animations will run at the same velocity and the lower speed control will disappear as well. Separate controls might be useful if changes in the patterns of the two representations occur at different speed in world time (Blok et al., 1999).

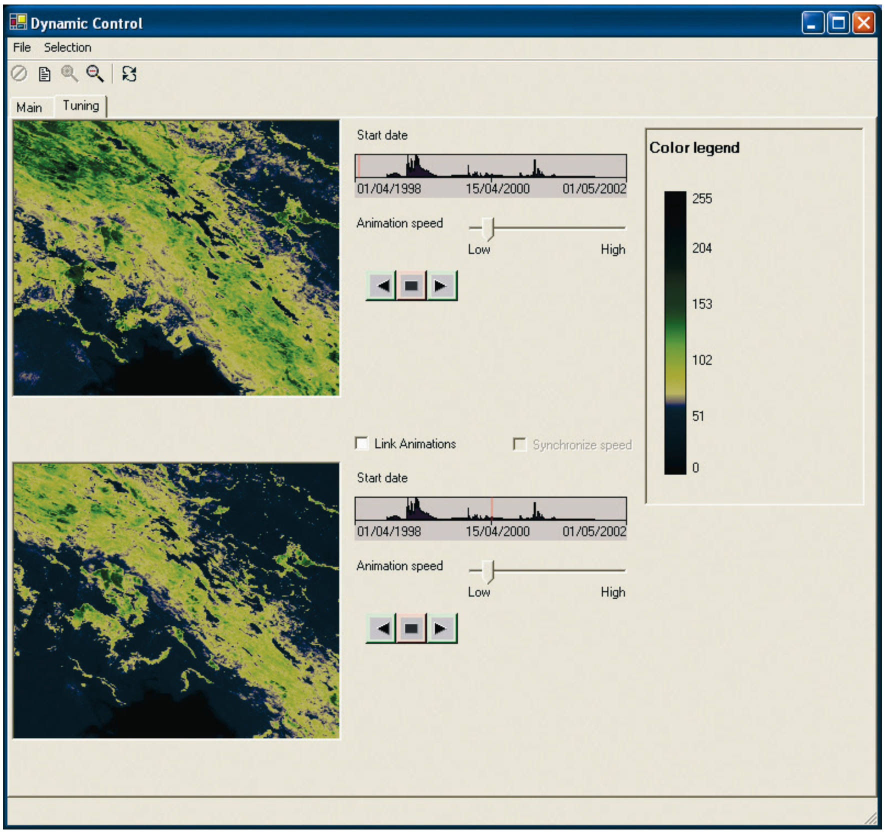

Figure 5.4 The tuning window

The only *buttons* that can be used in addition to the media player controls in the tuning window are the loop and clear selection; zooming is not possible. The only available *menu* is *selection*. It offers the same options as in the main window, except for the temporal moment and period options.

5.4 Implementation

All operations and the way in which users can initiate them are implemented in an application made by the software developers of ITC's Information Technology (IT) department. Implementation was an iterative process that started with the definition of requirements of the functionality (see Chapter 4) and a priority list for realization within the available time frame. On a regular basis (usually weekly), progress was discussed with the main developer. After some basic functions had been implemented, a regular test version could be released. Detailed walkthroughs of each version revealed a number of problems, which were all reported to the developers; the main issues were also discussed in regular meetings. The problems found during this first evaluation were solved as well as possible before the application was exposed to domain experts (see Section 5.5 and Chapter 6).

The interface has the well-known WIMP style, which stands for Windows, Icons, Menus, Pointer (or sometimes: Windows, Icons, Mice, Pull-down menus). On mouse-overs, tool tips appear to explain the functions of the buttons and dates appear in the time bars. The dates are interpolated based on the whole time range and the total number of frames; the dates at which individual frames are generated are not specified in the program. The programmed animation speed for main and tuning window ranges from low = 0.2 frames per second (fps) to high = 20 fps. The speed that is reached, however, depends to a certain extent on the computer system used, the size of the application window on the screen and the size of the image file. Therefore, absolute frame rates are not indicated. Overall speed will be affected if the blinking or duration options are used. Blinking (a sequence: normal-highlighted-normal-highlighted frame) takes approximately 250 ms per event. Holding a frame because of a selection in the duration menu lasts 1 s. In the alternate mode 2 fps are displayed.

Image data, base map layers, some colour files and the table for the hydrographic graph can all be opened with the file/open option. The images are stored in an ERDAS IMAGINE (.img) raster file. The base map layers, generated in vector format, are exported as bitmaps (.bmp). All .bmp-files stored in the base map folder that is opened are automatically represented with a check-box in the base map layer pane of the interface (in alphabetic order). Two colour tables are fixed in the application: the default DNs and the (classified) NDVI table. Other colour tables can be added or replaced, because the application supports text files with the extension .clr as colour tables. The files must be located in the same folder as the raster file; they are automatically loaded and appear in the selection menu under the representation option. Data for the hydrographic graph in the time bar are stored in an Excel table. If desired, another graph can be loaded; it just requires another Excel table, formatted in the same way.

The prototype is a .NET application. Microsoft. NET is an entire software platform. One of its components is . NET Framework 1.1, an object-oriented development environment that can be used to create various applications that can be launched locally on a computer, but they can also be integrated with other systems through the Internet by XML Web Services. Integration is possible by adding a Web Services layer around each application or system that exchanges information and functionality in a standard way; XML (eXtensible Markup Language) is the new Internet standard. . NET applications are created with developer tools such as Microsoft Visual Studio. NET; several programming languages, like C #, are also supported (Miller, 2003; URL 5.1). The prototype of *aNimVis* was completely developed with Visual Studio. NET and C #.

Table 5.1 Name and brief description of the files that belong to *aNimVis*

Name	**Description**
aNimVis.exe	The application
gdall11.dll	Package for accessing GIS (raster) data
gdal.dll	Package to interface between gdal and .NET environments
msvcr71.dll	Core dll required by gdal.dll
statusmessaging.dll	Core dll required for the status bar

Table 5.1 lists all the files of the application. Two packages need to be installed, however, before it can be used; both can be downloaded from the Internet:

- Microsoft . NET Framework version 1.1. (dotnetfx.exe is the installation package for the . NET framework);
- MS Access Components (mdac_typ.exe is the installation package; version 2.7 or higher is needed to read the Excel table that contains the data for the graph in the time bar).

5.5 Evaluation of the design in a focus group session

5.5.1 The focus group method

In usability literature, it is strongly recommended to conduct more than one evaluation of a product (e.g. Nielsen, 1993; Dix et al., 1998). Applying several, even small and simple, methods to obtain feedback almost always improves a product substantially. It also reduces the risk of failure. One relatively simple, formative usability engineering method that is commonly applied to obtain qualitative information about a prototype is a heuristics evaluation. A small number of evaluators (commonly 3–5 *usability engineers*) are asked to examine the interface of a prototype and to judge its compliance with recognized usability principles: the heuristics (Nielsen, 1993). Another common method, use of a focus group, was applied in this research. In a focus group session, *domain experts* evaluate the effectiveness of a prototype in the context of their domain; this was therefore considered more appropriate than a heuristics evaluation. After the session participants are introduced to the product, and a discussion is held to collect information on opinions and experiences. The main advantage of this method is that it reveals broad patterns of use, misconceptions and errors; it is also relatively easy, affordable and can be quickly assessed. A possible disadvantage is that the (qualitative) results may be biased, for example if the participants are not freely expressing their opinions and feelings, or if the moderator lacks control over the session. Sometimes more than one session is conducted to obtain the opinions of different groups (Nielsen, 1993; Morgan, 1998a, 1998b). In a Geovisualization context, the method was applied by Monmonier & Gluck (1994) to better understand user reactions to animation. Other examples are Harrower et al. (2000), Fuhrmann (2002) and Lucieer (2004); see also Suchan & Brewer (2000). On average, a session takes 1–2 h. The recommended number of participants varies slightly: 5–10 (Monmonier & Gluck, 1994) or 6–9 (Nielsen, 1993). A moderator prepares questions or statements to be discussed, leads the discussion and ensures that all participants contribute.

5.5.2 Procedure and participants

The main goals of the focus group session were to obtain opinions and reactions on the prototype and to minimize potential usability problems in the later evaluation. Another goal was to discuss the relevance of the tasks planned for the evaluation session. It was expected that, if not all, at least the most serious problems would be discovered. All six domain experts approached agreed to participate in the focus group session. At the last moment, one of them had to withdraw and no replacement could be found at such short notice. Nevertheless, this expert was eager to provide individual feedback; this was done a few days after the group session. All participants of the group had an academic background and were skilled users of both GIS and image processing software. Three of them had a lot of experience with NDVI time series and monitoring; the other two had worked with NDVI or other time series and had experience in information technology as well. The main developer of the prototype was also present during the session to contribute, if necessary, to the discussion about problematic aspects or redesign issues. He also noted any bugs encountered by the participants during the familiarizing phase, which was very useful.

The session took place on 12 March 2004 in a computer cluster at ITC (Enschede, the Netherlands). Software had been installed and checked on seven PCs for demonstration purposes and for hands-on experiences. Furthermore, a beamer and projection screen were available for the demonstration, as was a recorder to audio-tape the discussion for further analysis. The session started with a brief introduction and a demonstration of the prototype by the moderator (the researcher) that lasted about 25 minutes. Participants were requested to look at the prototype from a monitoring perspective. It was emphasized that the prototype was meant for visual and interactive exploration of the data representations, and that analytical or computational techniques were not supported in the current set-up. After the introduction, participants were given the opportunity to familiarize themselves individually with the prototype. A handout was provided to stimulate a structured walk-through of the application; attached were also some typical monitoring questions (see Section 3.3), to which they could try to find answers. This part of the session was scheduled for 50 minutes, but actually lasted only about 30 minutes because two of the group members announced at the beginning of the session that they had to leave earlier than planned. Since the discussion is the most important part of a focus group session, the moderator decided that the planned 45 minutes for discussion should be maintained at the expense of some time for familiarization with the application. It meant that there was sufficient time for the structured walk-through, but

no attempts were made to answer all the monitoring questions. The consequence of this was that these tasks could, unfortunately, not be discussed.
The discussion focused on the representation of the data and on the functionality and potential usefulness of the application. The moderator attempted to involve all participants, sometimes by prompts to participants who had been silent for some time, and sometimes by asking participants to answer a key question individually (Krueger, 1998), for example about the most important things that needed to be improved in their opinion. The discussion led to valuable feedback (see Subsection 5.5.3 for results).

The person who had to withdraw from the group session received the same introduction, demonstration and handout as the group. After some familiarization with the software, he provided individual feedback, which was largely in line with the feedback obtained from the members of the group (see below).

5.5.3 Results

Results of the discussion and other feedback are summarized in Figure 5.5. Wishes/suggestions made and bugs are listed there, together with the priority levels for implementation in the next version of the prototype. First priority was given to bugs and to other items that were deemed necessary for a proper evaluation of the use of the dynamic visualization variables (an important research objective). Second priority was given to those items that were considered important additions but not *absolutely* required in the context of the research. The remaining items, which may be important but not relevant from the perspective of the research objectives, were given third priority.

In the discussion about the graph, one participant mentioned that it would be useful to see the graph of a *selected* pixel or area in the time bar. This option, or average pixel values, was also mentioned by the expert who gave feedback a few days after the group session. The participants of the focus group realized, however, that it would mean that an enormous amount of data would need to be accessible. It was then concluded and agreed by the majority that it was more important to be able to exchange data with image processing software, where functions to view graphs at a pixel or area level are available, than to be able to see all kinds of graphs in the prototype. One participant maintained that it would be very helpful to include such a function in the prototype.

For the exchange of data between packages, it was considered important to be able to somehow mark interpretations of the patterns seen in the prototype (e.g. by screen digitizing a mask with coordinates) before the data are further analysed in image processing software. As one participant mentioned: *'What you see needs to be interpreted. You don't want to go to other software to interpret it in a difficult way without a movie ...'* In the current prototype, pixel coordinates cannot be seen. The only option is to draw patterns seen in the animation on paper, which is of course rather cumbersome.

Discovering anomalies is important in a monitoring context (see Chapter 3). There was a brief discussion among the group about possibilities to discover anomalies with the prototype. One option would be to compare a recent image with an image containing long-term average values; another option would be to calculate anomalies in image processing software, and then run it as animation in the prototype.

Wishes and suggestions	Priority level for implementation 1st	2nd	3rd
Colour schemes and thematic legend			
- more colour schemes (such as schemes used by various organizations, like in WinDisp)		●	
- clear representation of missing values (e.g. due to clouds)	●		
- interactive colour selection, e.g. with classification/slicing			●
- option to change the values in the thematic legend (e.g. from -1 to 1 or different in case of other data)			●
- descriptive statistical values of a selected thematic class, like number of pixels or area, patchiness			●
Time indication and time selection			
- hydrographic graph in the time bar is too specific for the participants; an NDVI graph would be useful to facilitate selections in time	●		
- add a date counter, particularly in the tuning window	●		
Support of identification and comparison			
- improved zoom function (up to pixel level)	●		
- maximize the window of the application on the monitor screen		●	
- DEM or other information about relief		●	
- option to compare with other data sets in tuning or in a separate window (e.g. to detect anomalies)		●	
- controls to step through the animations in the tuning window	●		
- screen digitizing to extract lines/polygons of patterns in the time series		●	
- add coordinates			●
Bugs or operation problems			
- no option available to reset to the default animation state	●		
- selection of moments/periods in the pop-up window should be improved	●		
- selection of thematic values should be improved: sliders cannot easily be moved independently	●		
- tuning sometimes fails to start	●		
- linked animations in tuning are not running at the same speed	●		
- the start button in the alternate mode is sometimes disabled	●		
- the legend does not always change if another representation is selected	●		
- blinking is not very clear	●		
- duration should work for a thematic interval	●		

Figure 5.5 Results of the focus group session and other feedback to the initial prototype with priority levels for implementation in the next version

The relationship between visual and analytical approaches to the data was also discussed by the group. The general opinion was that the prototype adds value to interpretations that can be done with image processing software, but that improvements still need to be made. One participant said: *'A purely statistical approach is blind. You forget something. An expert should first look at the data and then apply statistical techniques.'* Another group member mentioned: *'Many things are not visible in one image, but in more: changes, processes. If I want to compare a time series now, then I am to a large extent limited to producing several colour composites or making small movies, but these are not so interactive as they are here.'* The experts further mentioned that it is very cumbersome to work with colour composites only: *'With few images, it is possible, but if you want to see important things in larger Meteosat, SPOT VEGETATION or NOAA time series, something else is needed and then visualization is really important.'* It was mentioned that it is possible to extract a few relevant images from a larger series for further calculations in this way. The group concluded again that calculations are not absolutely necessary in the prototype because they can be done in other software in advance or afterwards, but then the prototype needs to be accessible from other software, for example as a module or a plug-in.

A question raised at the end of the focus session was whether the prototype could be used for applications other than monitoring. One participant mentioned that the prototype is in principle suitable for every data set that can be reduced to single values for each pixel (e.g. biomass, grazing capacity, crops). Somebody else remarked that boundaries and gradients in the data over time can be nicely seen. These can be used for a different kind of vegetation mapping: one in which boundaries are not as fixed as in current vegetation maps. Discovering the phenology of crops or rangelands, particularly any developing trends, was mentioned by another expert.

5.6 Adaptations to the prototype

The results of the focus session were discussed with the software developers. The amount of programming and research time that was left for improvements was limited. It was decided, therefore, to aim at the removal of all reported bugs and operational problems, to tackle the first-priority issues and only those second-level issues that could be solved within the time available. Third-level priorities were not considered in this stage.

All reported bugs and operation problem were solved with one exception: blinking of thematic values (above a threshold) was not changed because of a lack of programming time and some communication problems. An optional default view was added in two ways: as a button on the button bar and in the selection menu.

With respect to the first- and second-priority wishes and suggestions, colour schemes were added and changed. In the version for the next evaluation, seven schemes were included: two continuous ones, three schemes with 10–13 classes, and two coarsely classified schemes with 4–5 classes. The choices were partly based on examples used for SPOT VEGETATION data found on the Internet and partly on WinDisp tables. Since the thematic legend only provides some numbers between 0 and 255, and no class names, it was decided to explain the different schemes and indicate the classes with clouds/no data in a document to which participants of the next evaluation could refer (see Chapter 6). The graph in the time bar was replaced by a graph showing the average NDVI value of each frame (image) in the animation. It clearly shows seasonal patterns. Date counters were added in the main and in the tuning window; they dynamically indicate the (interpolated) time of the image(s) being displayed. Zooming up to pixel level was implemented. No time was left at this stage to also include panning, a useful function in combination with powerful zooming. The size of the window of the application on the monitor screen was maximized. With respect to elevation, to include a DEM would require redesign of the application so it was decided to add contours as a base map layer instead. This only gives a rough idea of the relief and cannot replace a DEM, particularly because no contour values could be added. Although tuning is intended for comparisons, it is not designed for comparison of different representations of an area (e.g. images from different sensors), but for comparisons between two possibly related themes (e.g. vegetation and rainfall) or for comparisons in time within one theme (e.g. the growing seasons of 1999 and 2000 in NDVI data). A data set of a possibly related theme, covering the same area and period, could not be found. However, since testing of the tuning function is also possible with the available NDVI time series, no further efforts were made to extend the comparisons in the tuning window at this stage. Adding another window to enable comparisons of different representations was not feasible within this research. Another wish that could unfortunately not be implemented at this stage is screen digitizing to mark lines or polygons of patterns seen in the animation, and storing or exporting them (e.g. as a mask).

After implementation of these changes, a new version, now briefly named *aNimVis*, was ready for further evaluation. Illustrations of the revised main and tuning windows are included in Appendix 2a.

5.7 Summary

As a case study, a SPOT 4 VEGETATION data set containing ten-day synthesis images was obtained for a period of more than 4 years. This data set was used to design and implement a prototype application called *aNimVis*. Prototype development is and was an iterative process, with close cooperation between the researcher and the software developers. User feedback on an initial design was obtained through a focus group session. This session and some additional feedback proved to be very useful for making further improvements. Possible adaptations were ranked according to the need to implement them from the perspective of the research objectives. Most of the first- and second-priority adaptations could be made. That made the prototype ready for further evaluation, which will be described in Chapter 6.

6 EVALUATION

6.1 Introduction

The overall goal, main objectives and generic questions of experts involved in the monitoring of dynamic spatial phenomena are described in Chapter 3. Some of these generic user questions will be entered as tasks in the evaluation of the visual exploration environment created to support experts in finding answers to their questions. The design and implementation of this environment, *aNimVis*, is described in Chapter 5. But first, the question as to whether such a visual environment based on *animated* representation of imagery could, in theory, support experts in finding answers to their questions needed to be asked. This question underlies many of the issues discussed in Chapters 2, 3 and 4 (see also Figure 1.2). In Chapter 2 problems related to 'seeing' change are identified, since monitoring is about change. Characteristics of change that can be visually explored are distinguished in Chapter 3. Main pattern-related cognitive tasks and temporal levels of interest that support users in gaining insight into the behaviour of dynamic phenomena are described in Chapters 2 and 4, respectively. Then, methods by which the *dynamic visualization variables* can be used to acquire or discover information from time series (a main objective of this research) are considered in Chapter 4; they are implemented in *aNimVis*. The prototype was then adjusted after a focus group session (Chapter 5). The next step, described here, is the detailed evaluation of the use of such an environment by domain experts in a monitoring context. This evaluation is necessary to be able to draw conclusions about the theoretical constructs described in earlier chapters and in Section 6.2.

Section 6.2 presents the main objectives of the evaluation and a conceptual model. The model attempts to predict major use of animation activities in solving various problems with the application. Strategies and cognitive processes of domain experts during execution of tasks are important aspects of the evaluation. After all, gaining knowledge of these aspects is another main objective of this research. Section 6.3 starts with a brief overview of commonly applied qualitative evaluation methods, followed by justification of the selection of the think aloud method, interviews and questionnaires (Subsection 6.3.1). The next subsections describe the materials that have been produced and the test environment (Subsection 6.3.2), participants (Subsection 6.3.3) and the evaluation procedure (Subsection 6.3.4). Results are presented in Subsection 6.3.5 and some of these results are discussed in Section 6.3. A brief summary is given at the end (Section 6.5).

