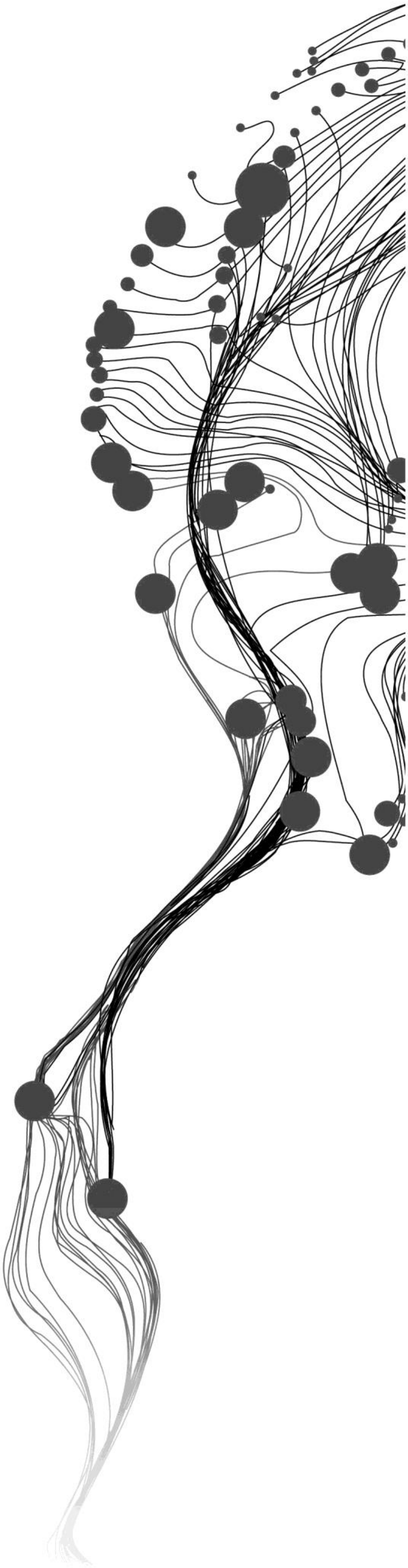
SUPPORTING VISUAL EXPLORATION OF ANIMATED TIME SERIES WITH MODIFIABLE TEMPORAL UNIT

RANI CHARISMA DEWI
February, 2012

SUPERVISORS:
Ms. Dr. Connie A. Blok
Dr. Ulanbek D. Turdukulov
Dr. Raul Zurita-Milla



SUPPORTING VISUAL EXPLORATION OF ANIMATED TIME SERIES WITH MODIFIABLE TEMPORAL UNIT

RANI CHARISMA DEWI
Enschede, The Netherlands, February, 2012

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

SUPERVISORS:
Ms. Dr. Connie A. Blok
Dr. Ulanbek D. Turdukulov
Dr. Raul Zurita-Milla

THESIS ASSESSMENT BOARD:
Prof. Dr. Menno-Jan Kraak (Chair)
Dr. I. Delikostidis (External Examiner, University of Munster)

ABSTRACT

Seeing change in geodata is important for various purposes such as viewing the status of on-going developments and to predict the future. Animation is selected in this research as a potential method to visualize change in time series. But different phenomena may change in different time intervals. Hence users require methods and tools to control temporal units used to visually explore. In addition, users might be overwhelmed by the number of changes displayed in an animation of long time series. Therefore users may also want to change to a different time unit when using animation. But the animation environments often do not enable such changes. Supporting tools to modify the temporal unit are therefore needed for improving any animation environment. In this way, users can modify the temporal units according to their needs.

There are several kinds of interaction with time: constructing and controlling the animation, temporal panning, temporal query, temporal zooming, and temporal data transformation. As in spatial zooming, temporal zooming is also includes zooming in and out. Temporal querying and temporal zooming can be used to modify the temporal unit. Implementation of temporal zooming out and temporal queries are the focus of this study. Some of the methods proposed and applied as the modifiable temporal unit tools are time sampling, time aggregation, time brushing, and time selection based on the threshold. To support the users in their choice of the new time unit, a general overview of the data, or the relation between the attribute and time should be given before conducting time selection/modification. A time series graph is employed to do it.

Proposed methods are implemented in ILWIS, open source GIS software originally built by ITC. ILWIS is chosen because extending open source software will be useful, especially for users from developing countries. Prior to the implementation of the methods, a review of existing tools in ILWIS is carried out. Existing tools and methods that might be used for time unit selection are improved, and tools that did not exist have been developed.

Unfortunately user evaluation of the prototype and evaluation of the effect of modifying the temporal units on the user have not been done in this study. Therefore, the effectiveness of the proposed tool and the level of satisfaction in using the proposed tools could not be identified. However the prototype produced in this thesis work can be used to select different temporal units to monitor changes and to reduce the amount of information displayed. They may also be used to find a proper temporal unit for monitoring events. The combination of the time series graph and time selection tools allows the user to answer visual exploration questions related to attribute (what), location (where) and time (when, how long, how often). As a case study, NDVI data, considered useful for monitoring vegetation conditions have been used to implement the functionalities of the tools. The case study shows how geographic phenomena can be identified by the tools.

Keywords: animation, time series, time unit selection, modifiable temporal unit.

ACKNOWLEDGEMENTS

Praise is for Allah SWT, God the Almighty for granting me the mercy and countless blessings.

First, I would like to express my sincere appreciation and gratitude to Dr. Connie A. Blok for her continued guidance, patience, and encouragement in supervising me and also giving me the trust to continue the research. Nonetheless, I also express gratitude to Dr. Ulanbek D. Turdukulov, and Dr. Raul Zurita-Milla for their comments and suggestions. This thesis would not have been possible without their generous dedication of time, knowledge, and advice.

I would convey my appreciations to Mr. Martin Schouwenburg, the programmer in GIP, for his helped and suggestion in the process of implementation of this research. Without him, the implementation phase might not be done. Not forget to mention Mr. Bas Retsios who gave me guidance for the implementation.

Let me also say thank you for my Indonesian friends who create home away from home. Special thanks go to Arie Yulfa, Fitriani Agustin, Idham Effendi, Hidayah Hamzah, Nugroho Christanto, Fesly Paranoan, Debi Mutia, Doddy Yuwono, Tiur Simanulang, Syarif Budhiman, and Anas Fauzi for our cheerful life in Enschede. Thank to my GFM 2010-2012 classmates, especially for Reza Ahmadyieh, Kingsley Obi, and Molham Darwish for their friendship.

I wish to express my appreciation to StuNed, the Studeren in Nederland Scholarship Program, for its financial support to pursue this study. For Ministry of Public Works of Republic of Indonesia, particularly, I would like to thank Benny Hermawan, Amwazi Idrus, Waskito Pandu, and Lisniari Munthe for giving me the opportunity to study in ITC.

In the other side of the Earth, my deepest gratitude is for my parents, Rustijanta and Tri Ligaria, for their endless love and prays. I dedicate this for you, especially for your birthday gift, mom. I would also say thank you to my sister and brother, Dian Suci and Adhitya Wisnu for their wonderfully warm support during my study.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Motivation and problem statement

Geographic phenomena change over time. Some phenomena, such as geological features or glacier movement, change slowly while other phenomena, i.e. atmospheric condition, change rapidly. These processes are captured by satellite sensors in satellite imagery with high temporal frequency. The imagery can be used for constructing long time series that may reveal patterns and trends of dynamic phenomena. Thus we can learn spatial, temporal or spatio-temporal patterns, and relations between patterns, and trends from satellite time series. Understanding the dynamics of phenomena is important. For example, understanding of vegetation change is required for sustainable resource management, habitat conservation, and also for understanding the role of climate change (Kross et al., 2011). Domain experts do monitoring to understand the spatial change and the spatial interaction. Moreover, by monitoring, they not only try to understand the change and interaction, but also to predict what could happen in the future.

In general, human need their vision to learn and understand the dynamics of geographic phenomena (Turdukulov, 2007). Therefore geo-visualization is employed to support these activities because it can stimulate visual thinking about spatial patterns, relations, and trends (visual exploration) (ITC, 2010). To visualize change, animation is a possible choice. Animation has a better ability to represent a dynamic process than static images (Harrower & Fabrikant, 2008). Kraak and Ormeling (2010) explain that animation shows trends and process; and provides insight into spatial relations. However, animation has also some limitations (Harrower & Fabrikant, 2008). The ability of satellite sensors in capturing data leads to existence of numbers of images. Displaying all available images in an animation will produce information overloads that causes change blindness. Users might fail to see important changes, forget what they have seen in animation, or encounter a split attention problem, e.g. by trying to keep up with the changing display while consulting legends. But overall, animation is potentially suitable for the visual exploration of dynamic phenomena or mapping change.

Change is associated with time. The time aspect is important for studying geographic activities (Kraak, 2000; Meentemeyer, 1989). To observe different geographic phenomena, one also needs different appropriate temporal units for monitoring. Visual exploration of time series collected at (for example) daily intervals results in different patterns than visual exploration at coarser temporal interval (Harrower et al., 2000). Therefore appropriate temporal units should be decided to monitor and analyse particular geographic phenomena. But currently, the decision on the choice of a temporal unit depends on the data availability or on trial and error (Çöltekin et al., 2011). An animation environment often only shows the animation with the spatial and temporal unit in accordance with the data (Harrower, 2001). They do not offer possibilities to modify or change/select the temporal unit of an animation. Animation environments need improvement. For example: tools that enable users to change/choose different temporal units to support visual exploration activities are needed.

This research will concentrate on methods to develop tools that help users to modify temporal units of animated time series in flexible ways. Thus users can find the appropriate temporal unit for phenomena they observed. These temporal units can be selected based on regular or irregular time intervals. Regular time intervals may be obtained from regular sampling in time (e.g. daily, weekly, or monthly); or replacing individual pixel values by a representative value over a time unit (e.g. minimum, maximum, or average pixel value over a week or different time units). Whereas irregularity might be caused by selection/filtering of images based on events or on thresholds or key values.

Previous research's results or recommendations about visualization tools, especially tools that are used to modify temporal units, will be taken into account to enhance the functionality of an animation environment in supporting monitoring.

1.2. Research identification

The main objective of this research is to design a prototype animation environment with tools that enable users to modify the temporal unit in order to support visual exploration of time series.

NDVI data will be used for the implementation of the methods, which will be integrated into ILWIS. It needs further study to decide which case studies that will be used. The following are sub-objectives that are defined to achieve the main objective:

1.2.1. Sub objectives

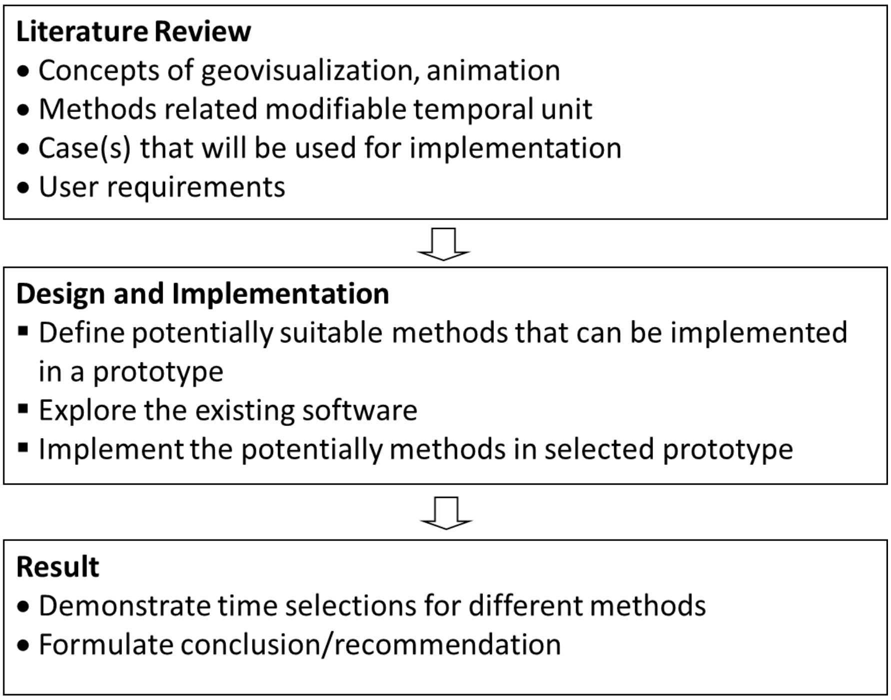
1. Find methods that support visual exploration of animated time series with modifiable temporal units.
2. Decide which methods are potentially suitable to implement in the user interface.
3. Design and implement potentially suitable methods in a user interface/prototype.