6.2 Conceptual model

This research is focused on dynamic visualization variables and their use in a monitoring context. As mentioned above, a major research objective is to develop methods by which these variables can be *used* to acquire or discover information from time series. Hence, use has to be evaluated. In Subsection 4.5.2 it is suggested that the use of the dynamic visualization variables generates certain effects (e.g. visual isolation, re-expression, adjustment of the rate of change) and that linking these effects to user questions or tasks might be a more useful framework for application of the variables than linking them to measurement levels of the data. In addition to use, *user behaviour* is then an important aspect of the evaluation. This is emphasized in the second major objective: to gain knowledge of strategies and cognitive processes of users while they are working on tasks with the application. Particularly the role of the effects has to be taken into account. The research objectives have been formulated on the basis of the assumption that knowledge of the aspects mentioned may lead to theoretical advancements and that it will shed light on the kinds of methods and controls required to increase the effectiveness of animated representations.

First, I want to introduce an animation use model that attempts to describe how monitoring questions or tasks are processed by users who visually explore time series with an application like *aNimVis* (see Figure 6.1).

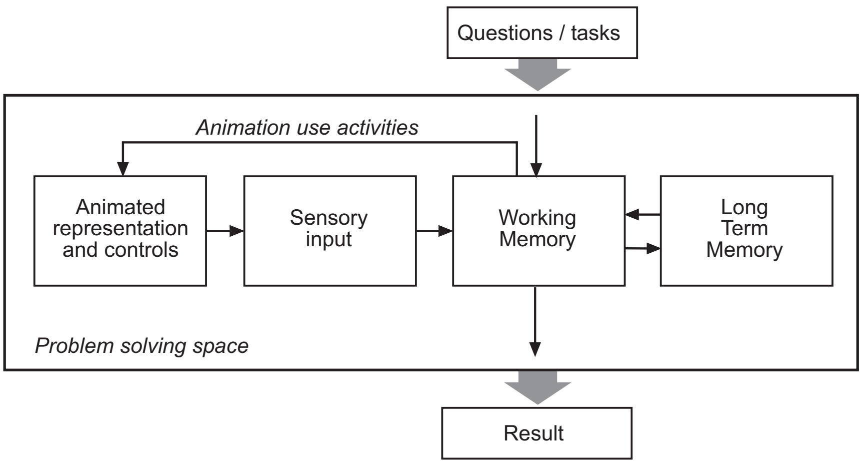

Figure 6.1 Model of animation use. User questions/tasks are processed in an exploratory problem-solving space. Problem-solving generates a result, for example an answer, a new question or a task.

Questions or tasks activate working memory, where the visual exploration processes 'seeing that' and 'reasoning why' (see Section 2.3) are executed. These processes are based on sensory input and exchange of information with knowledge and experiences stored in long-term memory (see also the information processing cycle of the pattern identification model, discussed in Section 2.3). During processing, animation use activities are performed. These activities consist of cognitive tasks – such as determining strategies, pattern identification and comparison (Section 2.3) – and interactions with the controls of *aNimVis* to adjust the representation. It is assumed here that use of these controls is partly influenced by sensory input, but that it is mainly driven by cognitive processes, particularly the strategy to generate some effects. One aim of the evaluation then is to look at strategies that become apparent from reasoning and from (type and sequence of) interactions performed by participants, as well as looking at the role of effects of the dynamic visualization variables in this. Main phases in task execution are also distinguished.

A conceptual model has been designed to predict which effects will be used by experts to find answers to each of the questions that have been selected for the evaluation. Based on the generic monitoring questions listed in Section 3.3, a task was prepared in which participants were requested to search for answers to five questions (see Table 6.1). The questions were rather general, but formulated this way in order to allow room for differences in domain knowledge and to – perhaps – to reveal a range of approaches followed by different experts. Questions 1–4 focus on specific aspects in part of the animation only, while Question 5 enables less constrained visual exploration of the whole animation. The questions are ordered from least to most demanding in terms of cognitive processing load (see the levels of complexity in the table). The assumption is that longer periods and comparison require more processing than shorter periods and identification. Questions about anomalies in Section 3.3 have been excluded because anomalies are deviations from long-term averages and SPOT VEGETATION data exist only since 1998.

Table 6.1 Questions appearing in the task given to participants in the evaluation session

Generic monitoring questions	Period	Main cognitive tasks involved	Level of complexity
1. What changes do you consider significant?	March–August 1999	Identification and comparison	1 2
2. Are there any significant differences or correspondences between the two periods?	April–August 1999 and 2000	Comparison	2
3. What changes do you consider significant?	1 year from April 1998	Identification and comparison	3 4
4. Are there any significant differences or correspondences between the two years?	2 years from April 1998	Comparison	4
5. Try to discover whether there are any:			
- specific processes going on, also try to reason about possible causes;	whole time series (April 1998-May 2002)	Identification	5
- spatio-temporal patterns (cycles, trends, etc.);		Identification	5
- significant spatial or temporal relationships.		Comparison	6

As a first step, the interactions mentioned in Table 4.3 were re-arranged into functional groups, adjusted to include controls added to the final version of aNimVis, and numbered (Appendix 1A). Stepwise, the level of animation tools increases: media player, general and base map controls (numbers 1–11) are at the lowest level, followed by the tools belonging to the various menus (12–20); then the 'tuning' tools (21–29) except for those belonging to the 'selection' menu (30–31), which are at the highest level. Next, a table providing an overview of the sequence of interaction tools with all the effects mentioned in Table 4.3 was prepared (Appendix 1B). This table was then converted into seven new tables, one for each of the (sub)questions mentioned above; in each one, a prediction was made about the tools to be used by domain experts during their execution of tasks. The *sequence* of tool use was not included. After all, the predictions are based on effects and several tools may be more or less interchangeable because they generate the same effect. It is also expected that some tools might be used repeatedly and in different problem-solving phases (e.g. the media player controls), while others are perhaps used only once. Predictions are classified into three categories: likely, possible and unlikely, which means that a tool will be used by >50% of the participants, 25–50% or <25%, respectively. Figure 6.2 shows two examples (in Subsection 6.3.5 all tables will be described, together with the results). 'Tuning' tools (numbers 21–31) fall in the lowest category, unless comparison is a main cognitive task to answer a question (see Figure 3.3). Some tools generate more than one effect but, of course, only one prediction can be given for each tool. Therefore at least *one* of the multiple effect predictions will always correspond to other predictions in the same (effect) column, while others may deviate. Predictions are based on subjective expectations of the researcher about the usefulness of the effects that tool use is supposed to generate. This conceptual model only serves as theoretical expectations, or hypotheses that need to be tested in the evaluation.

In order to gain some insight into the 'problem-solving paths' followed by domain experts who perform tasks with *aNimvis*, the reasoning and interactions of those experts needs to be 'tapped' somehow. It must be realized, however, that no matter what methods to gather data are selected, not *all* the processes will become obvious. Main reasons, particularly with complex problem-solving tasks like map reading, are that participants in an evaluation will probably not uncover everything they are thinking and there are unconscious processes going on as well (Hackos & Redish, 1998; Lloyd, 2000). A further consideration is that data acquisition methods vary in their suitability to uncover cognitive processes and hence appropriate selection is important.

Processes executed in the 'problem-solving space' sketched in Figure 6.1 end with some kind of result, such as answers – or no answers – to questions, new questions or tasks. A second aim of the evaluation in this research was to analyse how tasks are ended, whether there are answers provided to the questions or not. The nature of the answers – which could, for example, be assessed by investigating whether type I (seeing false patterns) or type II (missing patterns) errors are made (MacEachren & Ganter, 1990) – will not be taken into account. Firstly, interpretations of the data cannot be verified in the field. Secondly, it is very difficult to determine what answers in a visual exploration task are wrong or what patterns have been missed. Users may have different goals, knowledge and perspectives on the data.

In addition to the aspects just mentioned, user reactions to *aNimVis* were considered because these reactions can be used to improve animations. Evaluation of *aNimVis* is, however, not a main aim since the most important role of the application in this research is to serve as a vehicle that enables evaluation of aspects of use and user behaviour with animated representations in a monitoring context. The prototype was evaluated as a stand-alone application. Although exchange of data to other environments is a desirable characteristic (see also results of the focus group sessions in Chapter 5), there is a risk that too many variables that cannot be controlled will be introduced.

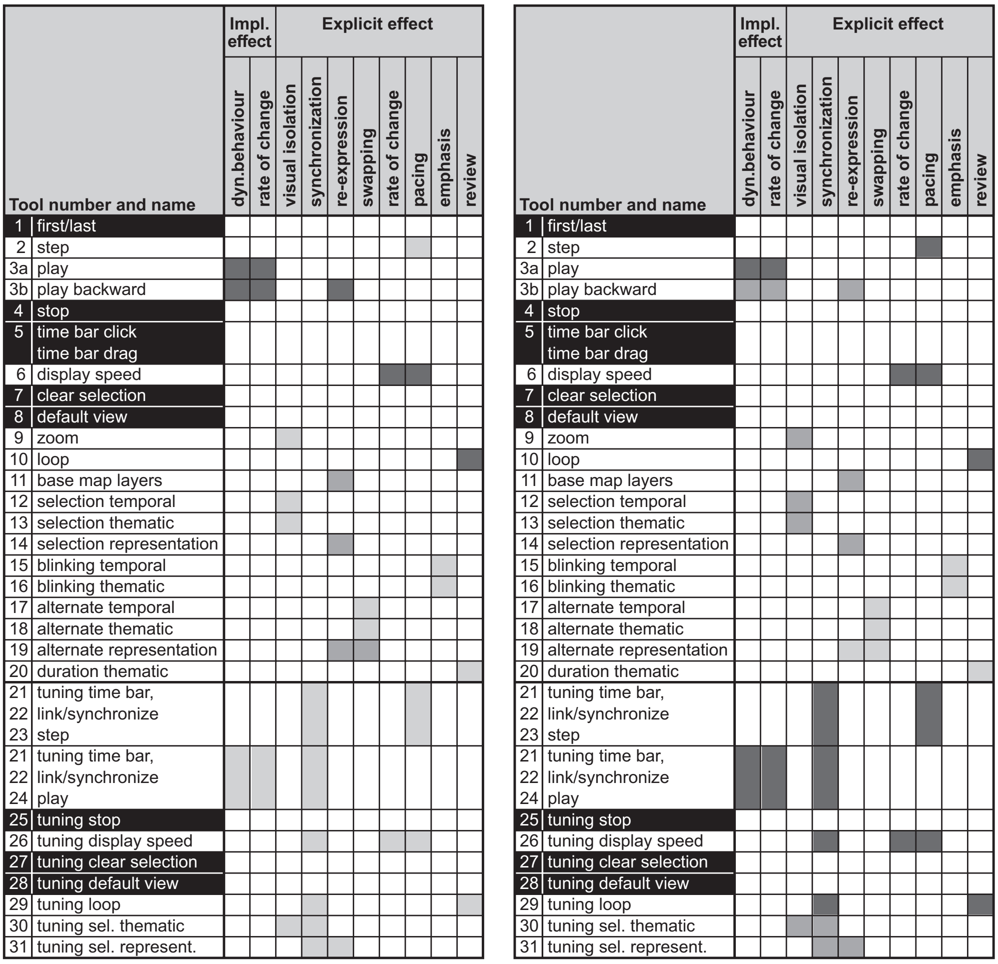

Figure 6.2 Predictions of tool use based on the effects generated by the tools: left: for spatio-temporal patterns; right: for spatial or temporal relationships. Value in the cells (from dark to light) refers to likely, possible and unlikely use. No predictions are made for tools in the black boxes because their effects are not strong enough.

6.3 Empirical testing

6.3.1 Think aloud method, interviews and questionnaires

The best way to 'tap' the train of thoughts (including user reactions and emotions) and to study series of events and processes is by qualitative methods (Suchan & Brewer, 2000;

van Someren et al., 1994). These methods differ from the mathematically and statistically oriented quantitative methods by the qualitative nature of data gathering and data analysis. Quantitative data gathering techniques (e.g. measurement of the physical reaction of users to stimuli) do not provide insight into cognitive processes: they show how users react or what they do, but *not* why; nor do they show what their preferences are (see also Section 1.2). A variety of qualitative methods is nowadays commonly used in human computer interaction (HCI) research. These methods also gain importance in map use research; Suchan & Brewer (2000) provide an overview of applications. Roughly, qualitative methods can be divided into:

- Query techniques; examples are questionnaires, interviews, focus groups and heuristic evaluations.
- Observational techniques; examples are direct observation of task execution (e.g. while participants are thinking aloud) and indirect observation based on logging (e.g. automatic recording of user actions at a keystroke level in action logs or eye movement registration).
- Document analysis, for example of maps, images or other written documents (after Nielsen; 1993; van Someren et al., 1994; Dix et al., 1998).

In query and observational techniques, participants in an evaluation may generate the data during or after task execution. Data generation *during* problem-solving may negatively affect the cognitive processes (e.g. if participants have to react to questions posed by the experimenter, or by performing complex tasks), but the main advantages are that it is very direct and that memory errors do not occur. A main drawback of data generation (e.g. as comments, in interviews or questionnaires) *after* task execution (in retrospect) is that participants may have forgotten what they did or thought, particularly in long sessions and after complex tasks. Animated representations are complex, and users will be asked to perform several tasks in the evaluation session. That rules out the techniques that collect the data after the task – at least as primary data collection methods – in this research. Focus groups and heuristic evaluations are more suitable for the evaluation of a product than for tracing cognitive processes. Documents are not generated by participants working with the current prototype.

Observational techniques have some disadvantages too, but are nevertheless most suitable for this research. Simply observing users during task execution does not provide insight into decision processes, attitudes, etc., but asking participants to verbalize the thoughts that come into their mind without first rationalizing or interpreting them provides a wealth of data (Ericsson & Simon, 1993; van Someren et al., 1994). Usually the thinking aloud is recorded on audio and/or video tape. Recordings are verifiable and they facilitate analysis of the data. If man-computer interaction is evaluated, action logs at a keystroke level are also common. Logging provides data that are complete and 'semantics-free': logs tell what users have done, but not why, or how they reacted (Dix et al., 1998). A combination of techniques results in rich and abundant data, the most complete data on problem-solving processes. Actual system use, problems, preferences and cognitive processes can be derived. Ericsson and Simon (1983) and McGuinness

(1994) claim that cognitive processes are hardly disturbed by thinking aloud; many people are naturally 'talking to themselves' in problem-solving tasks. There are, of course, also some weak points. Interference between verbalization and task execution cannot be fully ruled out, particularly in the case of complex tasks. Participants may provide selective and incomplete data (see Section 6.2); some people find it difficult to (continuously) verbalize their thoughts and knowing they are being observed may influence their behaviour.

There are also some drawbacks of the think aloud method with respect to analysis of the data. The data, which are generated *during* task execution, do usually not include explanations of the participant's thoughts or rationalizations of their behaviour. The consequence is that the experimenter has to *interpret* the meaning of the verbalizations, actions, perhaps even facial expressions and other types of body language. All these data have to be integrated for analysis. Use of equipment that synchronizes data streams helps, as does software that facilitates the structuring and representation of the data (see e.g. van Someren et al., 1994; MacEachren, 1998), but deciding about interpretation remains a human task. This task is subjective, difficult and very time-consuming. The usual procedure is that protocols are derived from the data. 'Raw' protocols are segmented, interpreted and then compared to predicted protocols (or a conceptual model) before conclusions can be drawn. Ericsson & Simon (1983) and van Someren et al. (1994) advocate a detailed analysis of all the data. In many studies, however, only those parts of the recordings that are considered relevant are analysed in detail, while remaining pieces are treated in a more superficial way. In this context, Nielsen (1993, p.19) states that sophisticated, detailed analysis of think aloud verbalizations is generally unnecessary to reveal the most important aspects (see also Dix et al., 1998).

In summary, the main disadvantages of possible interference in cognitive processes during complex tasks because of the thinking aloud and the tedious analysis do not outweigh the advantages of the think aloud method. Main advantages of this qualitative method, applied during task execution, are that it is the most direct and complete method to 'tap' non-interpreted, non-rationalized thoughts of participants during problem-solving; no memory errors occur and a wealth of data is gathered, particularly if sound, images and actions on the screen are all captured. In map use research, Thorndyke & Stasz (1980) were early adopters of the method. Since the early 1980s, it has been used in various investigations (see van Elzakker, 2004) and appreciation for it seems to have grown. Recently, for example, the method was used by Fabrikant (2000) (who only took notes of the sessions), Fuhrmann (2002), Ogao (2002), Griffin (2003) and van Elzakker (2004).

Attempts can be made to avoid part of the disadvantages. Interpretations are sometimes made by more than one researcher and combinations of methods and techniques are used. Interviews and questionnaires are useful supplementary methods (Dix et al., 1998). Interviews are flexible; questions that arise in the experimenter during observation of the participant can be posed. Interviews may also reveal problems, comments or alternatives, but not performed actions during the thinking aloud test. Questionnaires are suitable for gaining personal data and opinions. They are less flexible than interviews, but easy to standardize and compare. Another advantage might be that the influence of social interactions (and possibly answers given to please the experimenter) is smaller.

In this research the think aloud method was used with audio/video recordings and logging of all the interactions with the application. Post-test interviews (in which the participants were prompted to clarify some aspects of their problem-solving behaviour and to give any comments they felt like giving) and questionnaires (to acquire personal data and some opinions) were used as supplementary data gathering techniques to evaluate all the aspects mentioned in Section 6.2.

6.3.2 Materials and environment

Four documents were prepared before the individual evaluation sessions were conducted. The first document, '*Getting familiar with aNimVis, Animated Image Visualization*', can be considered as a concise manual for the application (Appendix 2). The document was used to structure the demonstration of the application given by the experimenter at the start of each session. During and after the demonstration, the document was available to the participants. They could refer to it any time, particularly during the familiarizing phase that followed upon the demonstration and during the think aloud part of the session.

The second document, '*Additional user information for aNimVis*', contained a look-up table to explain the relationship between digital numbers (DN, ranging from 0 to 255) and NDVI values (from –0.1 to 0.92) in the default representation. Another table was included to provide a quick overview of the differences between the various classification and colour schemes that can be selected in *aNimVis*. Finally, some hints were added to help participants to solve unexpected interface problems. This document was also available during the whole session. Appendix 9 shows the classification and colour schemes that were available after the third session (see Subsection 6.3.4).

The third document, '*Visual exploration of animation in a monitoring context*', was provided at the start of the think aloud part of the session; it contains a description of the task. First, the context was sketched in a brief scenario and details about the data were provided. It was emphasized in the scenario that the domain expert decides to *start* with visual exploration of the time series to obtain quick and qualitative insights, and that this phase may be followed by data analysis and perhaps comparison with other data sets in another software environment (but not during the session). Then the questions were asked. After the first two sessions, Questions 1–4 were slightly adjusted (see Subsection 6.3.4). Appendix 3 shows the document that was used for all but the first two participants.

Finally, a questionnaire was prepared. It contains biographical questions, questions related to educational and professional background, monitoring and computer experience, and questions about the opinion of participants regarding *aNimVis*

(Appendix 4).

Another part of the preparation before the think aloud sessions could be conducted was that I had to become familiar with the test environment and equipment, install the required software and make sure that the application was running. A single-room research laboratory, especially equipped for think aloud testing (van Elzakker, 2004), could be used for the sessions (Figure 6.3).

Figure 6.3 View on the research laboratory setup. Left: the video camera; centre: the monitor, digital quad unit and video recorder; right: participant working with aNimVIs.

In many studies, video/sound recordings and action logs are only synchronized in the analysis phase after the test, i.e. during play back, which is rather cumbersome. Dix et al. (1998) recommended the use of equipment that merges the data into a single screen. Such equipment is, fortunately, available in the lab. The heart of it is a digital quad unit that integrates incoming video signals from various sources. One source is the monitor of the computer. A special graphics card converts the VGA signals of anything visible on the monitor into video. Other sources in this research are images from the video camera and sound. The perfectly synchronized images can be displayed in separate quadrants on a screen (in this case a 66-cm colour TV monitor). Only the two lower quadrants were used in this research. On the left-hand side, the video images of the participant were visible, and on the right-hand side the computer screen. Although these images were reduced and converted from high-resolution VGA signals into low-resolution video signals, the animated representation, the interface and all the interactions could be easily followed. Special software to log all actions on the screen was therefore not needed.

Signals from the digital quad unit can also be recorded on a single videotape with a video recorder. The recorder is a professional S-VHS video recorder; it does not only capture the images integrated in the digital quad unit, but also sound from the camera and sound from an additional wireless microphone set. The latter source often provides higher-quality sound recordings than a camera, and sound is clearly important in a think aloud session. An analogue video camera with tripod and stereo microphone was used. The camera was used to capture images of the participant; it can also be used as a player to show the recordings made during the think aloud session in the post-test interview. The recordings on the first tape are then copied onto a new video tape in the video recorder, together with all the sounds from the interview (see van Elzakker (2004) for more details). All the data streams are thus synchronized and integrated during the recordings by the equipment. Finally, the computer in the lab was a standard PC with a 48 cm monitor attached to it. After installation of the necessary software to run the application, *aNimVis* and all the additional files (see Section 5.4) were copied onto the hard disk.