1.2.2. Research questions

1. What methods can be used to do time selection of animated time series for visual exploration?
2. Which methods are potentially suitable for implementation in a prototype?
3. What are user requirements?
4. How to design and implement the potentially suitable method(s) in a prototype?
5. Which case studies can be used to demonstrate the methods/tools?
6. What recommendation that can be derived from the results of the implementation?

1.3. Methodology

The following phases of methodology are proposed to meet the research objectives:



Literature Review
- Concepts of geovisualization, animation
- Methods related modifiable temporal unit
- Case(s) that will be used for implementation
- User requirements

Design and Implementation
- Define potentially suitable methods that can be implemented in a prototype
- Explore the existing software
- Implement the potentially methods in selected prototype

Result
- Demonstrate time selections for different methods
- Formulate conclusion/recommendation

Figure 1.1 Research methodology

1.4. Thesis outline

The remaining part of the thesis is organized in four chapters:

Chapter 2 discusses the main concepts about geovisualization and visualization tools. This chapter will also explain several possible methods for the modification of temporal units and the influence of temporal units to conduct the study of vegetation.

Chapter 3 describe the conceptual framework for visual exploration and how it is supported with time selection tools.

Chapter 4 describes design and implementation of proposed methods in ILWIS. First described is the data that is used for implementation, then existing tools in ILWIS that are related to the modifiable temporal unit and should be improved as modifiable temporal unit tools, or new tools. Implementation of the proposed methods is also described.

Chapter 5 contains the conclusions that are formulated by answering the research questions, and recommendations.

2. MAIN CONCEPTS

As discussed in the previous chapter, visual exploration of time series is done in order to understand the dynamics or process of change. Given a long time series of satellite imageries, animation is chosen as representation method for visual exploration.

This chapter briefly discusses geovisualization and visual exploration (Section 2.1, 2.2, 2.3), continued with some limitation of animation (Section 2.4), type of interaction with the data (Section 2.5), modifiable temporal unit (Section 2.6), possible methods for selection time (Section 2.7), and it gives an overview of previous research related to visual exploration of time series data (Section 2.8). The purpose of this chapter is to define the terms in geovisualization and some possible methods to modify the temporal unit that can support visual exploration of geodata.

2.1. Geovisualization

Nowadays, the geographical (spatial) component has an important role in modern data. Visualization of data containing this component is known as geovisualization. Geovisualization, short of geographic visualization, is a process to represent data that refer to location, attribute, and time of objects or phenomena on Earth(Kraak & Ormeling, 2010). Blok (2005) mentioned that it can be considered as “making visible” by creating graphic or external representations in a particular context of use: visual exploration; and in terms of cognitive or internal representations by using maps.

Geo-visualization is applied for four purposes: exploration, analysis, synthesising, and presentation (Kraak & Ormeling, 2010). This research focuses on geovisualization for exploration purposes. Exploration means searching for patterns, trends, and relationships in unknown data with high interaction to get understanding of the data and develop hypotheses that may be used as input for geospatial analysis. Domain experts might be interested in the patterns in the data, distribution of phenomena, anomaly events, sequence of (dis)appearance of phenomena, trends in pattern development, and relationships and differences in patterns (Blok, 2005). For example, data visualization is used to monitor vegetation. Understanding the process of change in vegetation is important. It can be used for land cover change detection, sustainable resource management, habitat conservation, and also as an indicator of role of climate change (Blok, 2005). Patterns can be used for further analysis, such as to study more about the occurrence of anomaly events, relations in space and time. Furthermore pattern and trend can be used for future prediction. Studying change can also be used as an indicator of on-going development

Remote sensing technology can support this monitoring activity by providing continuous relevant data over time. The use of satellite sensors to obtain spatial data and their ability to capture the spatial data in high temporal frequency results in large sets of data. The analysis of such large sets of data is often a difficult task and searching for patterns, trends, and relationships is a difficult challenge.

2.2. Visual exploration

Visual exploration is a process of abductive reasoning or reasoning to the best explanation (Blok, 2005). It starts with no hypotheses of the data and tries to develop them by exploring the patterns, relationships, trends, etc. The hypotheses then are assessed for compliance with the visible patterns and trends.

Visual exploration's main objectives are discovery, explanation, knowledge acquisition, and decision making (Blok, 2005). Its results are influenced by many factors, but mainly depend on user’s ability and knowledge. Other factors that influence it are application domain, observed phenomenon, data, and visualization methods and tools.

Shneiderman (1996) defined the "information visualization mantra": overview –zoom and filter –detail on demand. The mantra indicates how information visualization supports users in the process of finding the information. Overview provides a general understanding of the whole data represented. An overall pattern of data can be identified from the overview. This can provide assistance in understanding the information that will be used for further analysis. For further tasks, users can look and choose the features that seems interesting to be observed. But these features may not be easily seen from the overall data representation. Then users need to select and filter information that may interfere with their activities in performing visual exploration. Finally details on-demand should allow users for selecting parts of the data to be visualized in more detail.

Technology development in recording, capturing, and storing data causes data explosion. But only valuable data/attribute data is used to do a specific task. And finding the valuable data needs ability to explore the data. Keim (2001) extend Shneiderman's "information visualization mantra" with "visual analytics mantra": analyse first – show important – filter and zoom – detail on demand. Before displaying required information (show important), data calculation and operations (analysis) is needed. Then users can interact with the data generated, rather than with the raw data, and used tools such as filtering and zooming for further analysis. Finally detail on detail on demand can be done to obtain more information about interesting data.

In collecting time series data, satellite records/captures images of a specific place on the earth with the same interval of time. But often data analysis is not conducted using all the images that are captured. Raw satellite image is often very noisy and temporal selection or aggregation is necessary to eliminate short term and random variations. Furthermore Blok (2005) mentioned that data acquisition, such as temporal extents and resolution affects how spatial dynamic is delivered (Figure 2.1).

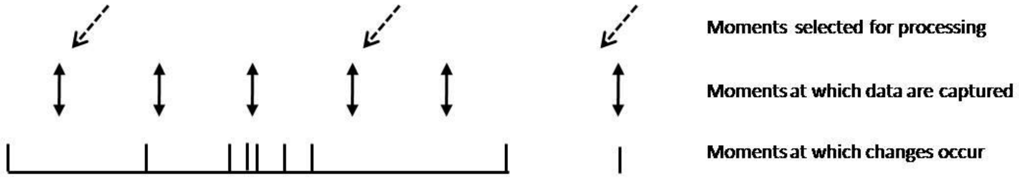


Figure 2.1 Spatial dynamics visualization depends on data acquisition and selection of snapshots (Blok, 2005)

Visual exploration tasks on spatio-temporal data can be focused on the components of geospatial data: location, attribute, and time (Kraak & Ormeling, 2010). The questions where, what, and when are basic questions that are used to achieve the visual exploration tasks. Visual exploration tasks are -for example - done to detect changes over time, such as temperature change between day and night. The simple temporal question 'when?' can be extended to how long, in what order, etc. These questions could be asked with both linear and cyclic time in mind, at different (temporal) scale as well. This should result in detecting trends and patterns that lead to understanding of the data.