6.3.3 Participants

In order to reveal the strategies and reasoning of potential users of an application like aNimVis, participants had to be recruited with relevant domain knowledge and experience in monitoring. Fortunately, ITC employs a number of highly experienced staff in the task domain; there are also PhD students and visitors who are representative of the potential user community. Ten persons who could be considered as domain experts participated in the evaluation sessions. Three of them also took part in the focus group session, which had been held a few months earlier. This is not a problem, since the aims of the think aloud evaluation (see Section 6.2) differ from those of the focus group session (Subsection 5.5.2).

After studying a number of projects, Nielsen (1993) recommended using 3–5 participants per test since this often gives an optimal cost-benefit ratio. Conducting a number of relatively small tests at different stages of product development is often preferred to one large test, at least in the usability engineering domain, since it reveals more problems and reduces the risk of failure and errors. Dix et al. (1998) state that pragmatic considerations (like availability of participants and costs) often influence the number. For a controlled experiment, however, at least 10 participants are needed. Ten participants in the evaluation session of this research therefore seemed a reasonable number, particularly because a think aloud evaluation can be considered as an in-depth study.

There were 6 male and 4 female participants; only one of them was younger than 30 years, while three participants were older than 50 years. The group was highly educated (see Table 6.2); two of the participants with a MSc or equivalent degree are currently PhD students. The group was rather homogeneous in many other aspects. All of them were very experienced computer users. Some other main characteristics of the participants are summarized in Tables 6.3 and 6.4. These personal data were obtained through a questionnaire after the test (see Subsection 6.3.2). Part of the results of this questionnaire (about the experiences with aNimVis) is presented in Subsection 6.3.5.

Table 6.2 Educational background of the participants in the evaluation

Educational background	Number of participants
Main university degree:	
M.Sc. or equivalent	5
Ph.D.	5
Main discipline:	
Biology/ecology	3
Tropical agriculture	1
Forestry/forest monitoring	2
Physical geography	2
GIS/Geoinformatics	2

Table 6.3 Monitoring experience and activities of the participants in the evaluation

Monitoring activities of the participants in the evaluation	Number of participants
Experience in monitoring:	
<1 year	1
1–3 years	0
>3 years	9
Frequency of monitoring activities:	
regularly	4
occasionally (depending on projects and research)	6
Monitoring scale	
international	1
national	5
regional	10
local	6
Use of NDVI	
regularly	6
occasionally	4
Use of time series	
yes	9
no	1
Use of software for monitoring	
ENVI/IDL	3
ERDAS IMAGINE	7
ILWIS	5
PCI	2
WinDisp	1
Most often used satellite data for monitoring	
Landsat TM	5
NOAA/SPOT	5
MODIS/IRS	3

Table 6.4 Familiarity of the participants with the data and the area used for the think aloud test.

Awareness of test data and area	Number of participants
Familiarity with the test data	
very – moderately	4
slightly	2
completely unknown	3
Familiarity with the test area	
very – moderately	2
slightly	5
completely unknown	3

6.3.4 Procedure

The evaluation sessions were all conducted between 9 June and 8 July 2004. Each session started with an introduction, in which the overall goal of the research and the goal of the evaluation session were described. It was emphasized that the participant would not be able to use computational techniques at this stage and that *aNimVis* would be used in the evaluation as an environment to *visually* explore the data. It was further explained that the functions in the visualization environment are mainly limited to controls to *select subsets* of the data, to determine the animation *order* and to control the *duration* and the *frequency* of the visibility of subsets of the data. Details about the procedure of the session were provided as well.

After the introduction, the application was demonstrated. It followed the explanation described in the manual, which was also provided to the participant at this stage, together with the document containing additional user information (see Appendices 2A and 2D). In the demonstration and the familiarizing phase that followed, a data set of north Iran was loaded into *aNimVis* (see Figure 5.1). It had the same characteristics as the data set used for the think aloud part of the session, but there was only one base map layer available in this case: a grid. The introduction and demonstration together took about 40 minutes.

Then the participants were given all the time they needed to become familiar with the application. They were told that the aim was to familiarize with the interface, not yet to explore the data. They could also get used to the test environment, the equipment and the evaluation method, because they were already asked to think aloud. The participants were told to tell *what* they were doing and thinking, not *why*. This phase was recorded on video, originally just to check if everything worked fine, and the participant was speaking loud enough to be understood. The first participant, however, started to decide what representation he liked best, and he used this representation also as the basic one in the think aloud phase. After it was realized that participants may take decisions that influence tool use in later stages, all the familiarizing phases were completely recorded and analysed as well.

At the start of the think aloud phase, the data set of north Iran was replaced by the test data (south Iran, with parts of Iraq and Kuwait), and the task was handed out (see Appendix 3). No problems occurred with the equipment, and the thinking aloud went fine in most cases. Some participants had to be reminded occasionally, only one participant more often, to keep talking (see Subsection 6.3.5). Nine participants were thinking aloud in English. Although only two of them were native English speakers, the non-native English speakers did not seem to be hindered by using a foreign language. One participant preferred Dutch, his mother tongue. No significant differences were noticed, however, between the verbal protocols. During the familiarizing and the think aloud phases, I was sitting behind the participant, out of sight to minimize the influence of my presence, but positioned in such a way that all the displays and user interactions on the monitor could be followed. Communication could not be completely avoided. Apart from reminders to keep thinking aloud, a few bugs were still encountered in the application, leading to interferences or communication; some questions were asked and one participant told a few side stories about the area that came to mind. These interruptions (and other possible interferences in the cognitive processes) were taken into account in the analysis phase (see the summaries in Subsection 6.3.5).

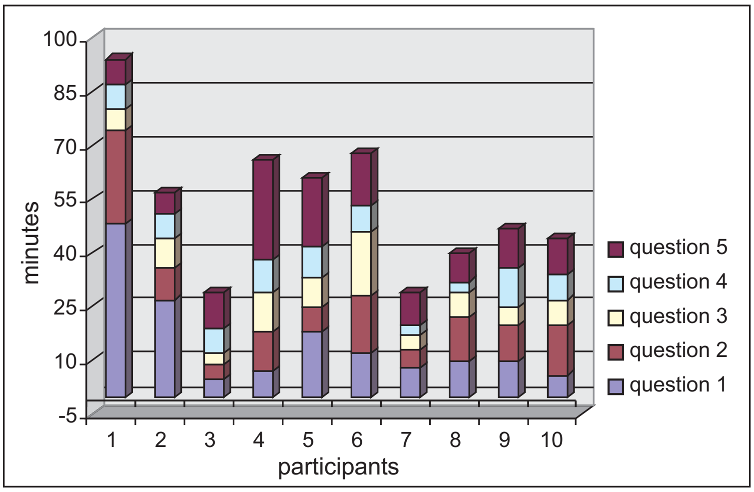

Figure 6.4 Time spent per participant on task execution during the think aloud phase of the evaluation session

The first participant spent a long time on Question 1 of the task (see Figure 6.4); the same – albeit to a lesser extent – happened with the second participant. Some changes were therefore made in the task description to limit the amount of time needed. In Questions 1 and 2, participants were no longer asked to look at the whole area but to focus on a small area (the framed area in Appendix 3). In Questions 3 and 4, participants were given the opportunity to focus on a particular type of vegetation or crop instead of at the whole value range. It was realized that these changes could affect task execution and that this should be taken into account in data analysis. An adjustment was also made in the colour schemes that could be selected in *aNimVis*. Several options were added after the focus group session, but the third participant mentioned in the interview that scales that are not SPOT-specific should be removed. He also advised to enhance the DN scale. Both suggestions were followed before the next session. No further adjustments were made after this.

The experimenter made notes of the questions that arose while watching the problem solving behaviour of the participants. Immediately after the think aloud session, these questions were asked. Although it was possible to use the video camera as a player to show relevant parts of the previously made video tape during the interview, none of the participants felt the need to review his behaviour. The final question in all interviews was whether the participant wanted to add something. Interviews were also recorded on video tape. Finally, participants were requested to fill in the questionnaire (Appendix 4). Altogether, the sessions lasted from 2 to more than 3 hours.

6.3.5 Results

As indicated above, data gathering started with the familiarizing sessions. Both the verbal and the action data were analysed, albeit not at the same level of detail as the data acquired during the think aloud phases. Analysis was mainly directed towards aspects that might affect the participant's tool use or problem-solving behaviour during the think aloud phase and to comments about the applications. Aspects that were considered are:

- Time spent on familiarizing, but only to see whether there were participants who really deviated from the average time (23 minutes). Quick were Participants 4 and 10, who only spent 12-13 minutes. Participant 9 took 50 minutes, but to a large extent on interpreting the data and on communication with the experimenter (me; see the summaries below).
- Types of tools used; experience with a tool in this phase might affect its future use; Figure 6.7B gives an overview of participant's use of the main tools.
- Decisions, comments and other aspects considered relevant were extracted from the verbal data. These are partly included in the summaries of the evaluation sessions below, and partly in Appendix 8, Tables 1 and 2.

The think aloud data were analysed in more detail. Verbal protocols (almost literally transcribed) and action protocols, containing all (timed) interactions with the application, were both derived from the video tapes. The (raw) verbal protocols were interpreted. Interpretation started with a segmentation of the protocols into main problem-solving phases, taking the action protocols into account as well. Within each phase, reasoning and answers were analysed, and interruptions in the problem-solving process were identified. From the results of this analysis and further analysis of the action protocols, several other documents, tables or graphs have been generated. All of these will be discussed below.

6.3.5.1 *Time spent on task execution*

Figure 6.4 shows the time spent on each of the questions by every participant. A lot of variation is visible, particularly if one looks at Question 1. As described above, however, Questions 1 and 2 have been adjusted, and the graph shows that the balance from Participant 3 onwards has been improved.

6.3.5.2 *Main-problem-solving phases*

The raw verbal protocols were segmented into main problem-solving phases. Segmentation is based on shifts in reasoning and tool use. The following phases have been distinguished:

- *First orientation*: involves inspection of the image, the thematic and temporal legends and/or base map layers.
- *Selection of theme, area or time*: refers to choosing a subset of the data on which attention can be focused.
- *Identification*: establishing the locational, thematic and/or temporal characteristics of a phenomenon.
- *Comparison*: establishing differences and correspondences between phenomena in space, between themes and/or in time.
- *Reflection*: review of the task that may contain a summary of the findings, comments on the execution, or a comparison with execution in which additional materials are available, in an image processing environment, etc. (see for example the '*Summaries of problem-solving behaviour*' of Participants 3 and 6 below).

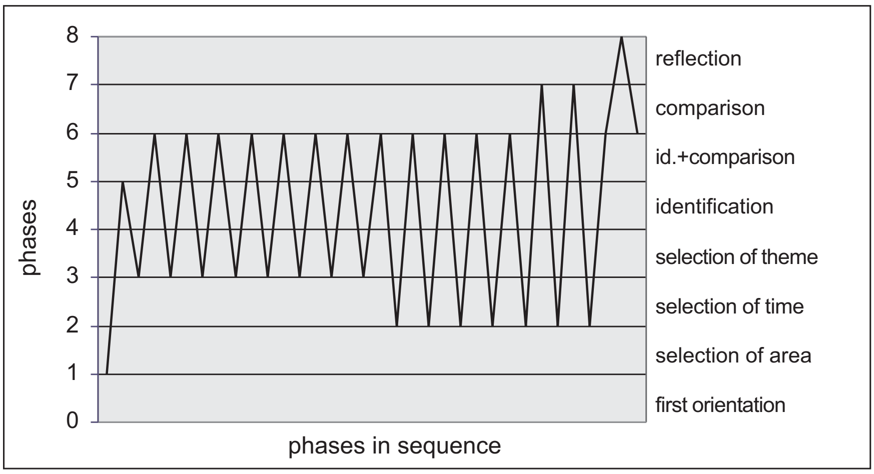

Figure 6.5 Main problem-solving phases of Participant 1 for Question 1

Identification and comparison have been distinguished as main cognitive tasks in visual exploration. Therefore they are included as phases. Since animated representations are rather complex, easily overloading the user, attempts to reduce the contents by selections of spatial, thematic or temporal subsets have been considered as important main phases as well. Furthermore, task execution may start with a first orientation, and be concluded with a reflection.

The main problem-solving phases per question for each participant can be found in Appendix 5. The number of phases varies strongly. Participant 1 is an extreme case: 62 phases can be distinguished, of which 34 form a very regular pattern, in Question 1 (Figure 6.5). After Question 2, the detailed approach changed, and became more comparable to that of some other participants.

Identification can hardly be distinguished as a separate phase. In an animated representation, where changes are continuously happening, identification is in many cases not possible without comparisons in time. The main cognitive task 'identification' mentioned in connection with the generic monitoring questions (e.g. in Table 6.1), therefore, has to be changed into 'identification and comparison'. This combination is most often used in Questions 1, 3 and 5 while comparison dominates, as could be expected, in Questions 2 and 4 (see Figure 6.6).

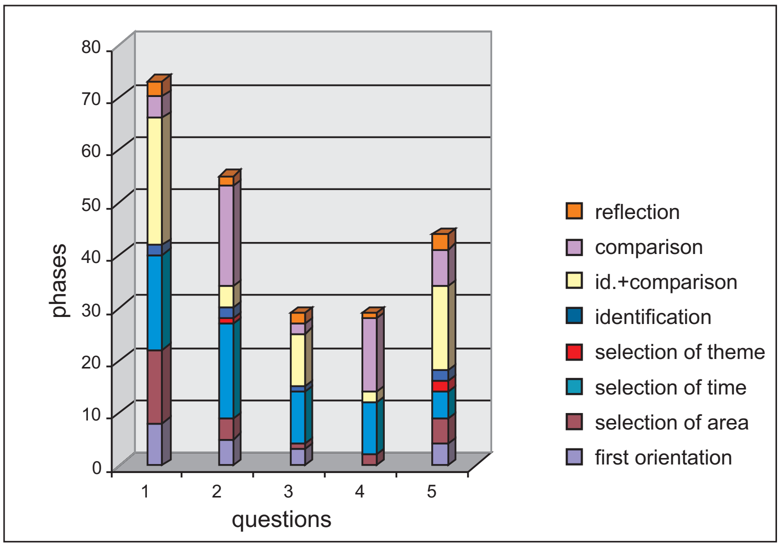

Figure 6.6 Problem-solving phases used by all participants per question

The most important phase over all questions taken together is selection of time. Selection of theme (expected to play at least a role in Questions 3 and 4) hardly occurs. The main reason is that participants without knowledge of crops in the area are hardly able to select a particular type of vegetation or crop (as is clarified below). Another observation, then, is that adjustment of the questions after the first two sessions did not influence the main problem-solving phases. Participants 1 and 2 did not make thematic selections in Questions 3 and 4, and neither did many other participants. Participant 2 did not make area selections in the first two questions, and Participants 6 and 10 also did not do this.

6.3.5.3 Summaries of problem-solving behaviour

The segments created by the main problem-solving phases were further analysed and interpreted. These interpretations provide insight into the strategies followed by the participants, the answers provided and the interruptions and problems evolving during the problem-solving process. In addition, user feedback could be derived. Part of this information is summarized in the brief narratives below. The summaries contain aspects of the familiarizing and the think aloud phases; the post-test interviews are also incorporated. These summaries describe the main characteristics of the problem-solving behaviour of individual participants. They also indicate whether answers to the monitoring questions were given. As described above, the quality of the answers has not been assessed. Many answers, however, show that domain knowledge was used or triggered, while other answers are based on knowledge of the area; some may also be based on visual impressions only. It is assumed here that domain knowledge was triggered by sensory input if particular crops or vegetation types were identified, if participants reasoned about relationships with other phenomena, or if they attempted to explain the patterns. The summary also provides information on interruptions. Other elements such as problems, wishes and suggestions are listed separately. Tool use, derived from action protocols, is also dealt with separately.

PARTICIPANT 1

Familiarizing phase
The participant started this phase by selecting the colour scheme he liked; this was the basic scheme for the whole session. He began interpreting the images, like many others, although that was not necessary for this phase.

Think aloud phase
After having read the questions, the participant explicitly determined a strategy to deal with Questions 1 and 2. He planned to select a continuous representation and to find out what grid cells had changed; then he wanted to switch to a classified representation to reduce the information and next to concentrate on the grids with changes, and perhaps pick dates. For Question 2 the strategy was the same, but it also included comparison, maybe grid cell-wise, and then seeing what had been happening. He executed the tasks by a detailed exploration, particularly for Question 1. He first played the whole animation (as an unclassified representation), and then the period mentioned in Question 1 to find areas on which to focus next. He decided to keep track of the changing patterns by looking at low and high values and dates in each month separately, and by drawing models of the findings. In this way, he identified three to four areas of interest; he then zoomed in to each of them separately and said: '*look for dates at which values drop, that will tell*

us much.' After this, he summarized the results and selected a classified representation to check if the pattern was the same. Finally, he concluded that if you want to look for anomalies, they should be around these four areas. Since the areas were identified already, he could start zooming in to them immediately in the second question. Although there were some problems with tools, he could work around them and find differences and correspondences, as well as a time lag. As indicated above, Questions 1 and 2 took a very long time: much longer than the complete think aloud part of anybody else (see Figure 6.4) and nobody else made drawings. For the remaining questions he followed a more general approach, which can also be seen from the main problem-solving phases (Appendix 5). He still looked for minimum and maximum values, for shifts and dates, also in Question 5, which he found rather difficult, particularly to find relationships. To pick up trends, he played the animation at the highest possible speed. 'Tuning' was used several times, but mainly to click at different dates in the time bar rather than to aim at synchronization. Answers were given to all the questions. Domain knowledge was reflected in his reasoning and answers.

Interview

The participant explained that he went through an elimination process, whereas somebody from Iran would not need to search for relevant areas. Unfamiliarity with the area also made him draw the models to get some cues. Dates were used to pinpoint patterns that break up. On the question whether he found it cumbersome to compare all those temporal selections in Question 1, he replied: '*No, compared to the tools I have been using, this (aNimVis) is far easier.'*

PARTICIPANT 2

Familiarizing phase

This participant needed quite some assistance in the familiarizing phase. Nevertheless, the time spent to familiarize was below average. He knew the area and started to interpret already in this phase. He was enthusiastic about the threshold sliders in the thematic 'selection' option (but did not use it anymore in the think-aloud phase).

Think aloud phase

This was the only participant who went to the tab already during the first question. He selected the beginning of the period of interest in the first time bar and the end of the same period in the second time bar, then played the upper animation forwards and the lower one backwards. He clearly did not understand the tool and also had some difficulty with 'selection temporal periods' in the main window. The participant wondered for a relatively long time what the black spots could be: dry farming, snow, clouds? He explored the pattern and looked at dates, then thought that it was perhaps snow. He used relatively few tools: play, stop and clicking in the time bar were the dominant ones during the whole session. There were, nevertheless, answers to each of the questions; these answers showed that knowledge of the area had been used, but that sometimes also domain knowledge was triggered when unfamiliar changes were encountered. Re-expression was mainly used because the participant did not like the NDVI colour scale rather than to compare whether different representations influenced the patterns seen.

Interview
During the interview, the participant confirmed that he was sometimes verifying if he could see the things he knew about the area in the images, but the software '*gives a very good impression of the area and the changes …'* He could not explain why he ran the two animations in opposite directions in the 'tuning' window. When asked why he did not use 'blinking', 'duration' and 'alternate', he responded that it was because the questions did not ask for a specific object.

PARTICIPANT 3

Familiarizing phase
The participant mentioned that he only wanted to work with the DN scale to make, for example, his own classification with the thematic 'selection' options. He showed how he would do that for crop mapping. He would use the threshold sliders to identify homogeneous areas with a spatiotemporal behaviour that clearly differs from the surroundings. He would do that in several passes to identify, for example, irrigated areas, natural vegetation and dry farming. He would then extract polygons of those areas (for mapping purposes) and mask the areas inside the polygons in the animation to reduce the content. In those areas that would finally remain, he would focus on spatiotemporal gradients and map these gradients as isolines, but he would use statistical functions to make these calculations (e.g. in ERDAS IMAGINE). Then fieldwork would be necessary to verify the results. The participant used very few tools in the familiarizing phase (see Figure 6.7A); the only menu option is thematic 'selection'.

Think aloud phase
When he read the task description, he commented that a four-year period is a bit short to answer Question 5, but that short-term processes can be discovered, particularly the start, peak and end of growing seasons. The strategy of this participant during the whole task was more or less the same: he almost continuously played the animation, with the loop on, to see what was happening. As in the familiarizing phase, there were few interactions: most frequently used were the base map toggles and temporal 'selections'. When working on Question 2, he first selected the new period and compared it from memory with the period seen in Question 1. He nevertheless noticed already some differences and correspondences. He then selected both periods and reminded himself while the animation was running: *'Period 1, Period 2, ...'* In Question 4 he used 'tuning' to make comparisons. He remarked that it works nicely, but that he wanted to select not only starting dates of both animations but also end dates. In other words: periods (see Appendix 8 for further reactions to 'tuning'). Thematic 'selection' was only used in Question 5. During the session, the participant referred several times to the approach sketched above (see the familiarizing phase), and he added that detailed topographic maps would be helpful to validate where agricultural fields are, or a reservoir if one expects irrigated areas. Reasoning and answers in this session showed that domain knowledge and some knowledge of the area had been used to interpret what the

participant saw. For example: '*Here you see clearly that there has been some rain and the vegetation is there less than one month; must be very degraded grazing lands …*'. or '*… a little bit dryer, but if it has any impact on production, the production comes from irrigated areas, the only type of land use that will be affected is grazing …*'.

Interview
The participant explained that it takes some time before you start to see patterns in an animation. Because the 'blinking' and 'duration' option distract from 'the movie', he did not like to use them. A discussion on the colour schemes followed; the participant recommended to remove the scales that are not SPOT-specific and to improve the contrast in the DN scale such that the differences between black (no data/clouds) and dark green (high NDVI) become clearer.

PARTICIPANT 4

Familiarizing phase
Participant 4 used very little time to familiarize himself with the application: only 12 min. He tried several combinations of tools, such as temporal *and* thematic 'selection'. Temporal 'blinking' was not considered to be very interesting.

Think aloud phase
Task execution started with stepping *'to see small changes'*, then playing, but overall the participant was very frequently stepping (or clicking/dragging in the time bar), and not much playing. Clicking in the time bar was sometimes used to (manually) 'alternate' between two dates. In Question 3, where focus on a particular vegetation type or crop was asked, the participant went to the SPOT course classes scheme to focus on the middle range of NDVI values and reasoned: *'High areas are usually O.K.; low areas are sometimes suitable as rangelands but not so much in use anyway; other areas are at risk; interesting to see how stable the pattern is'*. Patterns were identified, and even possible crops mentioned, but the participant also remarked that crops are difficult to identify if one does not know the area. 'Tuning' was used three times, also in Question 5 to compare the patterns of a dry year from memory with the patterns of two adjacent years by running the latter together in the 'tuning' window. The participant tended to summarize the findings before turning to a next question (see the reflection phases). Use of domain knowledge was clearly visible in the reasoning and in answers to the questions.

Interview
The participant indicated that he preferred the SPOT course classes scheme to a thematic 'selection' in Question 3 because it provides context. If a medium value disappears, one can see what happens: drying out or getting greener. He continued that thematic 'selection' is useful if one knows what is growing in the area: *'I could define a threshold and say if the green is above this, then my crop is starting to grow or my rangeland is green enough so the cattle can move in'*. He did not use 'blinking' because it disturbs the pattern, and mentioned that although 'duration' may work at high speed, looking at the animation *and* the red

alert is not easy. Some tools were not used because the participant said that he was not aware of them, or forgot them.

PARTICIPANT 5

Familiarizing phase
The participant knew the area and started to interpret a lot already in this phase. He was used to slice values in imagery (time series) to delineate and classify areas, similarly to Participant 3. Also like Participant 3, he used only a few tools in this phase. At the end he said: '… *gives you a lot of possibilities for playing with your data, but still what I am missing is … some reference data, or a colour composite, a base map or whatever, ….'*

Think aloud phase
In Question 1, he started to run and watch the whole animation to identify where the main agricultural areas were. He recognized some crops from their NDVI values. Only then did he select the period of interest and find many answers; knowledge of the area clearly played a role, in addition to domain knowledge. He used 'tuning' in Questions 2, 4 and 5 and indicated, like several other participants, that he would like to have additional options available here (see Appendix 8). In Questions 3 and 4 this participant was able to focus on a specific crop (sugarcane) because of his knowledge of the area. In Question 5 he made a thematic 'selection' with two thresholds: the lower one to separate land from water and the upper one to distinguish between bare soil and vegetation. He increased the display speed, adjusted the thematic sliders and clicked in the time bar to compare dates. He was able to identify many changes in this way: *'Is much clearer'*. Frequent interruptions occurred during this session, partly because of questions posed by the participant and partly because of interferences by the experimenter. The latter consisted of occasional reminders to keep thinking aloud and were further related to the participant's interpretation of the questions, or were intended to avoid problems with tool use. If, for example, the participant wanted to use 'tuning' while there was still a temporal 'selection' active, the experimenter said: *'clear the selection first'*. This was only done for problems in the interface that were known from previous sessions, to avoid confusion and frustration. At the end of the session, the participant mentioned again that *aNimVis* is a nice system to play with.

Interview
To the question why some tools were not used the participant responded that after such short experience he was not familiar with the system and more time would be needed to learn all functions.

PARTICIPANT 6

Familiarizing phase
The participant did not interpret the images during this phase. He just tried the tools and commented on some of them (thematic 'blinking' seemed more interesting than

temporal 'blinking'; 'tuning' and 'alternate' were interesting). He looked at all the main functions, except the 'selection' menu in the 'tuning' tab (see Figure 6.7A).

Think aloud phase
The participant ended most questions with a summary and reflection on the task, for example by mentioning that he would normally also consult a map, an atlas or even photographs to be able to visualize the area. He would probably do that even before diving into the images. Like some other participants, he noted further that he would also take other data into account (e.g. rainfall). When he started to use 'tuning' in Question 2, he asked: '… *I can't make it stop after one year?'* He then decided to step through the period to keep control. 'Tuning' was also used in Question 4, again by stepping. At a certain moment, he realized that he was mainly attracted to the area in the southwest. He then tried to compare the patterns with another desert area in the northeast and found some differences. He mentioned that it is more difficult to follow the graph and changes in the upper corner of the running animation than in the lower corner; it is then easier to step. He also found the clouds in the data rather distracting. Out of curiosity, the participant sometimes looked outside a period mentioned in the question he was trying to answer. Answers in which use of domain knowledge could be noticed were given to all questions, but the participant made it clear that more satisfying answers could have been given with additional information or more knowledge of the area.

Interview
The participant explained that in 'tuning' one can make direct comparisons, while comparing selected periods in a sequential representation is more difficult. He said that he could have used 'alternate moments' as well, but that he was really comparing periods during the task. 'Blinking' did not seem useful. With respect to 'duration', he replied that he would maybe use it after a while, but not when using the application for the first time. Finally, he said: *'It would be quite interesting for me to try the system with some data or images I knew … just to see how it works then. This is with temporal data but you could also use it with, for example, simulation models.'*

PARTICIPANT 7

Familiarizing phase
The participant looked only at some of the tools. He seemed to have made some decisions already during the demonstration of the application. He looked at combinations of tools in various menus and was one of few participants who tried 'tuning' with a thematic 'selection' (see Figure 6.7A). He indicated that he rather looked at two juxtaposed windows in 'tuning'.

Think aloud phase
This participant played the animation almost continuously, with the loop on. He observed and evaluated what was happening, using a limited number of tools. The only menu used was 'selection temporal'. 'Tuning' was used for Question 4 only. Base map layers were regularly consulted to see how the patterns relate to the environment but

were immediately switched off again *'to concentrate more on the changes'*. He was quick, and explored the representations rather globally, hardly looking for details. This was noticeable in his reasoning and in the answers provided. Examples are: *'Nothing significant happens'* (Question 3) or *'Looks to me the same so far; not too much difference'*. Evidence that domain knowledge was triggered by the animated representation was therefore less pronounced than with Participant 3, who followed a similar strategy. Answers were given to all questions.

Interview

The participant explained that he did not use 'selection thematic' because one then creates hard boundaries which might not be there. Another reason was that he was looking for all kinds of things and did not want to lose the context. He found 'blinking' not useful and 'alternate' only perhaps, but he did not use the latter because the tasks were to look at periods instead of moments. When asked for additional comments, he remarked: *'It looks nice for the moment. But if you compare differences it may be possible to put them on top of each other, I don't know, …. maybe red and green glasses, stereo …'*

PARTICIPANT 8

Familiarizing phase

The participant used all the main groups of tools except 'zooming' (see Figure 6.7A). He commented on them as well. He appreciated, for example, that interactions can be done in a running animation, which is dynamically updated; he found the combination of temporal and thematic selections interesting: one sees both low and high values over time. He expressed doubts about temporal 'blinking', but said that thematic 'blinking' can be useful. 'Duration' can perhaps be used to extract clouded pixels, but he saw no other applications. In 'tuning', he wanted to include a selection of periods. He wanted to see other data sets here as well, but he was content with the possibility to explore time lags.

Think aloud phase

The participant mainly used the play mode of the animation (with some clicking and dragging in the time bar) but no stepping. In Questions 2, he first played the newly selected period and then tried various classifications before going to 'tuning' for comparison with the period of Question 1. He realized that periods cannot be selected in 'tuning' (Appendix 8), but continued and used thematic 'selection' in the 'tuning' window: *'Get rid of the low values. See if I can find a pattern then'*. Since the animation easily runs beyond the period of interest, he then moved to the main window to select 'alternate moments'. He liked this, also because one can zoom in here. In Question 4 he started again in 'tuning', but went to 'alternate moments' because of the limitations of tuning. In Question 3 he went to 'selection thematic'. There was evidence of the use of domain knowledge in this session, but not all questions were fully answered (in Question 5, only processes). Since many tools had been used, and lots of comments were provided, there was reason to believe that problem-solving was to some extent driven by the wish to evaluate the tools. The experimenter interfered a number of times in order to avoid (in the meantime known) problems with tools (see also the summary of Participant

5). In one case, the application had to be restarted to overcome a problem with 'alternate' (see Appendix 8, Table 1).

Interview
The experimenter asked whether the participant's strategy had been influenced by the availability of tools or whether it was tool-independent. He explained that it was a combination: inspecting a whole time series and looking at different representations is a kind of standard tool-independent first phase, which he normally applies. Then there is a question that needs to be answered, and one takes available tools into account. The participant concluded the session by mentioning that it would be nice if one could click in an image and obtain graphs.

PARTICIPANT 9

Familiarizing phase
The participant knew the test area a bit. The familiarizing phase took a relatively long time (50 minutes), but this participant became really involved in interpreting the images and the results of interactions. In addition, time was spent on communication with the experimenter, for example about the possible future use of *aNimVis* in a project and in education. He was particularly positive about the thematic 'selection' options: '*It enables you to see the spatial and temporal variation in selected classes, you see where and when it starts and in which direction it is going*'. He remarked that one needs to know then what the cover type is. Contradictory to the reactions of other participants, who sometimes seemed to have decided already during the demonstration not to use 'blinking', this participant was really enthusiastic. *'Oh that's nice. Yah, that's nice, that's nice. Then you can see how it comes and stays and then after that it dies … and it comes back again … hmmm, yah, I think for something like this you could think of many applications.'*

Think aloud phase
This participant had to be reminded quite often to keep thinking aloud (8 times) and a number of social interactions occurred in which he wanted to share some stories irrelevant to the task. Furthermore, there were a few interruptions related to Questions 3 and 4 (see below) and to problems with tools or tool use (see Appendix 8, Table 1). The participant stuck to a very consistent strategy. He read all questions before he started but became very much involved in the task and did not re-read Questions 3 and 4 later. After the identification of relevant changes in 1999 and the comparison with 2000, he just continued to compare with the next years and finally with the first one. All the time he focused on the area of interest defined in Question 1, mostly comparing only one frame of April and one frame of August. He did this by selecting moments in the 'selection' menu, then running the animation for quite some time with the loop on. Once he selected four frames (all in April and August), but he never played a period or the full animation. When he wanted to start Question 5, the experimenter remarked that he apparently did not try to focus on a particular type of vegetation (asked in Questions 3 and 4). He looked at the questions, answered that it is difficult to focus on a particular crop or vegetation and briefly inspected the whole image to conclude that the rest of the

area was not so much affected. Main problem-solving phases and tool use did not seem to be influenced by deviation from the task, however. Absence of thematic 'selections' seemed to be more related to uncertainty about the vegetation types in the area. The participant then started with Question 5, again focusing on the same area, and selecting frames in April and August. Answers were given to each question. 'Tuning' was used only once. Domain knowledge and also some knowledge of the area played a role in formulating the answers.

Interview
When questioned about the selection of (particular) moments only, the participant responded that it gave an indication while reducing the amount of data. Another question was why he did not use the thematic 'selection' or 'blinking' options, like in the familiarizing phase. He mentioned that 'blinking' is useful for continuously visible features like the forests along the Caspian Sea, but not much for the ever-changing patterns here, so it had probably to do with the area and perhaps with the questions. The participant was enthusiastic about *aNimVis*, since other packages do not offer similar functionality.

PARTICIPANT 10

Familiarizing phase
The participant was very quick and seemed comfortable with the tools. He only looked at how the tools worked and did not start interpreting the images.

Think aloud phase
The participant was mainly playing and only sometimes stepping (or clicking/dragging). Stepping occurred, for example, in the 'tuning' window in Question 2, when he was looking for a way to compare two periods. He looked at several options because he realized that 'tuning' had a limitation: '*I have to make sure that I only look at this period.*' Then he decided to step, most likely to maintain control over the display of the period of interest. Later, he returned to the main window and then found that it is also possible to select two periods with the 'selection temporal periods' option *'Oh, I can do another period. He-he …'* Making temporal selections (defining periods) took some time. He used the 'selection temporal periods' option again in Question 4, and reminded himself while looking at the animation: *'… first period …'* He then tried to use 'blinking moments' to mark the start of a new period, but, unfortunately, 'blinking' did not work. 'Tuning' was also used again in Question 4. This participant changed representations a few times to see how it influenced patterns. He was very quick but found some questions difficult, particularly Questions 3 (because it asked to focus, if possible, on a vegetation type or crop) and 5. Rather general answers were given to all questions; there was not much proof of domain knowledge. This participant had least experience in monitoring and no experience with time series; he was also unfamiliar with the test data and the area.

Interview
Period selections took longer in the think aloud part than in the familiarizing phase; the

participant changed techniques: from quick and easy selections in the time bar to the (here) more cumbersome typing or calendar use. The participant explained that he thought that selections on the time bar were not precise enough. He also explained that he would have preferred 'tuning' to compare two periods over the 'selection temporal periods' option, because 'tuning' enables direct comparison. Extending the 'tuning' options seemed a good idea to him. Finally, when asked about the appropriateness of the questions, he mentioned that the description of the tasks was okay but rather extensive and vague.

6.3.5.4 Main strategies applied by users

Users were able to extract relevant information from the animation, and insights can be obtained in the strategies of the participants. Three main groups of users can be distinguished:

- Some users mainly wanted to reduce the amount of data and then focus on subsets that are relevant to further exploration. Participant 1 is a strong example; other examples are Participant 4 (who frequently stepped through the data), Participant 6 (who indicated that the animation was too busy and that he would like to focus on areas separately, etc.) and Participant 8 (who was comparing two frames only all the time).
- Other users were mainly playing or using a combination of playing and stepping, but they also frequently interacted with the data. Participants 5 and 10 are examples of these users. The strategy applied by users was located somewhere between the previous and the next one.
- A last group of users wanted to play the animation almost continuously, take the time to observe patterns, see what is happening and made no use of the many tools or base map layers, because they distract. Examples are Participants 3 and 7.

It is difficult to label the strategies of Participants 2 and 8. Participant 2 did not seem to have a strategy: he seemed to be reacting to the visual input on an ad hoc basis; Participant 8 was partly tool-driven in his problem-solving behaviour.

6.3.5.5 Tool use and effects of animation use activities

It is possible to look at tool use per question and at tool use paths or trajectories that are followed by participants during problem-solving. Appendix 6 provides some examples: Appendix 6A shows the tools used by Participant 5 for all questions. Numbers along the y-axis refer to tool numbers in Appendix 1A. The path shows, for example, that Participant 5 started with frequent interactions at the lowest level (<11), then there were a few interactions with menus (level 2); he used 'tuning' twice, with some lower level interactions between them, and so on. Curves were generated for each participant, but general patterns can better be detected if the tool use paths of all participants are represented per question. Two examples of the latter are also included in Appendix 6: Appendix 6B for Question 1 and Appendix 6C for Question 2. Appendix 6B shows that all participants were acting at low levels, i.e. mainly using media player, general and base map layer controls. The only peak is caused by Participant 2, who surprisingly went to 'tuning' in Question 1. In Question 2, where comparison in time was required, the majority went to 'tuning', albeit at different moments, and a few participants remained active at lower levels. Deviations and similarities can easily be detected in those graphs.

The data gathered about tool use during the familiarizing phase and the think aloud phase were used to generate two matrices that provide an overview of selected tools used by each of the participants in both phases (Figure 6.7). Media player tools and base map layers were skipped; these basic functions were used by all participants. Selections of representations were dropped as well since they are not as important as the other interactions with moment of display: temporal and thematic selections. The matrices do not indicate how *often* tools were used, only *that* they were used. Part B shows that temporal 'selection' and 'tuning' were used by all participants. For 'tuning', this is a remarkable and unexpected result. A single animation may already overload the user and cause perception problems because of change blindness. In 'tuning', users had to cope with two animated representations. Whether changes were missed was not tested here, but it would be interesting to do so. Users were really interested in this function; most of the feedback obtained was also about 'tuning', and users who commented were unanimous in their recommendations for improvements (see Appendix 8, Table 2).

In general, temporal interactions were selected more often than thematic interactions, but 'blinking temporal' is an exception. The low level of interaction with the thematic functions can partly be explained from the fact that most of the participants lacked knowledge of crops in the area. Another explanation is that some of these tools did not seem useful to a number of participants, such as 'duration thematic' (not used at all) and 'alternate thematic' (e.g. see the summaries of Participants 3, 4 and 7). 'Blinking thematic' (not used at all) is an interesting case because Participant 9 was really enthusiastic about it (see also the summary above). Finally, it is also possible that these unfamiliar tools are not easily selected at first encounter with a new system (see summaries of Participants 5 and 6). Some positive comments were given about 'alternate', but participants did not always use it because they were focusing more on periods than on moments of time, as some of them mentioned.

The only participant who made use of many different tools was partly tool-driven in his problem-solving behaviour (see the summaries above). Almost all participants used fewer tools in the think aloud session than in the familiarizing phase – which is not surprising; in only a few cases they used tools that they had not already tried during the familiarizing phase. The most common exception is a well-known tool like 'zooming'. This may indicate that decisions about tools had been taken early, during the familiarizing phase. In Appendix 1A, tools are arranged at four levels. At the lowest level (of which only 'zooming' is included in Figure 6.7) there are many and frequent interactions. This is about the level that is offered by common media players, but many interactions in this evaluation took place at higher levels. At the second level (menus) the interactions are mainly concentrated in the 'selection' menu. All participants interacted at the next level ('tuning'), but only one interacted at the highest level ('selection' menu in the 'tuning' tab).

A. Main functions used in the familiarizing phase	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
zooming	●		●	●		●				
selection temporal	●	●		●	●	●	●	●	●	●
selection thematic	●	●	●	●	●	●		●	●	
blinking temporal		●				●	●	●		
blinking thematic				●		●		●	●	●
alternate temporal	●	●				●	●	●	●	●
alternate thematic	●					●		●		
duration thematic	●	●		●		●		●	●	●
tuning	●	●		●	●	●	●	●	●	●
tuning selection thematic	●							●		

B. Main functions used in the think aloud phase	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
zooming	●		●	●	●		●	●	●	
selection temporal	●	●	●	●	●	●	●	●	●	●
selection thematic	●	●			●			●		●
blinking temporal								●		●
blinking thematic										
alternate temporal	●							●		●
alternate thematic								●		
duration thematic										
tuning	●	●	●	●	●	●	●	●	●	●
tuning selection thematic								●		

Figure 6.7 Use of selected interaction functions during the familiarizing phase (A) and the think aloud phase (B)

In Section 6.2, predictions about tool use are introduced. The predictions were compared with actual tool use in the think aloud sessions. Appendix 7 contains the tables with results of those comparisons for Questions 1–4. For Question 5, three prediction tables were used: for processes, overall spatiotemporal patterns and relationships. In practice, however, it was impossible to separate the tools that were used for each part of the question. Users quite often first explored the animation to find an answer to one part of the question, such as processes, and then came with answers to the next parts as well, after little or sometimes even no further exploration and tool use. The tables for Questions 1–4 show that in all cases where actual tool use differed from the prediction actual use was lower. Overall, best predictions were made for Question 1, but it must be realized that the class boundaries in the predictions were purely based on assumptions of percentages of use.