2.3. Geovisualization methods

There are some graphic representation methods for visualizing change: single static map, series of static maps, and animated map (Kraak & Ormeling, 2010). They are not comparable, because the use of those different representation methods depends on the purpose and the data. In single static maps, change is shown by one or more specific graphic variables or symbols (like arrows). In series of maps, single maps represent snapshots in time. Change is perceived by looking at the series of individual maps. But it can be used only for a limited number of images; a user will face problems if it deals with long series.

Another representation method is an animated map. Animation is a dynamic representation of data that depicts change over time, space and/or attribute and represents the process of change. Map animation exploits the capability of the computer screen to rapidly update its content. In this type of representation, changes are represented by changes of a display, they are perceived to happen in a single frame by displaying several images in sequence. In animated maps, users can see the process of change by real movement on the map. Animations can be very useful in clarifying trends and process, as well as in explaining or providing insight into spatial relationship (Kraak & Ormeling, 2010). It is a suitable method to explore time series of satellite imageries because it has a better ability to represent a dynamic process than static images (Harrower & Fabrikant, 2008). Moreover, animation, utilizes computer technology, usually equipped with controls that allows users to interact with data to support their exploration activities. In this study, control in relation to time will be discussed.

2.4. Cognitive overloads and change blindness

There are two cognitive structures in human brain namely working memory and long term memory. Working memory has limited memory, it used to be called short term memory, while long term memory has unlimited capacity. There is an iterative interaction between those memories (MacEachren, 1995). Working memory consciously processes the information received. But with limited capacity, it can only process limited information at one time. Then knowledge received from the working memory is stored into long term memory. From long term memory, the knowledge is sent back to working memory to help us understanding the information received.

With the limited capacity of working memory, it becomes vulnerable to overload if the learning process becomes increasingly complex and the brains have to perform increasingly complex tasks. There are several causes of cognitive overload such as: too much information supply, too much information demand, multi-tasking and interruption, and an inadequate workplace infrastructure (Kirsh, 2000; Malamed, 2009). The activity of gaining new knowledge and performing visual exploration tasks will be less effective when there is abundance information to be processed at the same time. Cognitive overload may also be caused by uncertainty about the need for information, such as how much, when, what valuable information is necessary. This leads to excess demand of information from the merely necessary information that is needed to acquire the expected knowledge (Kirsh, 2000). Cognitive overload is also caused by complex interaction with many elements that must be handled simultaneously in the learning process.

Cognitive load theory is designed to provide a guidance for presenting information in a way that optimizes the learning performance (Sweller et al., 1998). And based on the cognitive load theory, there are three types of cognitive overloads that occur in working memory during the process of learning: intrinsic cognitive load, extraneous cognitive load, and germane cognitive load (Sweller et al., 1998). Intrinsic cognitive load is caused by the nature of the learning tasks, number of elements/material to be learned, and their complexity. Extraneous cognitive load is caused by activities that do not have any relation or do not help the process of learning. It might be caused by poor design of the material to be learned. Germane load refers to effective cognitive load that result from involving learners to consciously engage in cognitive processes that are directly relevant with the new knowledge construction.

Animation overloads users with a rapid sequence of images; it leads to unobserved important changes. Change blindness is a visual perception problem when users fail to notice important or obviously visible change (Nowell et al., 2001; Simons & Levin, 1997). Users might also be overwhelmed with the amount of images that is displayed in an animation, and not remember what they had seen (Kraak & Ormeling, 2010).

Inattentional blindness happens when users fail to see change because they are involved in finding another feature, or in another task (Blok, 2005). Another potential cause of change blindness is split attention. It often happens when users use more than one source to gain knowledge from a display (Kraak & Ormeling, 2010). In the animation, users might miss some scene displayed when they consult in (time) legend. Although cognitive overload and change blindness might be unavoidable, they might be reduced by designing a good user interface.

2.5. Interaction

Interaction refers to controls that allow users to interact and manipulate data elements that have an effect on the image display through a user interface (Blok, 2005). According to Edsall et al. (2009), interaction should overcome the shortfall of the display, help to discover otherwise unobservable pattern, and to explore particularly large dataset. By interaction, users can access additional information and manipulate the representation. On large datasets, interaction allows the user to access data or attributes that will be used to reduce the amount of information to be received. In addressing the problem of shortage of displays, such as monitor resolution, colour, two dimensional interactions such as zooming, panning, re-projecting, focussing are commonly used.

To explore large databases or datasets, (Edsall et al., 2009) classified some operations into roll-up/drill-down and slice and dice. The operations are related to the visualization mantra that discussed in Section 2.2. Roll up is related “analyse first”, and slice and dice to “filtering”, and drill-down to “detail on demand”. In order to give general overview of the data, roll up (analyse first) is a way to simplify the data by aggregation, generalization, and abstraction. Then users can select the interesting parts “filtering” by slice and dice, for example select an interesting particular area to be explored. While by drill-down, users can look into the data in more detail. Furthermore Edsall et al. (2009) add some interactions: selection of themes, brushing and linking, and conditioning may also be used to explore large database/datasets.

In order to achieve the purpose of visual exploration, it is recommended that users should have control over data and presentation (Harrower & Fabrikant, 2008). Visualization tools are controls that enable users to build or manipulate graphic representations of data in computer environment (Blok, 2005). Since animation is a computer based visualization method, it has usually at least some interactivity with which the users are able to control the animation parameters.

2.5.1. Interaction with dynamic variable

An animation environment named aNimVis (animated image visualization) was developed by Blok (2005). Compared with static images, animation contains additional variables, especially in the temporal dimension. aNimVis was developed to investigate the interactive use of four dynamic visualization variables for animated time series.

aNimVis is an interactive prototype that allows users to interact with time series and to manipulate the dynamic variables to achieve relevant information from time series data. By controlling the dynamic variables, interesting patterns and behaviours can be emphasized. Table 2.1 defines four dynamic variables and examples of interaction with those dynamic visualization variables.