If the results are evaluated from the perspective of the effects generated by the tools represented in the columns, then the use of *implicit* effects (effects that are always visible in a running animation) is always high, as predicted (see Figure 6.8). The lowest score is obtained in Question 4, because some users were stepping instead of playing, particularly in the 'tuning' mode. In the use of *special* effects (effects that are created by interactions) there are some deviations. Figure 6.8 indicates how many participants used each of the effects for each question. Deviations from the prediction exist mainly for re-expression in Question 3 (higher than expected), for swapping in Questions 1, 2 and 4 (lower than expected), rate of change and pacing in Questions 3 and 4 (both lower), and review in Questions 2, 3 and 4 (also lower). Individual tools sometimes deviate a bit (e.g. in Question 2, 'alternate thematic' does not reach the level of other tools in the same effect column).

Effect	Q1	Q2	Q3	Q4	Q5
Dynamic behaviour/rate of change	10	9	9	7	10
Visual isolation	10	10	10	7	7
Synchronization	1	7	0	7	2
Re-expression	3	3	<u>6</u>	5	5
Swapping	<u>0</u>	<u>0</u>	3	<u>0</u>	1
Rate of change	6	6	<u>1</u>	<u>1</u>	6
Pacing	7	7	<u>4</u>	<u>5</u>	6
Emphasis	0	0	0	1	1
Review	9	<u>4</u>	<u>2</u>	<u>4</u>	2

Figure 6.8 Effects of animation use activities for each question. Numbers in the cells indicate the number of participants who generated the effect. Value (from light to dark) indicates use by <25%, 25–50% and >50%, respectively.

The deviations are represented in Figure 6.8 by underlined numbers. It is not clear why re-expression has been used slightly more often in Question 3, nor why rate of change and pacing are not used very often in Questions 3 and 4. Swapping should not be considered as a separate effect. During the sessions it became clear that 'alternate moments' is actually used to visually isolate and quickly compare two moments. Alternation of values was not used at all, but the effect would also be visual isolation. The effect of 'alternate representation', on the other hand, is clearly re-expression. The low scores for review after Question 1 are caused by the way in which tool use was recorded in the action protocols. Recorded are the start of interactions and, in the case of buttons and toggles, the moments at which they are switched off again. Some participants switched the loop on during Question 1, but never switched it off, and actually review was high in all cases.

In Table 6.5 the results have been corrected and generalized. The importance of tools that enable users to view the dynamic behaviour and the rate of change of data, and to synchronize representations in case of comparisons in time are clearly demonstrated in the sessions (see also the summaries above). In the future development of animation tools, this should be taken into account.

Table 6.5 Overall importance of effects of animation controls

Effect	**Overall importance**
Dynamic behaviour/rate of change	high for all tasks
Visual isolation	high for all tasks
Synchronization	high for comparison only
Re-expression	medium for most tasks
Rate of change	variable
Pacing	medium to high
Emphasis	low for all tasks
Review	high for all tasks

6.3.5.6 User feedback

Valuable user feedback was obtained during the sessions. Appendix 8, Table 1 contains *problems* encountered with *aNimVis*. The bugs need to be removed if the application is further developed. Several users had problems with the definition of moments or periods in the temporal selection pop-up windows. These windows offered various options. Selection in the time bar works fine, but some participants preferred to make selections at exact dates (although there is only one image per 10 days). The pop-up windows offer two other options: typing and selection in a calendar. The latter requires too much clicking for selections in a data set of more than 4 years; typing was a bit cumbersome because dates were not always accepted and no message was returned to explain what went wrong. Other issues are that several users found it hard to read the names in one of the base map layers, or were distracted by problems in the data. These are categorized as desired improvements in Table 1.

Comments made on the tools (see Table 2 in Appendix 8) have been classified into two categories. Wishes are strong desires for extensions of the functions, expressed by many users. Wishes regarding tuning were very strong: almost everyone commented on tuning, and the wishes for improvement were unanimous. Incorporating these wishes should therefore be given a very high priority. Other main wishes and some suggestions made by just one or two users are listed in the table.

A final source of information about user reactions to *aNimVis* is the last part of the *questionnaire* filled in at the end of the evaluation sessions (see Appendix 4). Answers to the other parts have been described in Subsection 6.3.3. The participants were requested to note three good and three bad things about *aNimVis*. Answers are listed in Appendix 8 Table 3. In total, 29 'good' and 23 'bad' things were noted. Participants were also asked to give a general usability rating for the application. The results are displayed in Table 6.6. One participant added the remark *'if linked to GIS'* to his 'very satisfactory' rating.

Table 6.6 Overall usability rating of *aNimVis*

General usability	**Number of participants**
Very satisfactory	5
Moderately satisfactory	3
Neutral	0
Moderately unsatisfactory	0
Very unsatisfactory	0
No answer	1

The last question in the questionnaire asked whether the participant would use the application if it was linked to a GIS or image processing environment. All of them answered positively. The reasons are listed in Appendix 8, Table 4.

6.4 Discussion

It can be read from Table 6.1 that the cognitive load increases from Questions 1 through to 5. There are, however, hardly any signs that the questions used during the evaluation session are indeed of increasing levels of complexity. It is not visible in the time needed by individual participants to answer the questions, the number of phases in the reasoning nor the tools used by the participants, at least not for Questions 1–4. There are, however, clear signs that Question 5 was complex. Participants found it more difficult than other questions. It is also visible from the total number of reasoning phases (Figure 6.6): it drops after Question 1 and increases for Question 5. Time used by all participants together for each question reveals exactly the same pattern. A possible explanation for this decrease after the first question and the increase for the last one is that at the start (Question 1) everything is still new and procedures are not yet established. Then procedures become established and the number of phases and total time drop until Question 5 has to be answered. The difference in period between Questions 1–2 and 3–4 does not seem to have much influence, nor do the main cognitive tasks (identification and comparison).

If we look at the questions used, some observations can be made. Most participants were not able to focus on a particular crop or vegetation type in Questions 3 and 4 because they did not know what crops are growing in the area. Participants who knew the area well were better able to provide specific answers. Question 5 was not easy to answer because the participants only had the NDVI data set at their disposal. Usually, if they are interested in relationships, for example, they consult other data as well. This may have influenced tool use, particularly in Questions 3–4. It is likely that, for example, 'selection thematic' would have been used more often if participants had been aware of particular crops. It does not make much difference for the effects because visual isolation is already very important for all tasks. The questions were rather general as well, but this was done on purpose to evoke a range of approaches.

Some of the controls were hardly used if at all. Some explanations for this have been given above (see the section on tool use and effects of animation use activities). It is well realized that in a purely demand-driven approach some controls would not have been considered at all. But, this research is a more fundamental investigation into the potential use and the cognitive aspects of use of the dynamic visualization variables.

6.5 Summary

This chapter describes the results of the evaluation sessions held with 10 participants. Data gathering techniques used for the evaluation are the think aloud method, a post-test interview and a questionnaire. Data were also obtained from the pre-test familiarizing phase. Together, these techniques have provided a wealth of data on cognitive processes, tool use and feedback on the application. The verbal and action protocols, generated from integrated video recordings, were the most important products for further analysis. Main phases in reasoning could be identified, as well as strategies applied by the participants. Reasoning and answers given to the generic monitoring questions given as tasks to the participants indicate that domain knowledge could be triggered by the visual input (the animated representation) and the interactions with the application. Interactions were analysed from the action protocols. It was surprising that all participants wanted to use the perceptually difficult tuning function, even with its current limitations. Actual tool use was compared with predicted tool use and predicted effects of tools. Deviations were found, but important effects could be identified. These effects can be taken into account in the future development of interactive animations. The feedback from the users, obtained in several ways, can be used for the same purpose.

7 CONCLUSIONS AND RECOMMENDATIONS

7.1 Main contributions and conclusions of the research

7.1.1 Introduction

The focus of this research was on the use of animated representations to explore spatial data. Monitoring – using satellite imagery – was been chosen as a case study since it is about keeping track of change, and a major characteristic of animation is that it shows change. The research was limited to the variables of the temporal dimension of animated representations: the dynamic visualization variables. One of the main objectives was to develop methods by which these variables can be used to acquire or discover information from time series in a monitoring context. Since little is known about the way in which users work with animated representations of geodata, the other main objective of my research was to gain knowledge of cognitive processes and strategies applied by domain experts during use of an animated exploration environment.

Investigation of the characteristics of the dynamic visualization variables and detailed evaluation of their use with a prototype of an animation environment by domain experts in monitoring has shed light on user strategies, cognitive processes and use of animation controls. The main aim of my research was not primarily to evaluate the effectiveness of a particular prototype as such, but *aNimVis* was used as an animation environment to gain insight into cognitive processes, user strategies and reactions to animation controls. By doing so, it becomes possible to make recommendations for the future development of animated methods and tools in order to improve the effectiveness of animation as a method for representing spatial data in a more general way, at least to support experts involved in monitoring, but perhaps also to a broader extent.

7.1.2 Research questions

I will summarize this investigation using the main research questions around which this research was focused as major headings.

1. *To what questions about dynamic spatial phenomena do experts involved in monitoring seek answers?*

In Chapter 3, overall monitoring goals and objectives are identified based on interviews with several domain experts and literature. The overall goal is to gain insight into the behaviour of dynamic phenomena. The more specific objectives are: to detect changes that affect geographic phenomena of interest and to analyse both recent developments and longer-term dynamics. Knowledge of aspects of change that are important for monitoring was also gained in this phase: experts are mainly interested in the location, type and time of changes, in the occurrence of anomalies, in processes, causes and relationships and in spatio-temporal patterns and trends. The main questions that experts have could be derived from this investigation:

- Are there relevant changes?
- Are there relevant differences/correspondences?
- Are there anomalies or outliers?
- What processes can be distinguished?
- Is it possible to distinguish causes or relationships?
- Is it possible to distinguish overall spatio-temporal patterns (e.g. cycles, trends)?

These questions refer to the spatial, thematic and temporal components of the data. What changes, differences or correspondences are 'relevant' in these questions depends mainly on the application, the phenomena of interest and the area being studied.

Answering the first research question was an essential step on the way towards the development of the prototype and its final evaluation, since some of the monitoring questions were given as tasks to the domain experts in the evaluation session.

2. What dynamic aspects of spatial phenomena can be visually perceived in an animated representation?

In order to determine whether it is theoretically possible to find answers to monitoring questions by *visual* exploration, an investigation into the characteristics of change that can be perceived visually in animated representations of spatial data was undertaken. These characteristics need to trigger domain knowledge that is relevant in the search for answers to monitoring questions. In other words, not just disappearing green spots should be identified but, for example, spots where crops are harvested. A framework of generic concepts to describe aspects of change is proposed in Chapter 3. Four main groups of concepts are recognized: for changes in the spatial domain, in the temporal domain, for overall patterns and concepts that characterize patterns in terms of relative similarity. The concepts for change in the spatial domain in particular seem to be influenced by the context in which they are used and represented.

3. How can dynamic visualization variables be applied to support the finding of answers to these questions in animated representations?

First, potential problems related to reliance on visual input about changes from dynamic representations are discussed in Chapter 2. Risks like change blindness and inattentional blindness are also described in that chapter. The conclusion is that there are no doubt limitations in the human capability to 'see' change, but there seem to be possibilities to partly overcome these problems, particularly by interactions with the graphic representation of the data. The main cognitive tasks involved in visual exploration of patterns on maps (identification and comparison) are also introduced in Chapter 2.

Next, the dynamic visualization variables were investigated in depth (Chapter 4). Four variables were identified, as well as the relationships between them: moment of display as basic variable, order and duration as primary derived variables and frequency as a secondary derived variable. Rate of change and synchronization, earlier distinguished by other researchers, can be considered as *effects*, not as dynamic visualization variables. Ways to use the variables from a design perspective are also described in Chapter 4. The variables can be used to depict different components of spatial data, but also to control the animated representation by various interactions. From a user's perspective, working with animations, observing the representations and using the controls generate certain effects. The assumption was that if one knows what effects users want to generate – and preferably also for what questions or tasks – then it is possible to provide tools or develop methods that generate those effects. Two implicit effects (effects that are automatically occurring when an animation is played) and eight special effects (effects that are intentionally caused by interaction) were originally distinguished.

Chapter 5 describes the design and implementation of *aNimVis*, a prototype in which ideas about applications of the dynamic visualization variables are incorporated. The first version of the prototype was evaluated in a focus group session with domain experts. The session was organized to improve the prototype before the later evaluation; the session led to several adjustments to *aNimVis*.

4. *How are dynamic visualization variables used to find answers to these questions and what strategies do experts use to explore an animated representation for monitoring purposes?*

This question is answered in Chapter 6: there the detailed evaluation of the use of the adjusted prototype by domain experts is described. The evaluation was based on data gathered during the familiarizing phase with the prototype, on the thinking aloud during task execution, the post-test interviews and on a questionnaire. The most important aspects and findings are summarized below.

The main problem-solving phases
Overall, the most frequently occurring phase is selection of time. This is followed by identification and comparison, and then comparison.

Problem-solving behaviours and use strategies
Summaries of the problem-solving behaviours are made for all participants of the evaluation. Users were able to extract relevant information from the animation. From these summaries, three main use strategies could be identified. Some users mainly want to reduce the amount of data and then focus on subsets relevant for further exploration. Others are mainly playing or playing and stepping, but they also interact frequently with the data using other controls. A last group of users plays the animation almost continuously, taking time to observe patterns, but without much further interaction because it often distracts.

Tool use and effects of use activities
Tool use paths can be generated and compared; in this way overall use patterns per question can be analysed. When looking at tools above the basic level (media player controls, general controls and base map layers), various temporal selections and 'tuning' are used by all participants. For tuning, this is remarkable given problems like change blindness, since users have to play or step through two animations at the same time – a perceptually and conceptually difficult task. Actual tool use was compared with a model that predicted tool use. Those predictions were made on the assumption that users want to generate certain effects while they are working on a task. Actual tool use deviated somewhat from the predictions, but it is more important to look at the effects. Use of the *implicit* effects 'dynamic behaviour' and 'rate of change' was always high: the majority used the play mode of the animation(at least once for each question of the task). Analysis of the use of *special* effects revealed that the effect of 'alternate' is partly 'visual isolation' and partly 're-expression'; 'swapping' can therefore be removed from the list of proposed effects. Furthermore, the two most important special effects are 'visual isolation' and 'review'. This can be explained by the overwhelming character of an animation. Of much importance for comparisons in time is 'synchronization'.

User feedback
Feedback revealed problems with the prototype, good and bad aspects of it, a high overall usability rating and a list of desired extensions. Most common were wishes to extend the functionality available on the tuning tab. All participants would like to use *aNimVis* if it was linked to a GIS or image processing environment.

5. *Is it possible to establish a theoretical framework to guide application of the dynamic visualization variables in animated representations of spatial data?*

A start was made with the establishment of a theoretical framework. Taking into account the *effects* that users want to generate when they perform tasks with animated representations seems to be a more fruitful approach than looking at measurement levels of the data. The latter works fine for application of the graphic variables, but not for the dynamic visualization variables. Moment of display, order, duration and frequency can be used for data at any measurement level. In my research I attempted to link desired effects to (monitoring) tasks. Some links could be established (see Table 6.5), but more tasks and different questions should be taken into account to establish and further extend the relationships.

6. *Can design recommendations for effective use of animations be derived from the results?*

Given the different strategies of animation use in the context of my research, it seems that users who want to visually isolate part of the complex content can best be served with additional tools. Tools that enable a reduction of the complex content are- anyway – desirable to avoid problems like change blindness and inattentional blindness. Such tools enable effective use of animations. 'Guidelines' for animation design can perhaps also be derived from the extensive user feedback. The directions for tuning in particular are rather clear.

7.1.3 aNimvis

One of the results of this research is the creation of an experimental prototype that, although it definitely needs to be improved, seems to add some useful functions to the ones offered by most current GIS and image processing software; *aNimVis* is not programmed as a plug-in, but it can be turned into a working application as plug-in. In that case, it could also be extended with functions that go beyond interactions with the dynamic visualization variables only. The application is mainly suitable for qualitative evaluation and exploration of the dynamics in time series. It can handle relatively large data sets and may therefore (if extended) also play a role in visual data mining: qualitative impressions of large data sets can be quickly obtained.

7.2 Recommendations for further research

One recommendation that can be derived from the results above is to investigate the further extension of the theoretical framework. It means that research is needed in different contexts, with other data and users. Knowing what effects are desired can be useful for tool development. Tools can easily change in the course of time, but effects may have a longer-lasting value and offer room for a variety of tools that create these effects.

Another recommendation is to further investigate the problem-solving phases. Identification and comparison are rather coarse phases, which could perhaps be refined. Tool development can, perhaps, be better tuned to tasks if more variation in the problem-solving behaviour of users can be distinguished.

With the current prototype, users were sometimes wondering *what* period or moment was displayed if they had selected more than one moment or period. Therefore, they started to count, for example '*first period, second period*'. Adding visual cues to solve this problem does not seem the best solution, since it further adds to the visual processing load. Sound could be a good alternative, and further research in this direction is recommended.

Some suggest that 3–5 participants in an evaluation suffice (e.g. Nielsen, 1993). This might be the case if, for example, an interface design is to be evaluated. With more than 5 participants, the cost/benefit ratio decreases. For research like mine, in which user strategies and cognitive processes are important, it would not have been enough. Suppose, for example, that I had used 3 participants in this research, and they happened to be Participants 1, 2 and 7. The results would certainly be more puzzling. It is not clear whether 10 participants is enough, but at least some patterns can be detected now.

The combination of research methods applied in this study provided a wealth of data. If a research focuses on cognitive processes, I would recommend a similar set of methods with the think aloud method as the core data gathering technique. The main disadvantage of this method is the amount of data that has to be analysed. In some cases, a pilot think aloud test might help a bit. Main patterns may already become clear, and analysis of the bulk of data can perhaps be better focused on those patterns.

A final related recommendation is that patterns could sometimes be detected in this bulk of data if they are visualized. In this research, the temporal patterns of tool use, for example, were not taken into account, only the sequence. Those temporal patterns might reveal interesting things. Visual data mining and information visualization techniques should therefore be considered to analyse the data in several ways.

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APPENDIX 1A INTERACTION TOOLS IN FUNCTIONAL GROUPS AT INCREASING LEVELS OF COMPLEXITY

MAIN WINDOW		
Media player controls		1
1	first/last	
2	step	
3	play	
	play backward	
4	stop	
General controls		
5	time bar click	
	time bar drag	
6	display speed	
7	clear selection	
8	default view	
9	zoom	
10	loop	
Base map controls		
11	base map layers	
Menu selection		2
12	selection temporal	
13	selection thematic	
14	selection representation	
Menu blinking		
15	blinking temporal	
16	blinking thematic	
Menu alternate		
17	alternate temporal	
18	alternate thematic	
19	alternate representation	
Menu duration		
20	duration thematic	
TUNING WINDOW		
Basic controls		3
21	tuning time bar,	
22	link/synchronize	
Media player controls		
23	step	
24	play forward/bacward	
25	stop	
General controls		
26	display speed	
27	clear selection	
28	default view	
29	loop	
Menu selection		4
30	tuning sel. thematic	
31	tuning sel. represent.	

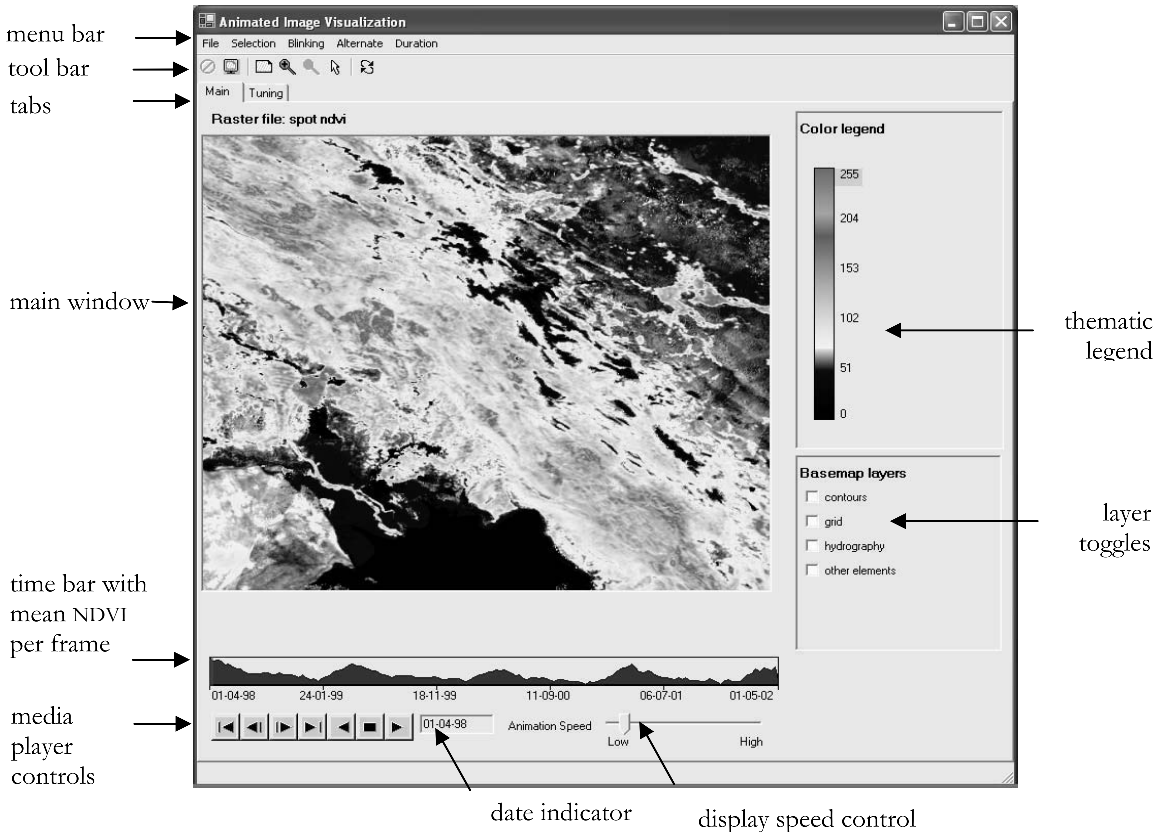
APPENDIX 1B IMPLICIT AND EXPLICIT EFFECTS OF ANIMATION USE ACTIVITIES

Tool number and name		Impl. effect		Explicit effect							
		dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review
1	first/last										
2	step								●		
3	play	●	●								
	play backward	●	●			●					
4	stop			●							
5	time bar click			●							
	time bar drag	●	●								
6	display speed							●	●		
7	clear selection										
8	default view					●					
9	zoom			●							
10	loop										
11	base map layers										
12	selection temporal			●							
13	selection thematic			●							
14	selection representation					●					
15	blinking temporal									●	
16	blinking thematic									●	
17	alternate temporal						●				
18	alternate thematic						●				
19	alternate representation					●	●				
20	duration thematic									●	
21 22 23	tuning time bar, link/synchronize step				●				●		
21 22 24	tuning time bar, link/synchronize play	●	●		●						
25	tuning stop										
26	tuning display speed				●			●	●		
27	tuning clear selection										
28	tuning default view					●					
29	tuning loop				●						●
30	tuning sel. thematic			●	●						
31	tuning sel. represent.				●						

APPENDIX 2 GETTING FAMILIAR WITH ANIMVIS

Animated Image Visualization

1. After opening, the default display looks like this:



The default display of the main window

2. Have a look at the following elements of the **main window**.

- The representation area for the <u>images</u>;
  Here: SPOT 4 VEGETATION (showing maximum NDVI values per pixel over 10 days) from 01.04.1998 – 01.05.2002. The area in the demo is North Iran, the area on which you will work next (also represented above) is South West Iran and small parts of Iraq and Kuwait.

- The <u>base map elements</u>; they can be switched on and off:

  - contours and hydrography:
    may provide additional info about the physical landscape;

- grid and other elements:
  may help you to focus on specific parts of the area during in a running animation.

- The time bar, the graph displayed in it represents the mean NDVI per frame. It gives an indication of the various seasons.

- The thematic legend: instructions for thematic interactions are always displayed at the top.

  The look-up table in the separate document 'Additional user information for *aNimVis*' displays the conversion from digital numbers to selected NDVI values.

3. You can **interact** with the display in the main window using the following controls (see figure above):

- media player controls;

- in a non-running animation, you can click in the time bar or drag the slider in this bar to select a start point for the animation;

- the display speed can be changed 'on the fly';

- controls provided by the buttons on the tool bar are (from left to right):

  - clear (temporal or thematic) selection;
  - default view (back to the DN (digital numbers) representation);
  - zoom to full extent;
  - zoom in;
  - zoom out;
  - normal (puts zoom cursor off, normal cursor on);
  - loop.

4. Next, there are several **menus** with **options.** Those options mainly refer to:

  - temporal interactions;
  - thematic interactions;
  - representations interactions.

- The **selection** menu has the following options:

    - <u>Default view</u> brings you back to the default DN (digital numbers) representation (same function as 'default view' button).
    - <u>Temporal selections</u>

        - *moment(s)* can be selected by:
            - clicking in the time bar;
            - typing a dates, then clicking the <u>'add'</u> button;
            - selection from a calendar;

        - *period(s)* can be selected by:
            - clicking in the time bar, holding the mouse and dragging until the required time interval(s) is(are) selected;
            - by tying dates, then clicking the 'add' button;
            - selection from a calendar;

        - changes to earlier selections can also be made.

    - <u>Thematic selections</u> include options to define (see top of legend space):

        - a *single threshold* in the value range (by a single click in the thematic value bar);

        - *two thresholds* (click in the bar, hold the mouse and drag until you reach the second threshold);

        - an *interval* (same approach as with two thresholds).
        - changes in the selections are possible 'on the fly'.

    - <u>Representation</u> offers various classifications and colour schemes (see overview in separate document 'Additional user information for *aNimVis*').

    - <u>Clear selection</u> to undo temporal or thematic selections (same function as button 'clear selection').

- The **blinking** menu offers:

    - <u>Temporal blinking</u>: can be applied to highlight selected *moments* in time (by clicking in the time bar). The whole frame will 'blink'.

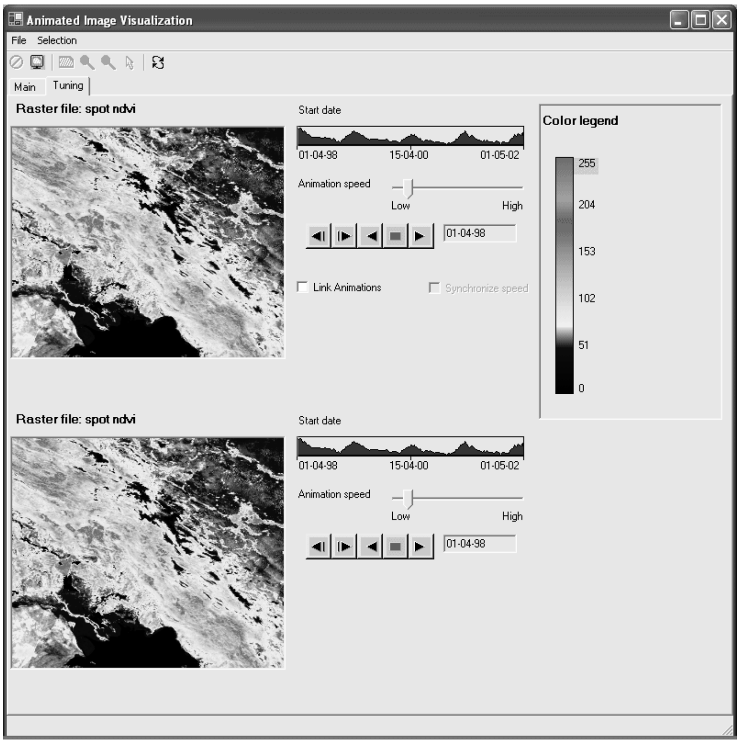
- Thematic blinking:
    - of a *value* (one click in the thematic legend); the frames in which the selected value occurs will be highlighted; *or*
    - of an *interval* (click, hold the mouse and drag until the interval is defined); the corresponding pixels will be highlighted.

  Hints:
  If you want to focus on one or more selected values, the second option will be better than the first one.
  Turning on the grid in addition might help you to focus on specific parts of the area with blinking pixels.

- The **alternate** menu enables you to:
    - Alternate moments: select *two moments of time* (by clicking in the time bar), then press the 'alternate' button. Press 'stop' before you make any new selections.
    - Alternate thematic: can be used to alternate between *two selected single values* for a single moment in time. To select the two values, click and drag the mouse in the thematic bar. Then press the 'alternate' button. The higher value will be represented in red, the lower in blue. Press 'stop' before you make any new selections.
    - Alternate representation: enables you to alternate between *two representations* with different classifications/colour schemes for a single moment in time. Press 'stop' before you make any new selections.

- The **duration** menu offers:
    - Thematic duration:
        - select a *single threshold value* (by a click), if values above the threshold occur in a frame, the animation freezes a second and a 'warning' is displayed, then the animation continues.
        - It is also possible to select an *interval* (click and drag the mouse).

5. Different kinds of interactions can be **combined**, e.g. selection of *periods* and *thematic values*, etc.



The display after selection of the 'tuning' tab.

6. In addition to the main window, there is a **tuning window** (accessible via the tuning tab). This window enables you to view two display windows simultaneously (see the figure above). Tuning can be used if you want to compare two different periods of time, e.g. two growing seasons.

Procedure:

- *Select* a moment to start the *first* animation in the first time bar.
- *Select* a *different* starting point in the second time bar for the *second* animation.
- If you want a simultaneous start of the animations, select *link animations*.
- Both animation will run in the same velocity if you also select *synchronize speed.*
- Alternatively, you may run the animations at different display speeds, e.g. to analyse whether there is a time lag in one of the periods.

There are a few additional controls:

- some media player controls, e.g.:
    - stepping through data;
    - change display speed

- some buttons (clear selection, default view and loop);
- menus: next to the **file** menu, here is only a **selection** menu available. It offers the same options as describe under the selection menu above, except temporal selections.

APPENDIX 3 TASK IN THE THINK ALOUD EVALUATION

Scenario

An expert involved in monitoring wants to gain insights in the vegetation dynamics a particular area. Those insights will ultimately enable him to act (e.g. warn in case of undesired developments), to generate models (e.g. to estimate the effects of interference in a development), or to extrapolate trends and predict future developments. The expert is particularly interested in the type of changes, in processes, possible causes and relationship, and in trends. Insights in short and in longer term dynamics are both important.

He decides to start the knowledge discovery process by visually exploring a time series of NDVI data to obtain quick and qualitative insights in the data. After that, he may decide to analyze the data and perhaps compare the results with other data sets in another software environment.

The data

The expert will use SPOT 4 VEGETATION images: synthesis products with maximum NDVI values per pixel over 10 days, and a spatial resolution of 1 km. Data are obtained from 01.04.1998 to 01.05.2002 (three images per month). The images cover South East Iraq and North Kuwait in the lower left corner, but the main part shown is South West Iran. The area roughly contains the lowlands and delta of the major rivers Euphrates and Tigris (including an ecologically important wetland area) in the SW and a broad NW-SW band of mountain ranges and highlands with peak of over 4000 m (Zagros and Kuhrud mountains). The upper right corner is a desert area. The whole area can be characterized as semi-arid.

Task

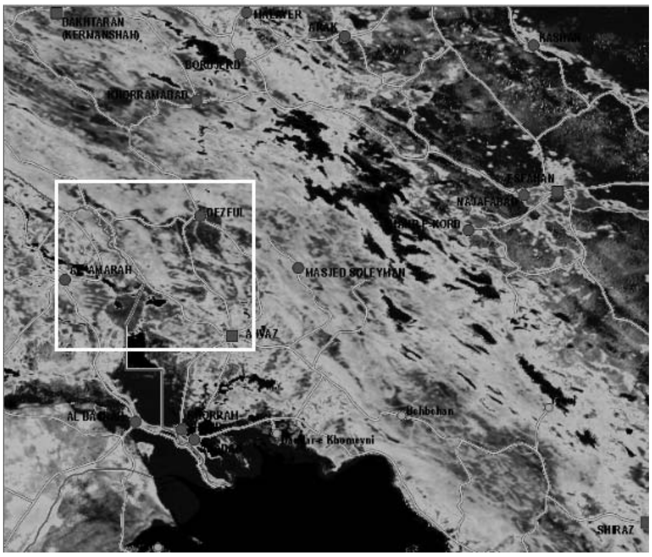
Now imagine that *you* are the expert. Use the skills acquired in the hands-on exercise *and* your domain knowledge to visually explore the time series and to discover what is happening in the area.

The following subset of monitoring questions has been selected to help you gain insights. Please deal with the questions in the sequence indicated below.

- **Part A: selected periods, selected area**

---

1. First focus on the dynamics in the area around Dezful and Al Amarah (see figure below for their location).
   Consider the period from (approximately) 1 March 1999 - 1 August 1999.
   Which changes do you consider significant?



2. Next consider the dynamics around Dezful and Al Amara for the same period, but one year later (approximately 1 March 2000 - 1 August 2000).
   Are there any significant differences or correspondences between the two periods?

- **Part B: selected periods, whole area**

---

3. Now consider the dynamics in the <u>whole area</u> for the longer period of 1 April 1998 - 1 April 1999.
   If possible, try to focus on a <u>particular type</u> of vegetation or crop.
   Again, which changes do you consider significant?

4. Then compare the dynamics found in question 3 with the dynamics in the next year: from 1 April 1999 - 1 April 2000.
   Are there any significant differences or correspondences between the two years?

- **Part C: whole time series**

---

5. Next, explore the whole time series (more than 4 years).
   Try to discover whether there are any:

   - specific *processes* going on, also try to reason about possible *causes*;
   - *spatio-temporal patterns* (like cycles, trends, etc.)
   - significant *spatial* or *temporal relationships*.

   If you want to focus in this question on *particular* aspects (e.g. specific types of vegetation, all the growing seasons, etc.), please indicate this while you are thinking aloud.

APPENDIX 4 QUESTIONNAIRE

Biographical information

1. Your nationality is:

   ………………………………………………………………………………………………………

2. And your mother tongue is:

   ………………………………………………………………………………………………………

3. In which of the age categories mentioned below do you belong?

   O < 30 years
   O 30-50 years
   O > 50 years

Professional information and experience

4. Your educational background is:

   O higher vocational training, namely: ……………………………………………………

   O university degree in:……………………………… ……………………………………...

   O other: ………………………………………………………………………………………

5. What is your current status?

   O student in (course): ………………………………………………………………………
   O employed
   O other: ………………………………………………………………………………………...

6. If you are employed, what is your current function?

   ………………………………………………………………………………………………………

7. And what is (are) your core activity (activities) in that function?

O management
O planning
O education
O research

O other: ……………………………………………………………………………………...

8. How long are you working with computers?

O < 1 year
O 1-3 years
O > 3 years
O no experience

9. How long do you have experience in monitoring of changes in spatial data?

O < 1 year
O 1-3 years
O > 3 years
O no experience

10. If you execute monitoring tasks, how often is this activity executed on average?

O once per week
O once per month
O once per year
O only occasionally

11. At which scale do you monitor changes (*more than one answer possible*)?

O international
O national
O regional (province(s), district(s), etc.)
O local

12. Have you worked with NDVI data before?

O yes, regularly
O yes, occasionally
O no

13. Do you work with time series?

O yes, mainly ………………………………………………………………………………..
O no.

14. Which software(s) do you use for the execution of monitoring tasks?

……………………………………………………………………………………………………..

15. Which satellite data do you use (e.g. NOAA, SPOT, etc…)?

……………………………………………………………………………………………………..

16. Are you familiar with the area represented in the animation?

O very to moderately familiar
O slightly familiar
O completely unknown.

17. Before you started this session, the data that are used in the tasks were:

O very to moderately familiar
O slightly familiar
O completely unknown.

Experience with aNimVis

18. Can you mention 3 good things about the application?

- ……………………………………………………………………………………………………
- ……………………………………………………………………………………………………
- ……………………………………………………………………………………………………

19. Can you mention 3 bad things about the application?

- ……………………………………………………………………………………………………
- ……………………………………………………………………………………………………
- ……………………………………………………………………………………………………

20. Overall, how to you rate the application in terms of general usability?

    O very satisfactory
    O moderately satisfactory
    O neutral
    O moderately unsatisfactory
    O very unsatisfactory.

21. If the application would be linked to a GIS/image processing environment, would you use it?

    O yes, because ………………………………………………………………………………...

    O no, because …………………………………………………………..

APPENDIX 5 PROBLEM-SOLVING PHASES

applied by Participants 1-10 in questions 1-5

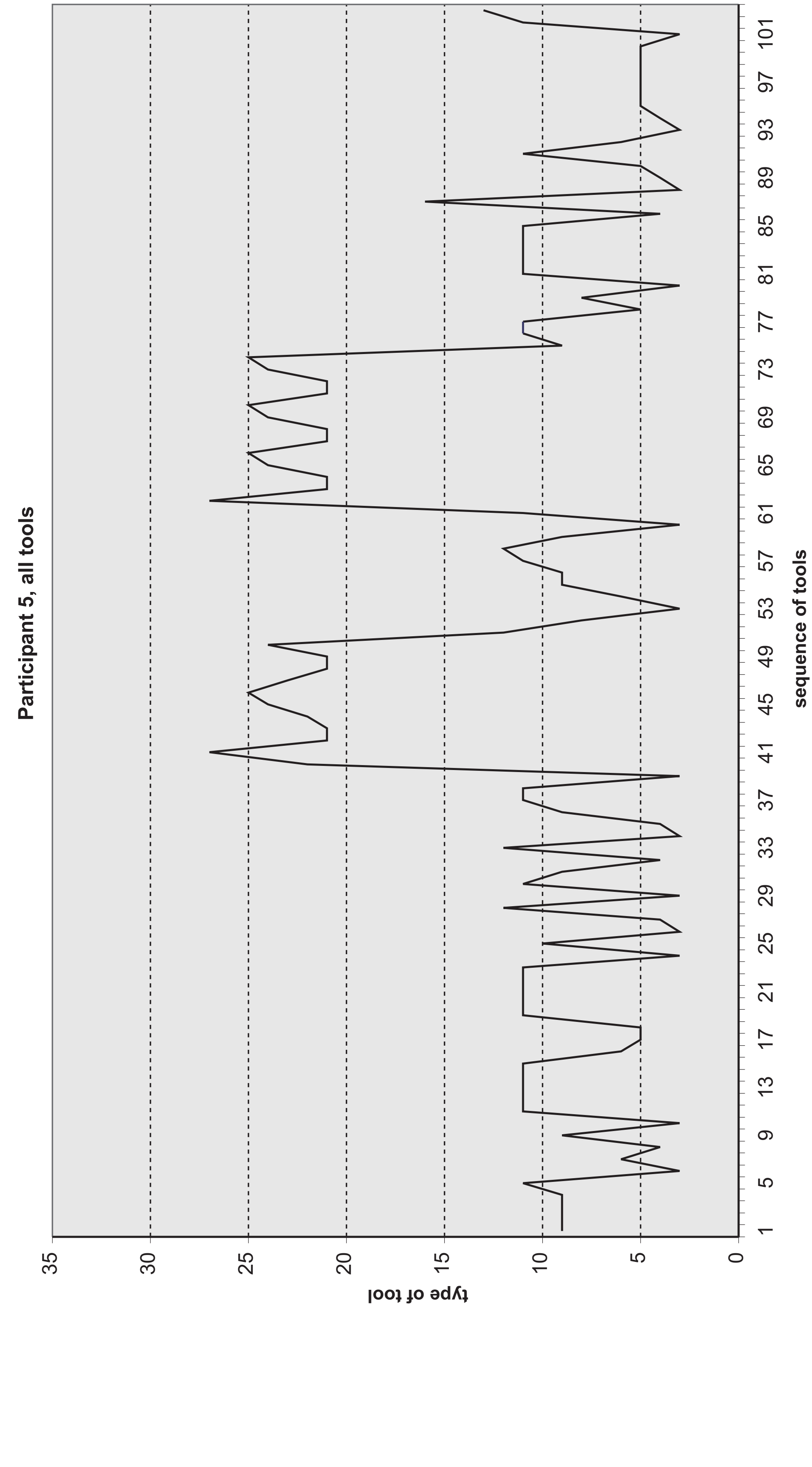
P1	P2	P3	P4	P5
First orientation Identification *8 x* Selection of time Id.+Comparison *4 x* Selection of area Id.+Comparison *2 x* Selection of area Comparison Selection of area Id.+Comparison Reflection Id.+Comparison	First orientation Selection of time *2x* Id.+Comparison Comparison	First orientation Selection of time Selection of area Id.+Comparison	Selection of area Selection of time Id.+Comparison Reflection	First orientation Selection of area Identification Selection of time Id.+Comparison
First orientation Selection of time Comparison Selection of area Id.+Comparison Selection of time Identification Comparison *2x* Selection of time Comparison	Selection of time Id.+Comparison Selection of time Comparison	Selection of time Comparison Selection of time Comparison	Comparison Reflection	Selection of time Comparison Selection of area Comparison
Selection of time Id.+Comparison	First orientation Selection of time Id.+Comparison	Selection of time Id.+Comparison	First orientation Selection of time Id.+Comparison	First orientation Selection of time Id.+Comparison Selection of area Id.+Comparison Reflection
Selection of time Comparison	Selection of time Id.+Comparison	Selection of time Comparison Id.+Comparison	Comparison Reflection	Selection of time Comparison