Andrienko et al. (2003) also mentioned some other animation parameters that may be potentially controlled by the users:

1. Speed
2. Direction
3. Extent, start and finish moments
4. Moment/interval to include in the animation:
    a. Step, the interval between time moments of successive animation frames
    b. Moment or periods within a cycle

    c. Arbitrary selection
5. Smoothness

From the interaction with dynamic variables that are explained by Blok (2005) and Andrienko et al. (2003), the selection of a new time unit is related to interaction with the moment and interval, whereas the other animation parameters, such as time extent and duration, further support use activities

Table 2.1 Dynamic variables and type of interaction (Blok, 2005)

Dynamic visualization variable	Definition	Type of interaction
Moment of display	Position of a state or a change in the representation in display time	Selection and deselection of : time, location, thematic attribute, graphic representation
Order	Structured sequence of states or changes in representation in display time	Manipulation of start/end of the animation
Duration	Length in display time of a state or change in the representation	Manipulation of the length of display time
Frequency	Repetition or number of identical states or changes in the representation per unit of display time	Repetition

Smoothness

Smoothing techniques can be used to reduce irregularities in time series data. Smooth changes in the animation can both enhance and reduce the ability of users to interpret and understand the animation (Becker, 2009). The irregularities might be so strong that they obscure patterns or trends which are important for the understanding of the process being observed. Smoothing can also reduce or cancel the effect of irregularities. Images captured with low temporal resolution lead to the occurrence of big changes between images. Major changes lead to the process of change, for example the process of moving object to be unnoticed by observers. Smoothing techniques, such as interpolation, might help the observer in interpreting the changes in time series. However, as described by Simons and Levin (1997), observers might still fail to notice the changes displayed due to change blindness.

2.5.2. Interaction with time

Harrower and Fabrikant (2008) generally indicated two types of time: linear and cyclic. In linear time, time is regarded as a constant that is always moving forward and measured at ordinal scale. While in cyclical time, time is measured by one round/cycle as time reference. Cyclic time is used to study the pattern of recurrent events, for example the cyclic nature of day and night or repeating seasonal patterns year after year.

Further Edsall et al. (2009) extend the interactions for temporal information:

1. Constructing and controlling animation. This is the first thing to do in building an animation. Since a temporal animation is a representation of events that occur in a time sequence, the user should be able to build the animation by sorting the images/frames associated with the time order.
2. Temporal panning. In temporal data, temporal panning control is mostly done by applying video controls like start, stop, pause, fast, forward, and rewind.

3. Temporal zooming. As well as zooming functions in spatial data, temporal zooming can be done to get another level of detail for the time. Changes in the level of detail over time is required because geographic entities can be perceived depending on the level of detail (Hornsby & Egenhofer, 1999). As in the spatial zooming, the zoom is also known as temporal expand (zoom in) and collapse (zoom out) as it is shown in Figure 2.2.
4. Temporal querying. Temporal querying allows users to select or sort images/frames to be shown in the animation. The query is used as an option for displaying linear time and cyclic time. Cyclic time for example if the user wants to know the specific data related to a cyclic period such as the variation of vegetation for each growing season each year. Users can customize the cyclic time into daily, weekly, monthly depending on the interest of investigations.
5. Temporal data transformation. Interactive tools for users to perform various data transformation can be added to graphical representation (maps). Users can perform data transformation, for example calculation of the data into a change or ration with a selected time (such as previous moments or moments within time extent). Then the map will represent the new data accordingly by re-applying the presentation techniques and symbolization. In addition temporal smoothing to reduce the fluctuations in the data can also be categorized under temporal data transformation.

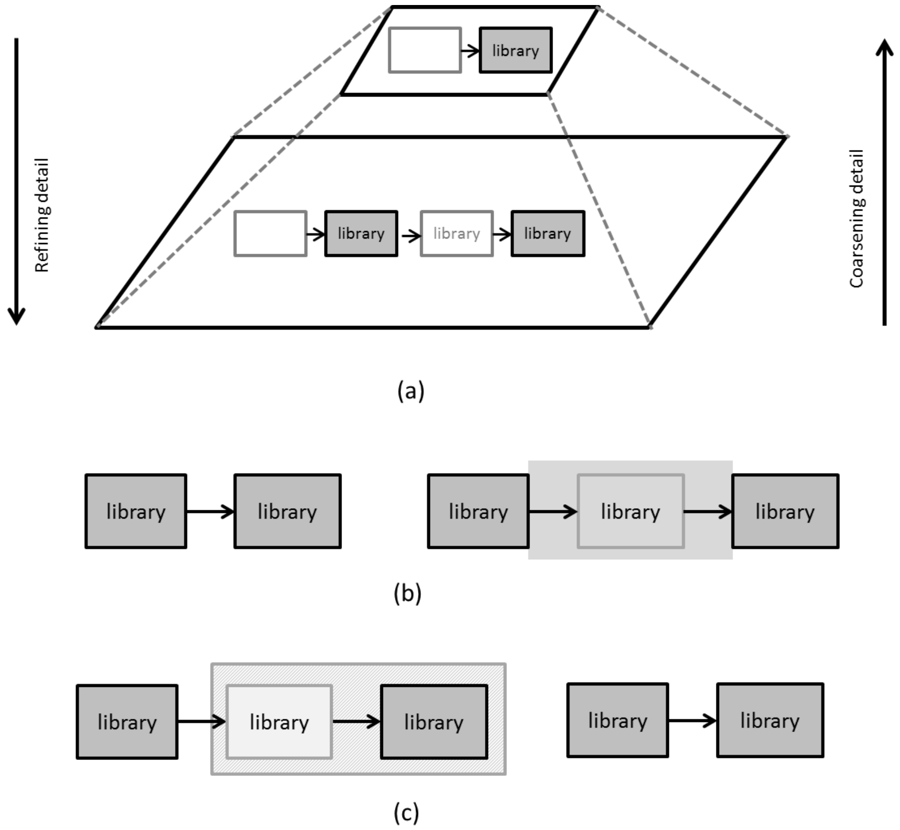


Figure 2.2 (a) Temporal zooming operation, (b) expand/zoom in operation, (c) collapse/zoom out operation (Hornsby & Egenhofer, 1999)

2.6. Modifiable temporal unit

Temporal data is increasingly used for analysing spatio-temporal variability, temporal extent and the periodicity of geographic processes (Çöltekin et al., 2011). The temporal unit problem is defined by Çöltekin et al. (2011) as the modifiable temporal unit problem (MTUP). For visual exploration and analysis purposes, the temporal resolution of data might need adaption and adjustment because every process has its own temporal and spatial resolution (Meentemeyer, 1989). Visual exploration of time series collected at (for example) daily intervals results in different patterns than visual exploration at coarser temporal interval (Harrower et al., 2000).

Depending on the sensor used, weather conditions can affect image quality. For example, it is difficult to obtain images for areas with persistent cloud cover using passive sensors. The ability of satellite sensors to produce large numbers of images (hyper temporal images) may cause a problem in storage and processing cost and time. Sampling or aggregating data using a temporal resolution that would be considered as new temporal unit would be the solution for reducing the number of data (Alexandridis et al., 2008).

Flexibility of temporal units, to be scaled by users, or temporal units that are modifiable are hereinafter referred to as modifiable temporal units (MTU). Similar to the modifiable area unit problem (MAUP), the MTU has a problem (MTUP). Temporal units that are defined may influence the rate of change or fake change and conditions (Çöltekin et al., 2011; de Jong & de Bruin, 2011). Different information might result when temporal units are modified or scaled. Variability of the data will be lost and the statistical value computed at different resolutions will be different when data aggregation is performed (Reynolds, 1998). de Jong and de Bruin (2011) mention that the starting phase of time series, its extent, and level of temporal aggregation are the problem aspects when modifying temporal units for time series data. They further mention that temporal aggregation as modifying temporal unit methods can result in unbiased vegetation index trends if the time series is perfectly periodic and the aggregation level corresponds exactly to seasonal periods. In a perfectly-periodic time series, time is equally divided , and every event (for this example every season) employs a precisely fixed interval of time (Bar-Noy et al., 2001). Aperiodicity, including phase shifting and incomplete periods at the start or early in the series may increase the effects of the MTU. Also aggregating some of the seasonal periods will eliminate the character of each season.

In order to reduce the bias, the selection of the initial phases and extents is required. Using vegetation indices, the beginning and end of the season can be seen from the trend shown by the data. Decrease of NDVI values over time show browning, indicating the end of summer or the beginning of autumn, while increase indicates greening, which can be considered as the start of spring or end of winter. Natural conditions may rarely have a perfect periodicy.

Modifying the temporal unit might be needed due to several factors. For example, in vegetation monitoring, the temporal unit might be modified because of type of vegetation of interest, season, area, aim or purpose of exploration, etc. (Monmonier, 1989). But the decision of a temporal unit commonly depends on the data availability (Çöltekin et al., 2011). Conventional animation environments often present inappropriate temporal (and spatial) units as it is in given data (Harrower, 2001). Using the appropriate temporal unit for observing an event is important because some events can only be observed at a certain time unit (Harrower et al., 2000). The use of temporal and spatial units should be based on the object that is studied, area of study and time of change. For example, the use of daily data with 1 meter spatial resolution will be less precise for studying a large area such as at continental scale. 10-day, monthly, or even yearly images will be more appropriate for studying long term surface variation than daily images (Anyamba & Eastman, 1996; Batista et al., 1997; Yang et al., 1997).

In the MTUP, the problems are related to three aspects: duration (how long), temporal resolution (how often), and the point of time (when) (Çöltekin et al., 2011). The visibility of these three aspect is related to the decision on the temporal unit (Kraak & Ormeling, 2010).

2.7. Possible methods for modifiable temporal unit

Reasoning about events or temporal aspects is important for analysing geographic phenomena. This work focuses on selection of time units. It presents two strategies to make temporal selections: regular and irregular temporal selection.

2.7.1. Regular time unit selection

Regular time unit selection can be divided into two different categories: sampling based on a constant regular time interval and aggregation of values to represent a certain time interval.

2.7.1.1. Time sampling/constant time interval

Time sampling is one of ways for data collection or observation and it is a commonly used (Oldfield, 2001; Repp et al., 1976). By time sampling, the observation is done by recording behaviour that occurs at certain time interval. Only behaviour/event that occurs within the interval will be recorded. It will not record behaviour that occurs before and after the interval.

As for data collection, it can also be performed to select the data to be displayed in animation. One of ways for selecting time is by time sampling (Andrienko & Andrienko, 2005; Kraak et al., 1997). By simply select the time interval; animation will be generated from sample images for each time interval of sampling. This is a simple method without any computation. A sequence is obtained by sampling data or images at a constant time interval. For example, users can select every image of the first day of the week, or the first day of the month (Figure 2.3).

Figure 2.3 Time sampling

However, as mentioned by Repp et al. (1976), data collected by time sampling time reflects inaccuracy events that occur. Time sampling method only records behaviour that occur occasionally, so the observer may not record many important behaviour and the result may be concluded from incomplete information. The high intensity or complex behaviour and the result may be concluded from incomplete information. The high intensity or complex behaviour become unobservable if the data collection is done with quite long time interval (Oldfield, 2001; Repp et al., 1976). Associated with sampling time to observe the vegetation changes using the animation, high fluctuation between time intervals might not be observed. Furthermore Oldfield (2001) explains that time sampling might be an appropriate method if the observation is not used to obtain the sequence, frequency, and duration of an event. Then the time sampling would be more appropriate to observe how an event/behaviour spends the time, for example how temperature at night or day.

2.7.1.2. Time aggregation

Data filtering and data aggregation can be used for providing a summary of data representation(Andrienko et al., 2008). Moreover, time aggregation can reduce the amount of data.

For the time aggregation as time unit selection method, the new time unit is obtained and adjusted by the aggregated value for the constant interval. Representations of temporal interval are resulted from the calculation of pixel values over time. Some combination methods might also be performed to obtain longer temporal aggregation/composites as in Figure 2.4. The length between first and last time that is aggregated is considered as the new time unit (Kraak et al., 1997).

Temporal aggregation also causes MTY effect. The result of temporal aggregation depends on the temporal extent and level of aggregation (de Jong & de Bruin, 2011; Forsell & Eriksson, 2011). Aggregation multiple periods increases the effect of MTU. Aggregating different seasons will eliminate the characters of each season and dismiss temporal trends (Wyatt & Ralphs, 2003). NDVI value is different in different season. The character of each season will not be seen if they are aggregated, such as aggregating winter and spring. Therefore, time extent, start time and end time, and level of aggregation should be considered before performing time aggregation.