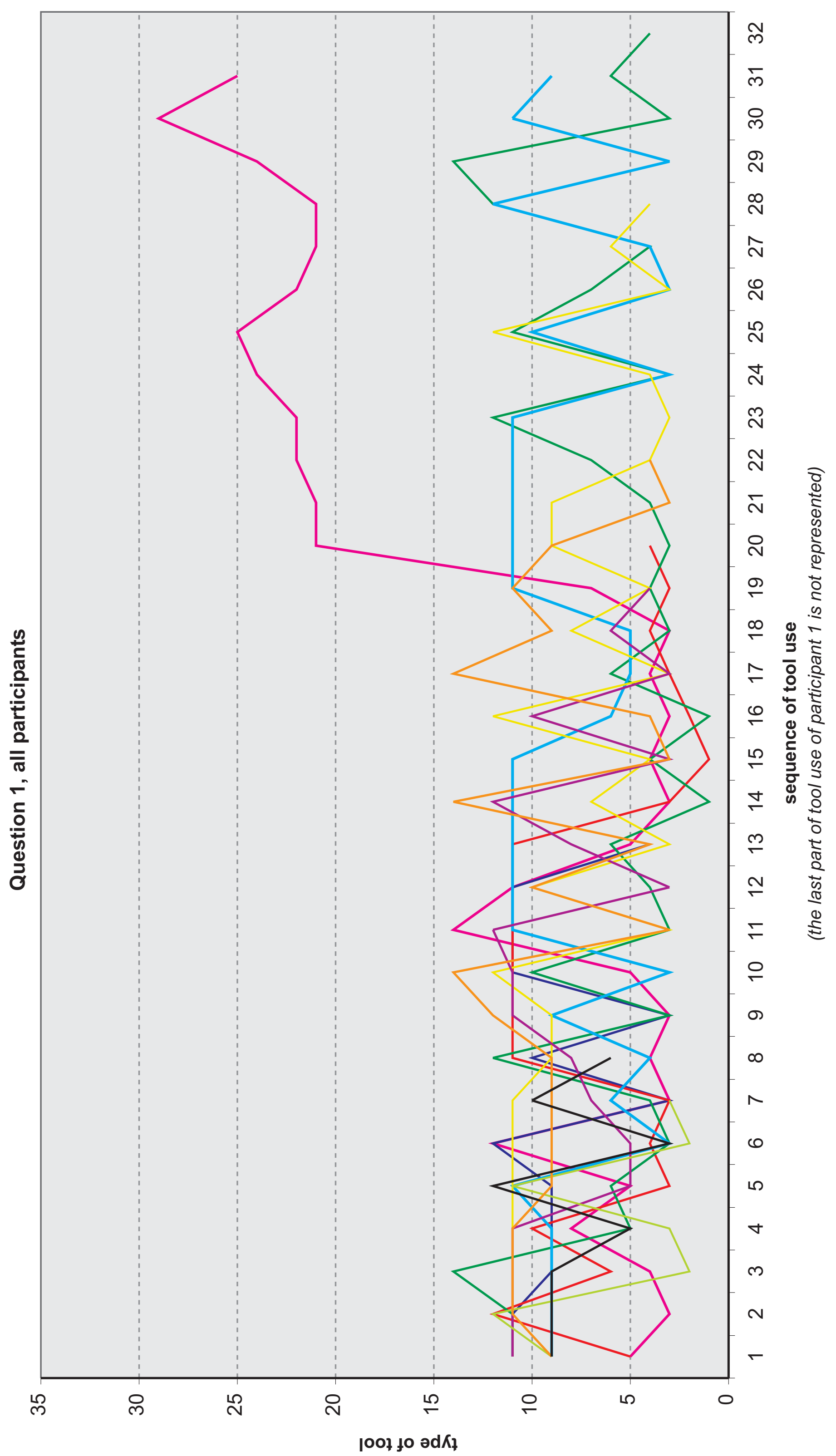
P6	P7	P8	P9	P10
First orientation Selection of time Id.+Comparison Reflection	Selection of time Selection of area Id.+Comparison	First orientation Selection of area Selection of time Id.+Comparison Selection of area Id.+Comparison Comparison	First orientation Selection of area Selection of time First orientation Id.+Comparison	Selection of time Id.+Comparison
Selection of time Comparison Reflection	First orientation Selection of time Id.+Comparison	First orientation *3x* Selection of time Comparison Selection of area Comparison	*2x* Selection of time Comparison Selection of area Identification Selection of time	First orientation Id.+Comparison Comparison Selection of theme First orientation Selection of time Comparison
Selection of time Id.+Comparison Reflection	Selection of time Id.+Comparison	Selection of time Identification	Selection of time Comparison Id.+Comparison	Comparison Selection of time Id.+Comparison
Comparison	Comparison	Comparison	*2x* Selection of time Comparison Selection of area Comparison Identification *3x* Selection of time Comparison Selection of area	Selection of time Comparison

P1	P2	P3	P4	P5
First orientation *2x* Selection of area Id.+Comparison Selection of time Identification Selection of time Id.+Comparison Selection of area Id.+Comparison Reflection	Id.+Comparison	First orientation Id.+Comparison Selection of area Id.+Comparison Selection of theme Id.+Comparison	First orientation *2 x* Comparison Id.+Comparison	Id.+Comparison Selection of theme Id.+Comparison Reflection

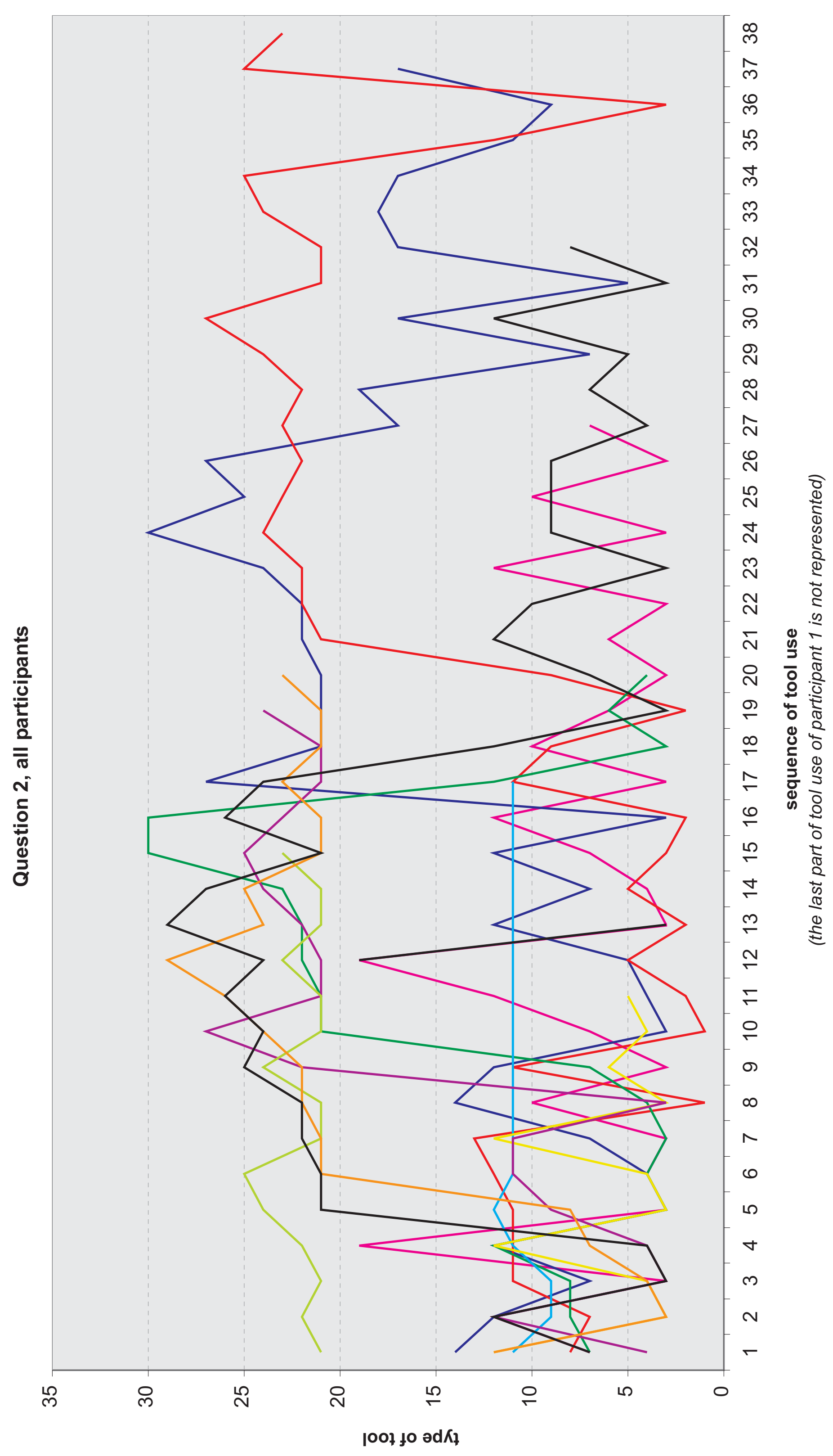
P6	P7	P8	P9	P10
Id.+Comparison	Id.+Comparison Selection of time Id.+Comparison	Comparison Id.+Comparison Comparison	Selection of time Comparison Identification Selection of area	First orientation Comparison Selection of time Comparison Reflection

APPENDIX 6 TOOL USE GRAPHS





Question 1, all participants
type of tool
0
5
10
15
20
25
30
35
sequence of tool use
(the last part of tool use of participant 1 is not represented)
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32



Question 2, all participants
type of tool
0
5
10
15
20
25
30
35
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38
sequence of tool use
(the last part of tool use of participant 1 is not represented)

APPENDIX 7 PREDICTED AND ACTUAL TOOL USE

Question 1. Predicted and actual tool use for changes in a relatively short period.

Tool number and name		Impl. effect		Explicit effect								Participant no.									
		dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review	dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review
1	first/last																				
2	step								1										2		
3a	play	1	1									1	1								
3b	play backward	2	2			2						3	3			3					
4	stop																				
5	time bar click																				
	time bar drag																				
6	display speed							1	1									1	1		
7	clear selection																				
8	default view																				
9	zoom			1										1							
10	loop										1										1
11	base map layers																				
12	selection temporal			1										1							
13	selection thematic			2										3							
14	selection representation					2										3					
15	blinking temporal									3										3	
16	blinking thematic									3										3	
17	alternate temporal						2										3				
18	alternate thematic						2										3				
19	alternate representation					2	2									3	3				
20	duration thematic									3										3	
21 22 23	tuning time bar, link/synchronize step				3				3						3				3		
21 22 24	tuning time bar, link/synchronize play	3	3		3							3	3		3						
25	tuning stop																				
26	tuning display speed				3			3	3						3			3	3		
27	tuning clear selection																				
28	tuning default view																				
29	tuning loop				3						3				3						3
30	tuning sel. thematic			3	3									3	3						
31	tuning sel. represent.				3	3									3	3					

Question 2. Predicted and actual tool use for differences and correspondences in relatively short periods

Tool number and name		Impl. effect		Explicit effect								Participant no.									
		dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review	dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review
1	first/last																				
2	step								1										3		
3a	play	1	1									1	1								
3b	play backward	2	2			2						3	3			3					
4	stop																				
5	time bar click																				
	time bar drag																				
6	display speed							1	1									2	2		
7	clear selection																				
8	default view																				
9	zoom			1										2							
10	loop										1										2
11	base map layers																				
12	selection temporal			1										1							
13	selection thematic			2										3							
14	selection representation					2										3					
15	blinking temporal									1										3	
16	blinking thematic									1										3	
17	alternate temporal						2										2				
18	alternate thematic						2										3				
19	alternate representation					2	2									2	2				
20	duration thematic																			3	
21	tuning time bar,																				
22	link/synchronize				1				1						2				2		
23	step																				
21	tuning time bar,																				
22	link/synchronize	1	1		1							1	1		1						
24	play																				
25	tuning stop																				
26	tuning display speed				1			1	1						2			2	2		
27	tuning clear selection																				
28	tuning default view																				
29	tuning loop				1						1				3						3
30	tuning sel. thematic			1	1									3	3						
31	tuning sel. represent.				2	2									3	3					

Question 3. Predicted and actual tool use for changes in longer periods

Tool number and name		Impl. effect		Explicit effect								Participant no.									
		dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review	dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review
1	first/last																				
2	step								1										2		
3a	play	1	1									1	1								
3b	play backward	2	2			2						3	3			3					
4	stop																				
5	time bar click																				
	time bar drag																				
6	display speed							1	1									3	3		
7	clear selection																				
8	default view																				
9	zoom			2										2							
10	loop										1										3
11	base map layers																				
12	selection temporal			1										1							
13	selection thematic			1										3							
14	selection representation					1										3					
15	blinking temporal									3										3	
16	blinking thematic									3										3	
17	alternate temporal						2										3				
18	alternate thematic						2										3				
19	alternate representation					2	2									1	1				
20	duration thematic									3										3	
21	tuning time bar,																				
22	link/synchronize				3				3						3				3		
23	step																				
21	tuning time bar,																				
22	link/synchronize	3	3		3							3	3		3						
24	play																				
25	tuning stop																				
26	tuning display speed				3			3	3						3			3	3		
27	tuning clear selection																				
28	tuning default view																				
29	tuning loop				3						3				3						3
30	tuning sel. thematic			3	3									3	3						
31	tuning sel. represent.				3	3									3	3					

Question 4. Predicted and actual tool use for differences and correspondences over longer periods.

Tool number and name		Impl. effect		Explicit effect								Participant no.									
		dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review	dyn.behaviour	rate of change	visual isolation	synchronization	re-expression	swapping	rate of change	pacing	emphasis	review
1	first/last																				
2	step								1										3		
3a	play	1	1									2	2								
3b	play backward	2	2			2						3	3			3					
4	stop																				
5	time bar click																				
	time bar drag																				
6	display speed							1	1									3	3		
7	clear selection																				
8	default view																				
9	zoom			2										2							
10	loop										1										3
11	base map layers																				
12	selection temporal			1										1							
13	selection thematic			1										3							
14	selection representation					2										3					
15	blinking temporal									3										3	
16	blinking thematic									3										3	
17	alternate temporal						2										3				
18	alternate thematic						2										3				
19	alternate representation					2	2									3	3				
20	duration thematic									3										3	
21	tuning time bar,																				
22	link/synchronize				1				1						2				2		
23	step																				
21	tuning time bar,																				
22	link/synchronize	1	1		1							1	1		1						
24	play																				
25	tuning stop																				
26	tuning display speed				1			1	1						3			3	3		
27	tuning clear selection																				
28	tuning default view																				
29	tuning loop				1						1				3						3
30	tuning sel. thematic			1	1									3	3						
31	tuning sel. represent.				2	2									3	3					

APPENDIX 8 FEEDBACK ON ANIMVIS

Table 1 Problems encountered with *aNimVis*

Bugs: need to be solved
The first frame of the animation cannot be included in a temporal selection. 'Blinking moments' does not work if a temporal selection exists. Existing temporal selections need to be cleared before 'alternate' and 'tuning' can be used. 'Alternate representation' does not work if one *starts* the selection with NDVI in the first box; selecting it in the second box - or after another selection has been made - is no problem. The media player buttons sometimes disappear. Clicking on the 'default view' button restores this. System restart is required if the slider in the thematic 'selection' menu is moved too far down.
Other desired improvements
Improvement of temporal selections in the pop-up windows (typing of dates; replacement of the calendar, e.g. by scroll bars). Improvement of the base map layer 'other elements' (a bit map). Removal of artefacts in the data (probably because of mosaicing) and better cloud corrections.

Table 2 Desired extensions of the functions in *aNimVis*

Main wishes
In 'tuning': inclusion of temporal selections (particularly periods), 'zooming' and base map layers. Also in 'tuning': a possibility to compare images from different sensors and different data sets Panning in addition to 'zooming' Pixel values available on mouse clicks in the image Temporal graphs on mouse clicks in the image or in the time bar
Some suggestions
Scroll bar in stead of calendar in the temporal 'selection' pop- up window To include a time or sequence indicator in the corner of alternating images Increased the vertical axis of the graph in the time bar Clearer indication of clouds in the legend Use of spacebar on the keyboard to stop the animation in stead of using the mouse

Table 3 Summary of answers provided to questions 18 and 19 in the questionnaire

Summary of 'good' things	**Summary of 'bad' things**
Overall opinion	**Overall opinion**
User friendly interface (2);	There are still some bugs (1)
Easy to use (3);	Mainly for low resolution (1 km or less) (1)
Ability to handle large temporal sequences (1)	Requires too many images (1)
Quick overview of entire series (4)	Maybe not useful (1)
Enables comparison of dynamics (1)	No high resolution reference map/image or other existing info (2)
It shows time, space and theme (1)	No link to image analysis and GIS environment (2)
Nice multi-temporal animation (1)	No computation (1)
Animation supports understanding (2)	No pixel values available (1)
Helps to decide how to tackle an area (1)	Only one graph instead of graphs per pixel (1)
Indicates how to do further processing (1)	No possibility to delineate areas or map units (1)
Enough options (1)	
Specific functions:	**Specific functions:**
Base map layers can be seen (1)	Tuning offers no base map layers (1)
Control of display speed (1)	Tuning offers no comparison with other image types (1)
Comparison of moments (2) and periods (1)	Tuning images are not juxtapositioned (1)
Different ways to step through temporal sequences (2)	No zooming in tuning (2)
'Tuning' (1)	No selection of periods in tuning (1)
Different representations, including classes (3)	'Blinking' & 'alternate' are not obvious choices (1)
	No custom colour sets (1)
	No colour editing and no annotations possible (1)
	Colour schemes are sometimes not visible (1)
	No comparison of two images in one (e.g. stereo) view (1)

Table 4 Reasons why participants want to use *aNimVis* if it is linked to a GIS or image processing environment

Reasons to use *aNimVis* if it is linked to a GIS or image processing environment
Analysis of large temporal data sets in the absence of software like *aNimVis* is very cumbersome
Quickly run through series of images
Of course, it helps to deal with changes
I don't know any other software that can visualize changes in that many images
It provides useful analysis tools not found in other software
If linked to Erdas
You can do change detection analysis if linked to RS/GIS
Monte Carlo simulation of spatial error could be a useful application for (parts) of the software
There are a lot of applications in forestry
Teaching

APPENDIX 9 ADDITIONAL USER INFORMATION ANIMVIS

This document contains some additional information to which you may want to refer:

- A look-up table with conversions from digital numbers to selected NDVI values
- (table 1).
- Additional information about the various representations under the menu *Selection* (table 2).
- Some hints: what to do if unexpected things happen.

Table 1 Conversion of digital numbers to NDVI values:
condensed list with the default DN (Digital Numbers) legend

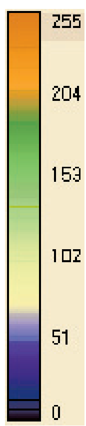
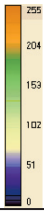
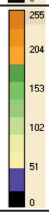
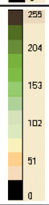
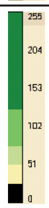
Default legend (DN)	Digital numbers	ndvi values
	255	0.92
	250	0.9
	225	0.8
	200	0.7
	175	0.6
	150	0.5
	125	0.4
	100	0.3
	75	0.2
	50	0.1
	25	0.0
	0	- 0.1

Table 2 Additional information about the different representations in the selection menu

Different representations (classifications and colour schemes)			Information
Continuous	DN's (digital numbers)		Unclassified (range from 0-255)
Classified	**NDVI**		> 50: 9 classes, equal steps 0-20 and 20-50: clouds, no data
	Spot classes		> 25: 12 classes, equal steps 0-25: clouds, no data
Course interpretation	Spot course		heavy vegetation medium vegetation light vegetation bare soil clouds, no data

What to do if unexpected things happen? Some hints

I want to undo a temporal or thematic selection:

- use the 'clear selection' button (top left); *or*
- in the selection menu: click 'clear selection'.

I want to select another representation:

- use the 'default view' button (top second) and then make another selection; *or*
- in the selection menu: click 'default view' and then make a new selection.

No images are represented (blanc window):

- try to click in the time bar, just a bit right from the start date.

Other problems: try one of the following

- in the selection menu: click 'default view'; *or*
- clear all selections, run the animation for a short time, then stop and make new selections; *or* exit the program, restart by clicking on the *aNimVis* icon on the desktop, select 'file', then 'open' and click the 'ok; button.