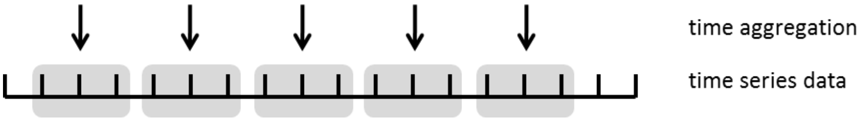


Figure 2.4 Time aggregation

Maximum Value Composite (MVC)

Maximum value per pixel is commonly used to represent a composite time interval. For instance, this algorithm is used for NOAA AVHRR, MODIS, and SPOT VEGETATION data processing. The Maximum Value Composite (MVC) is a quite effective method that selects less cloud affected pixel by selecting the highest NDVI value over a certain time unit (Holben, 1986). The MVC minimizes clouds effect, sun angle, water vapour and it is generally applied for atmospheric uncorrected dataset. But variety in vegetation canopy and atmospheric conditions make the method inconsistent and unpredictable (van Leeuwen et al., 1999). It also can improperly shift the NDVI boundaries, thereby artificially reduce the low NDVI area (Holben, 1986), for example reduces the width or rivers or the area of water bodies. The MVC is used by data providers to do the composite calculations to minimize the noise of available daily NDVI data, such as 10 day composites by SPOT-VEGETATION, and 16 day composites by MODIS.

Measures of central tendency

To get descriptive information about a representative value of a quantitative variable, measure of central tendency is used. There are three common measure of central tendency: mode, median, mean.

In monitoring activity, users might need information about the events that often occur in a certain time frame. In such case, mode is the most appropriate mode used for the measurement of central tendency. Its common sense interpretation is the advantage of the mode (Kachigan, 1986). It is also important that the mode is the value of variable occurring the most, not the frequency associated with the value.

An analyst will face problems if there is no mode in the data or there are multiple modes (multimodal). In those cases, related interval will be represented by other computation methods. But it will cause inconsistency in measurement if the replacement method is only implemented in the problematic intervals. Replacement methods should be implemented in the whole time series if the problem with multiple modes or no mode is faced.

Practically, vegetation conditions will always change over time and it will not be possible to obtain a mode in each time interval. Therefore mode will never be used to find the representative value of time interval or in the temporal composite method for NDVI data.

Another method to measure central tendency is the median. Since the median is a truly central value, it is not sensitive to extreme value in data (Field, 2009). Therefore it is appropriate as a measure of central tendency of skewed distribution of data. Data sorting must be done before performing median calculation, therefore the median can be used for ordinal, interval, and ratio data, but it cannot be used for nominal data because this kind of data does not have numerical order.

Last method to measure central tendency is the mean. Mean is sensitive to the extreme values in set of data, extreme values will dramatically increase or decrease the mean. While in median, the central tendency remains the same. Mode, median, and mean have their own ways when measure a central tendency of distribution of data. However when we work in symmetrical distribution, they are more or less equal. Compared with mode and median, mean has advantage in taking into account all values of every single observation (Field, 2009; Kachigan, 1986).

In finding representation of satellite images, the use of central tendency: mean, median, and mode may be less appropriate if they are used for atmospheric uncorrected data or if there still noise in data. Noise can mess up the calculations and the resulting value cannot appropriately represent the NDVI value of certain interval.

Aggregation into composites can be performed to determine the cyclic trend. As practiced by CrimeViz (University of New Hampshire, 2010) composite views are created by an average week by day, month by day, or year by month composite in order to make it easy to see the changing geographic patterns between weekdays and weekends, end of the month, or seasonal variation.

Normally, vegetation condition changes depend on rainfall which usually appears within 10 days (Groten et al., 1999). But it can be faster or slower depending on several factors: type of vegetation, type of soil, amount of water, disaster such as pest attack, logging, forest fire, or other natural disaster, etc.

2.7.2. Irregular time unit selection

Irregular time unit selection will be performed in two different categories: sampling by users and selecting time by putting the thresholds.

2.7.2.1. Time brushing

Besides basic animation tools, such as speed and direction controls, users should have the ability to select temporal extent and moment/interval to include in the animation, and temporal brushing tools. Temporal extent tool is used to adjust the start and end of an animation segment, while temporal brushing is used to select what times are included in the animation (Harrower et al., 2000).

The brushing concept was proposed by Monmonier (1989). Brushing in temporal domain (time brushing) allows users to search patterns that may occur only at certain times. It also can be used to explore and understand the spatio-temporal behaviour of geographic phenomena that may be visible only at or over certain time intervals. Since large amount of data is used for exploration activities, the use of brushing for data filtering is needed.

Time brushing function is usually attached to the time legend that shows the time in which a scene occurs. It allows the user to manipulate the time (within the time extents), such as moving to a particular point of time, specifying a period in time, selecting temporal resolution (Kraak et al., 1997). By time brushing, user can simultaneously control the speed of animation.

2.7.2.2. Threshold

Irregular temporal unit selection can be done by selecting a threshold value. Equally important is to observe the anomalous events (Blok, 2005). Anomaly is deviation from what is standard, normal, or expected ("Oxford Dictionary," 2012). Time unit selection by thresholds (Figure 2.5) is expected to assist users in observing the incidence of anomaly events.

Below are some potentially thresholds:

Long term average

The normal, as in anomaly definition, is considered as long term value, for example long term average at least 10 years (Blok, 2005). Comparing long-term average with certain time the NDVI value can be used to determined regional droughts and wet seasons. Value below the threshold indicates dry season on the other hand value above the threshold indicates wet season.

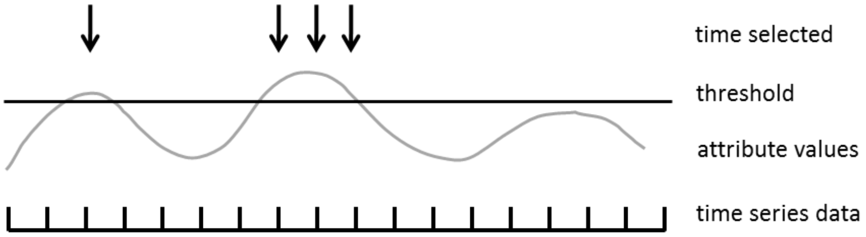


Figure 2.5 Time selection by threshold

Standard Deviation (SDEV) and Median Absolute Deviation (MAD)

Mean and Median are analogous since both of them are measures of central tendencies of data values. Since MAD is estimated as the median of absolute deviation of all values from the median, it is also comparable to standard deviation as dispersion of data values from the mean. Standard deviation and median absolute deviation can be used for defining a threshold in order to map the anomalies. For a dataset x_1, x_2, x_3...x_n, MAD is defined as:

$$MAD = median[|x_i - median(x_{-i})|]$$

The use of SDEV and MAD and their scale values depends on the dataset and the criteria and the definition of the anomaly itself. Zhang et al. (2007) demonstrated that MAD (median + MAD) is robust to apply in MODIS land products, including NDVI, active fire, snow cover, and surface reflectance for time series anomaly analysis. While Carranza (2008) uses median+2MAD for geochemical anomaly analysis.