Summary

DYNAMIC VISUALIZATION VARIABLES IN ANIMATION TO SUPPORT MONITORING OF SPATIAL PHENOMENA

Introduction

Our world is dynamic. Changes occur constantly in almost all phenomena at or near the earth surface. Understanding these dynamics to discover spatio-temporal patterns, relationships and trends is an important step towards the solution of many global, regional and local problems (e.g. global warming, desertification, pollution, endangered food security). Data that may reveal the dynamics are abundantly available nowadays, even to such an extent that these data are not even fully exploited yet, particularly remotely sensed data. These data are often studied using computational methods, but the human ability to quickly *see* shapes, patterns, relationships, trends and movement is very powerful. If qualitative, visual methods and techniques to explore and analyze the data can be integrated with computationally based functions, preferably in one environment, this would yield a rich range of tools to support problem-solving decisions.

Problem definition

The research focused on animation to support monitoring of spatial phenomena. Experts involved in monitoring want to keep track of the dynamics exhibited by specific phenomena. Animated representations are dynamic by nature and they enable users to quickly observe real world changes, even small ones. But animations have limitations as well; they may overwhelm the observer with sequences of rapid, volatile changes. Is it possible to extract relevant information, or to acquire knowledge from an animation? Evidence in the geosciences is mixed, and very little is known about how an animated representation is actually used. Slocum et al. (2000) indicate that more research is required, particularly on animation design and use. My research focused on both aspects, but design was limited to the variables of the temporal dimension of animated representations (the dynamic visualization variables): moment of display, order, duration and frequency. One of my main research objectives was to develop methods to incorporate the variables in animation design in such a way that information relevant for monitoring could be discovered or acquired. My other main objective was to gain knowledge on the strategies and reasoning applied by experts in monitoring during the use of these variables in an animated exploration environment. Following on from this, I was hoping that the results would shed light on methods and tools to use animations effectively, and that this would lead to design recommendations and a theoretical framework for the application of the dynamic visualization variables.

Research methodology

The methodological approach consisted of four phases. The first three phases are described below. The last phase, formulation of the results, is incorporated in the section 'Main results'.

User task analysis. Overall monitoring goals, objectives and questions of geoscientists involved in monitoring have been identified based on literature review and interviews with domain experts. As a case study, satellite data containing a commonly used vegetation index (NDVI) were used. Aspects of change that are important for monitoring were also identified in this phase.

Creation of an environment in which answers to monitoring questions can be sought by visually exploring animations. Potential problems related to a reliance on *visual* input for changes (obtained from dynamic representations) have been investigated. Dangers such as 'change blindness' and 'inattentional blindness' (caused by problems to focus attention on simultaneously occurring changes) are described. The conclusion is that although there are limitations in the human capability to see change, there are possibilities for partly overcoming the problems as well, particularly if users can interact with the animated representation. In order to enable users to observe the earlier identified aspects of change, important for monitoring, I investigated which characteristics of change can be visually perceived in animated representations. This led to a framework of concepts, describing the characteristics in general terms. Following on from this, it is supposed that seeing change in an animated representation is able to trigger domain knowledge that is relevant in the search for answers to monitoring questions. The main cognitive tasks that are involved in visual exploration of patterns on maps (identification and comparison) were distinguished. Next, the dynamic visualization variables were investigated in depth. Four (already mentioned) variables have been distinguished, as well as the relationships between them. Further investigation focused on ways to use these variables to depict aspects of spatial data and to control the animated representation by interactions. The assumption was made that the dynamic visualization variables generate certain effects. If you know which effects a user wants – and preferably also for which question or task – then it might be possible to provide tools or develop methods that generate those effects. A prototype animation environment, *aNimVis*, was produced in which ideas about applications of the dynamic visualization variables have been incorporated. The data set used in the prototype consisted of pre-processed ten-day synthesis images (SPOT 4 VEGETATION) of a part of Iran.

Empirical testing. The first version of the prototype was evaluated in a session with domain experts (a focus group). Results led to some adjustments. This was followed by a detailed evaluation by domain experts of the use of the adjusted prototype. Data for the evaluation were gathered during individual sessions in which the participants were thinking aloud while they familiarized with the prototype and while they were performing a task. Verbal and action protocols could be generated from the integrated video recordings made during the sessions. In addition, data were gathered with post-test interviews and a questionnaire. The main results are summarized below.

Main results

The 'problem-solving behaviours' of potential users, who attempted to answer some typical monitoring questions, have been analysed in various ways. An analysis of the problem-solving phases revealed that 'selection of time' is most frequently used. This is followed by 'identification and comparison', then 'comparison'. Users were able to extract relevant information from the animation. Three main animation use strategies could be identified. Some users mostly want to reduce the amount of data, and then focus on subsets that are relevant for further exploration. Other users mostly want to play the animation almost continuously, taking time to observe patterns, without much further interaction, because that often distracts. Between these two groups, there are users who are mostly playing, or playing and stepping, but they also frequently interact with the data using various controls. Tool use paths or trajectories reveal similarities and deviations in tool use among participants. Basic tools – such as media player controls (like play, stop, forward, backward) and toggles with base map layers – were used by all participants. The same applies for temporal selection tools (see also the problem solving phases) and for the tuning mode. For tuning, this is unexpected, since users have to play or step through two simultaneously displayed animations: a perceptually and conceptually difficult task. Actual tool use by the participants was compared with a model that predicts tool use. Predictions were based on the effects that are generated by the dynamic visualization variables. Implicit effects (automatically occurring when an animation is played) and special effects (intentionally caused by interaction) were distinguished. Use of the *implicit effects* 'dynamic behaviour' and 'rate of change' is always high: the majority uses (at least once for each question in the task given) the play mode of the animation. Analysis of the use of *special effects* revealed that 'visual isolation' and 'review' are the most important effects that users want to generate. This can be explained by the overwhelming character of an animation. If comparisons in time have to be made, 'synchronization' of two animations (in the tuning mode) is also highly important. One of the earlier proposed theoretical effects, 'swapping', can be dropped from the list of special effects. Finally, the feedback gathered from the users during the evaluation sessions revealed problems with the application, good and bad aspects, overall (high) usability ratings and desired refinements and extensions. The most commonly expressed wish was to extend functionalities in the tuning mode. All participants would like to use *aNimVis* as a complementary environment to visually explore and analyze data if it was integrated into a GIS or image processing environment.

A start has been made with the establishment of a theoretical framework for application of the dynamic visualization variables. Taking the *effects* that users want to generate when they perform tasks with animated representations into account seems a more fruitful approach than looking at measurement levels of data. The latter was introduced by Bertin for the graphic variables, but cannot be automatically transferred to the dynamic visualization variables. In my research I attempted to link desired effects to (monitoring) tasks. Some links could be established, but more tasks and different questions need to be taken into account to establish and extend the relationships further. Given the different strategies of animation use applied in the context of this research, it seems that those users who want to visually isolate part of the complex content can best be served with *additional* tools, beyond the ones examined here. Tools that enable a reduction of the complex content are desirable anyway, to avoid problems such as change blindness and inattentional blindness. Such tools will enable effective use of animations. Tool design 'guidelines' can perhaps also be derived from the extensive user feedback. The directions for tuning, in particular, are clear.

Samenvatting

DYNAMISCHE VISUALISATIEVARIABELEN IN ANIMATIES VOOR HET MONITOREN VAN RUIMTELIJKE FENOMENEN

Inleiding

Wij leven in een dynamische wereld. Er treden voortdurend veranderingen op in bijna alle verschijnselen die zich aan of op het aardoppervlak bevinden. Het bestuderen van deze dynamiek om daarin ruimtelijk-temporele patronen, relaties en trends te ontdekken is een belangrijke stap naar de oplossing van veel globale, regionale en lokale problemen (voorbeelden zijn de opwarming van de aarde, verwoestijning, vervuiling, gebrek aan voedselzekerheid). Gegevens waaruit de dynamiek afgeleid kan worden zijn tegenwoordig ruim voorhanden, zo ruim dat ze zelfs nog niet volledig benut kunnen worden. Dit geldt met name voor satellietgegevens, die meestal worden geanalyseerd met behulp van rekenkundige methoden. Het menselijk vermogen om snel vormen, patronen, relaties, trends en beweging te *zien* is echter bijzonder krachtig. Als kwalitatieve, visuele methoden en technieken kunnen worden geïntegreerd met rekenkundige methoden, bij voorkeur binnen eenzelfde werkomgeving, ontstaat een rijke verscheidenheid aan mogelijkheden om gegevens te exploreren en te analyseren.

Probleemstelling

Het onderzoek had betrekking op het gebruik van animaties ter ondersteuning van het monitoren van ruimtelijke verschijnselen. Specialisten die zich met 'monitoring' bezighouden willen de dynamiek van bepaalde fenomenen kunnen volgen. Animaties zijn van nature dynamisch, gebruikers kunnen daarmee gemakkelijk ruimtelijke veranderingen, zelfs kleine, waarnemen. Maar animaties hebben ook beperkingen; ze kunnen de kijker overweldigen met een snelle, vluchtige opeenvolging van veranderingen. Is het mogelijk om kennis te vergaren en relevante informatie op te doen met een animatie? Onderzoek in de geowetenschappen levert gemengde resultaten op; er is bovendien weinig bekend over het gebruik van animaties in de praktijk. Slocum et al. (2000) geven aan dat meer onderzoek nodig is, met name naar animatieontwerp en -gebruik. Mijn onderzoek was op beide aspecten gericht, maar het beperkte zich qua ontwerp tot variabelen van de dimensie *tijd* (dynamische visualisatievariabelen) van een animatie: weergavemoment, volgorde, duur en frequentie. Een van de belangrijkste doelstellingen was om methoden en technieken te ontwikkelen om de variabelen zodanig in het animatieontwerp te gebruiken dat er informatie uit te halen is die voor 'monitoring' relevant is. Een tweede belangrijke doelstelling was inzicht te verkrijgen in de strategieën en denkwijzen van specialisten in 'monitoring' tijdens het gebruik van deze variabelen in een geanimeerde, exploratieve werkomgeving. Hiermee hoopte ik inzicht te verkrijgen in methoden en technieken die animaties effectief kunnen maken. Bovendien werd verwacht dat deze aanpak zou leiden tot aanbevelingen voor het ontwerp van animaties en tot een theoretisch kader voor de toepassing van de dynamische visualisatievariabelen.

Onderzoeksmethode

Het onderzoek bestond uit vier fasen. De eerste drie fasen worden hieronder kort beschreven. De laatste fase, het formuleren van de resultaten, wordt in de paragraaf 'Belangrijkste resultaten' behandeld.

Analyse van taken van gebruikers. Het algemene doel, meer specifieke doelstellingen en vragen van geowetenschappers die monitoren zijn ontleend aan literatuurstudie en interviews met vakspecialisten. Als voorbeeld is uitgegaan van satellietgegevens met een veel gebruikte vegetatie-index (NDVI-gegevens). Tijdens deze fase is ook vastgesteld welke aspecten van ruimtelijk-temporele veranderingen belangrijk zijn voor het monitoren.

Het creëren van een werkomgeving waarbinnen antwoorden op monitoringvragen kunnen worden gezocht met behulp van visuele exploratie van animaties. Problemen die gepaard kunnen gaan met het vertrouwen op *visuele* indrukken van veranderingen (verkregen uit dynamische beelden) zijn onderzocht. Gevaren zoals 'blindheid' voor verandering en het niet zien van veranderingen omdat de aandacht zich moeilijk op verschillende wijzigingen tegelijk kan richten, zijn beschreven. De conclusie was dat er, ondanks beperkingen in het menselijk vermogen om verandering te zien, opties zijn om de problemen tenminste gedeeltelijk te voorkomen, met name als de gebruiker over interactiegereedschappen kan beschikken. Om de eerder vastgestelde belangrijke aspecten van verandering voor het monitoren in een animatie te kunnen zien, is onderzocht welke karakteristieken van verandering in algemene zin visueel waarneembaar zijn. Dit heeft geleid tot een raamwerk van concepten, in algemene termen beschreven. Op basis daarvan is aangenomen dat het zien van verandering in een animatie kennis kan oproepen die relevant is bij het beantwoorden van monitoringvragen. De belangrijkste cognitieve taken die worden gebruikt bij visuele exploratie van patronen op kaarten (identificatie en vergelijking) zijn vastgesteld. Daarna zijn de dynamische visualisatievariabelen diepgaand onderzocht. De vier (al genoemde) variabelen en hun onderlinge relaties zijn eerst beschreven. Vervolgens richtte het onderzoek zich op het gebruik van deze variabelen om ruimtelijke gegevens weer te geven en om de animatie er door interactie mee te controleren. Verondersteld werd dat dynamische visualisatievariabelen bepaalde effecten oproepen. Als je weet welke effecten een gebruiker wenst – en bij voorkeur ook voor welke vraag of taak – dan is het misschien mogelijk om gereedschappen te maken of methoden te ontwikkelen die deze effecten genereren. De ideeën over toepassing van de dynamische visualisatievariabelen zijn verwerkt in een prototype animatieomgeving (*aNimVis*). Daarvoor zijn voorbewerkte NDVI -beelden gebruikt (SPOT 4 VEGETATION) van een deel van Iran.

Empirische toetsing. De eerste versie van het prototype is geëvalueerd in een sessie met vakspecialisten (een 'focus groep'). Op basis daarvan zijn enkele aanpassingen gedaan. Daarna volgde een gedetailleerde evaluatie van het gebruik van het aangepaste prototype met potentiële gebruikers. Evaluatiegegevens zijn verzameld tijdens individuele sessies waarin de deelnemers hardop dachten terwijl ze kennis maakten met het prototype en tijdens het uitvoeren van een taak. Uit de geïntegreerde video-opnamen die van elke sessie werden gemaakt, zijn verbale- en actieprotocollen verkregen. Daarnaast werden nog gegevens verzameld via interviews en een enquête, die onmiddellijk na de test plaats vonden De belangrijkste resultaten worden hieronder samengevat.

Belangrijkste resultaten

Het 'probleemoplossend gedrag' van potentiële gebruikers die enkele typische monitoringvragen trachtten te beantwoorden, werd op verschillende manieren geanalyseerd. Uit analyse van de probleemoplossende fasen bleek dat 'selectie van tijd' het vaakst werd gebruikt, gevolgd door 'identificatie en vergelijking', dan 'vergelijking'. De deelnemers waren in staat om relevante informatie uit de animatie te halen. Er konden drie gebruiksstrategieën van animaties worden onderscheiden. Sommigen beperken de hoeveelheid gegevens om zich te kunnen richten op gedeeltes die relevant zijn voor verdere exploratie. Anderen laten de animatie bijna voortdurend lopen; ze nemen de tijd om patronen te ontdekken zonder veel verdere interactie, want dat leidt vaak af. Daar tussenin bevinden zich gebruikers die de animatie spelen, of spelen en er doorheen stappen, maar die ook frequent gebruik maken van diverse interactiemogelijkheden met de animatie. 'Gebruikspaden' of '-trajecten' laten overeenkomsten en verschillen in het gebruik van interactiemogelijkheden tussen deelnemers zien. Analyse van de interacties wijst uit dat alle deelnemers gebruik maken van basisfuncties, zoals de controlemechanismen die mediaspelers ook bieden (spelen, stoppen, voor- en achteruit) en interacties met de topografische ondergrond. Hetzelfde geldt voor temporele selectiemogelijkheden (zie ook de probleemoplossende fasen) en voor 'tuning', de optie om twee animaties tegelijk te bekijken. Voor 'tuning' is dat opmerkelijk, want het zien van twee gelijktijdig zichtbare animaties is in perceptueel en conceptueel opzicht moeilijk. Feitelijk gebruik van de mogelijkheden werd vergeleken met een model dat het gebruik voorspelt op basis van de effecten die de dynamische visualisatievariabelen genereren. Er is onderscheid gemaakt tussen impliciete effecten (die automatisch optreden als een animatie wordt gespeeld) en speciale effecten (die bewust worden veroorzaakt door interactie). De *impliciete effecten* 'dynamisch gedrag' en 'mate van verandering' kwamen veelvuldig voor: de meerderheid *speelt* de animatie (minstens eenmaal per vraag in de gegeven taak). Analyse van het gebruik van *speciale effecten* maakte duidelijk dat 'visuele isolatie' en 'opnieuw zien' de belangrijkste effecten zijn die gebruikers willen genereren. Dit kan worden verklaard door het overweldigende karakter van een animatie. Als vergelijkingen in de tijd moeten worden gemaakt, dan is 'synchronisatie' van twee animaties (in 'tuning') ook zeer belangrijk. Een van de eerder voorgestelde theoretische effecten, 'wisseling', kan van de lijst met speciale effecten worden afgevoerd. Tenslotte leverde de terugkoppeling via de evaluatiesessies nog gegevens op: problemen met het prototype, goede en slechte aspecten eraan, algemene (hoge) gebruikswaardering en wenselijk geachte verbeteringen en uitbreidingen. De meest voorkomende wens was om de functionaliteit van 'tuning' uit te breiden. Alle deelnemers zouden *aNimVis* als complementaire visuele werkomgeving willen gebruiken als het geïntegreerd zou worden met een GIS- of een beeldbewerkingprogramma.

Er is een start gemaakt met de opstelling van een theoretisch kader voor toepassing van de dynamische visualisatievariabelen. Uitgaan van de *effecten* die gebruikers willen genereren lijkt een vruchtbaardere benadering dan kijken naar meetniveau's van de gegevens. Deze laatste benadering, door Bertin geïntroduceerd voor de grafische variabelen, kan niet automatisch worden overgenomen voor de dynamische visualisatie-variabelen. In mijn onderzoek heb ik geprobeerd om gewenste effecten te verbinden aan (monitoring-)taken. Sommige verbindingen zijn tot stand gebracht, maar meer onderzoek is nodig om verdere relaties uit te bouwen. Gezien de verschillende strategieën die tijdens dit onderzoek zijn gehanteerd, lijkt het erop dat gebruikers die visueel een deel van de complexe inhoud van de representatie willen isoleren het meest geholpen zijn met *aanvullende* interactiemogelijkheden, die verder gaan dan de mogelijkheden die in dit onderzoek zijn gebruikt. Interactiemogelijkheden die de complexe inhoud kunnen reduceren zijn in elk geval wenselijk om problemen zoals 'blindheid' voor verandering te voorkomen. Dergelijke interactiemogelijkheden maken effectief gebruik van animaties mogelijk. Aanbevelingen voor het ontwerp van animaties kunnen ook worden ontleend aan de terugkoppeling van gebruikers van het prototype. De aanwijzingen voor 'tuning' in het bijzonder zijn duidelijk.

CURRICULUM VITAE

Connie Blok was born on 5 January 1951 in Ridderkerk, the Netherlands. From 1963 to 1968 she attended the regular Dutch secondary girls' school (mms). In 1975 she embarked on a part-time secondary school teacher's training course in geography and obtained her MO 1 certificate in 1979. After having met university entrance qualifications, she was admitted to Utrecht University in 1980, when she started her academic studies. She majored in cartography, with cultural landscape geography and psychology of perception as secondary subjects. In 1986, Connie was awarded a Master's Degree (drs.) with distinction (*cum laude*). In the same year, she started working at ITC (International Institute for Geo-Information Science and Earth Observation) in Enschede, the Netherlands, where she is still employed. For the past 18 years at ITC, she has been mainly involved in teaching and research in cartography, geovisualization and geoinformatics. Her current position is Assistant Professor in geovisualization. Her PhD research was embedded in ITC's BIOFRAG Research Programme. During this research work, she obtained travel awards to attend NCGIA's Varenius Project meeting on Cognitive Models of Dynamic Phenomena and their Representations, sponsored by the U.S. National Science Foundation, in Pittsburgh (PA), USA (1998); and to attend the Workshop Maps and Diagrams in Hamburg, Germany (1999). Connie Blok has been an editor of the Netherlands Cartographic Journal (Kartografisch Tijdschrift) for ten years. She is a corresponding member of the Commission on Visualization and Virtual Environments of the International Cartographic Association.

ITC DISSERTATIONS

1 Akinyede (1990), Highway cost modelling and route selection using a geotechnical information system.
2 Pan He Ping (1990), 90-9003-757-8, Spatial structure theory in machine vision and applications to structural and textural analysis of remotely sensed images.
3 Bocco Verdinelli, G. (1990), Gully erosion analysis using remote sensing and geographic information systems: a case study in Central Mexico.
4 Sharif, M. (1991), Composite sampling optimization for DTM in the context of GIS.
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6 Groten, S. (1991), Satellite monitoring of agro-ecosystems in the Sahel.
7 Sharifi, A. (1991), 90-6164-074-1, Development of an appropriate resource information system to support agricultural management at farm enterprise level.
8 Zee, D. van der (1991), 90-6164-075-X, Recreation studied from above: Air photo interpretation as input into land evaluation for recreation.
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