2.8. Monitoring vegetation

Animation as a data visualization method is also used to perform monitoring, visual exploration and analysis for studying phenology. For example WinDisp3 as developed by Groten et al. (1999) . WinDisp3 is animation environment that was developed for monitoring vegetation change, crops rangelands and food security at national level. This application is then developed into WinDisp5 by FAO Global Information and Early Warning System (2003). WinDisp allows the users to monitor time series of satellite images. It also provides some functions to support the activity. They are image calculation, statistics extraction, thresholds to exclude pixels, and interpolation. Image calculation is used for mathematic operations on one or more images to calculate difference and anomaly images. Users can also extract statistics for selected map features, such as province, region. Statistic features include average, maximum, minimum value, standard deviation, range and counts, according to user-specified thresholds. Thresholds are used, for example, to exclude pixels from statistic extraction.

Vegetation indices are commonly used for studying vegetation dynamics. The Normalized Difference Vegetation Index (NDVI)is calculated by subtracting the red band from the near-infrared (NIR) band and dividing their difference by the sum of the two bands (NASA, 2011).

$$\mathbf{NDVI} = \frac{\mathbf{NIR} - \mathbf{RED}}{\mathbf{NIR} + \mathbf{RED}}$$

Where NIR is located in a region of high reflectance of vegetation canopy and RED is located in a strong chlorophyll absorption region. The more vegetation, the higher reflectance in NIR bands, and in contrast the more leaves the lower the values detected in RED bands. This index normalises the difference between the bands. Theoretically, the NDVI values range from -1 to +1, higher NDVI value indicates higher or denser vegetation. But actually NDVI value range from slightly negative to approximately 1. Negative values indicating clouds and water, positive values near zero indicating bare soil, rock, sand, or snow, and higher positive values ranging from sparse to dense green vegetation. For computer processing, NDVI values are rescaled into digital values between 0 and 255.

NDVI calculation is influenced by some factors, such as different reflectance of different soils, cloud contamination, water vapour, aerosol, or malfunctioning of the sensors (Blok, 2005). To reduce the effect of the “noise”, maximum NDVI value per pixel is often selected to get composite image, 8-day, 10-day, 16-day, etc. The selection of temporal composite is chosen in order to reduce “noise”, such as the effect of cloud cover, atmospheric condition, and large viewing angle. Earth observation in time series of sensor data is characterized by view or sun angles. Both sun and satellite viewing angle are vary. They affect NDVI values, NDVI at almost nadir view are greater that they are in large viewing angle. Sun angle affects all reflectance, the smaller the sun angle the greater all reflectance value. The view angle affects red reflectance, large view angle increase red reflectance so it causes a decrease in NDVI value (Galvão et al., 2004). It affects inconsistency in calculation of NDVI value.

The temporal composite is determined by the orbital characteristics of the platform. The more often a satellite surveys a region, the more temporal information is available, and the chances of collecting cloud-free imagery are increased.

Vegetation index values normally show a progressive curve, they increase at the beginning of the growing season, they peak in the middle of the season and they decrease at the end of the growing season. The length of growing season is influenced by factors such as, season, type of vegetation, etc.

Different vegetation types have different phenological cycles, depending on climate, terrain and soil types, and human management. Different types of vegetation have different characteristics and optimal temporal units to monitor may need adaptation. For example, as described by Kross et al. (2011), by comparing different NDVI composites, they found that 10 day or 15 day NDVI composites can be used for analysing the start of season trend of broadleaf forests in Canada or similar areas.

Also, vegetation growth depends on climate factors (Vancutsem et al., 2007). Eurosiberian vegetation is more productive in summer than in winter, while Mediteranian vegetation has high activity from autumn to spring, and is less productive in summer (Meentemeyer, 1989). Depending on the seasons, monitoring phenomena with low activity may need bigger temporal units than monitoring highly active phenomena.

Usage of temporal unit is also different when it is used to observe forest loss in tropical area such as Sumatra and Kalimantan, Indonesia as it was done by Broich et al. (2011). Deforestation monitoring using remote sensing technique in Indonesia is challenging because of persistent cloud cover. Cloud free observations are rare over Indonesia. In this area, even when aggregating cloud-free data from large numbers imagery, annual, gap-free forest cover loss maps over large areas are difficult to derive. However, annual aggregation can be used to get accurate and consistent large area maps of forest cover loss to monitor it over a multi-year interval.

In urban expansion context, NDVI can also be used to detect the land use conversion from agriculture or forest to built-up area. Nevertheless, to detect this kind of conversion in an urban development context, using 10 days temporal resolution becomes less appropriate, since urban expansion is not easily recognized in days but years.

2.9. Summary

In this chapter, geovisualization, its objective, and basic questions are described. The purpose of observation, application, time frame and resolution should be considered in performing visual exploration of dynamic phenomena.

To support visual exploration of animated time series, appropriate temporal composites and temporal intervals need to be selected related to the visual exploration tasks. Different ways to modify the temporal unit are discussed in this chapter. These are regular selection of images based on sampling constant time and aggregation of pixel value in time interval; and irregular selections based on sampling by user or by putting a threshold. It is also describe that different temporal composite is also needed based on the purpose of monitoring and the observed object.

The facility to users in selecting temporal composite is expected to support the construction of knowledge: process, patterns, trends and anomaly that are relevant to be answered by visual exploration activity.

3. CONCEPTUAL FRAMEWORK

As discussed in Chaper 2, doing visual exploration activities, users require interaction with data. Focusing on time, it needs interactive tools to interact with time and the data. This chapter will first discuss the conceptual framework for visual exploration and how it is supported with tools (Section 3.1). Then continue with interactive tools to select time that will be implemented in order to support visual exploration (Section 3.2). And finally, a brief summary will be described in Section 3.3.

3.1. Interactive user control of time

Maps and other graphic representations, here is animation, can be used to provide insight in spatio-temporal patterns. The use of animation and its supporting tools for visual exploration are described in a conceptual framework as shown in Figure 3.1. in visual exploration activities, starting with the objectives and the problem, users approach the problem to be solved from location, attributes, and time viewpoints.

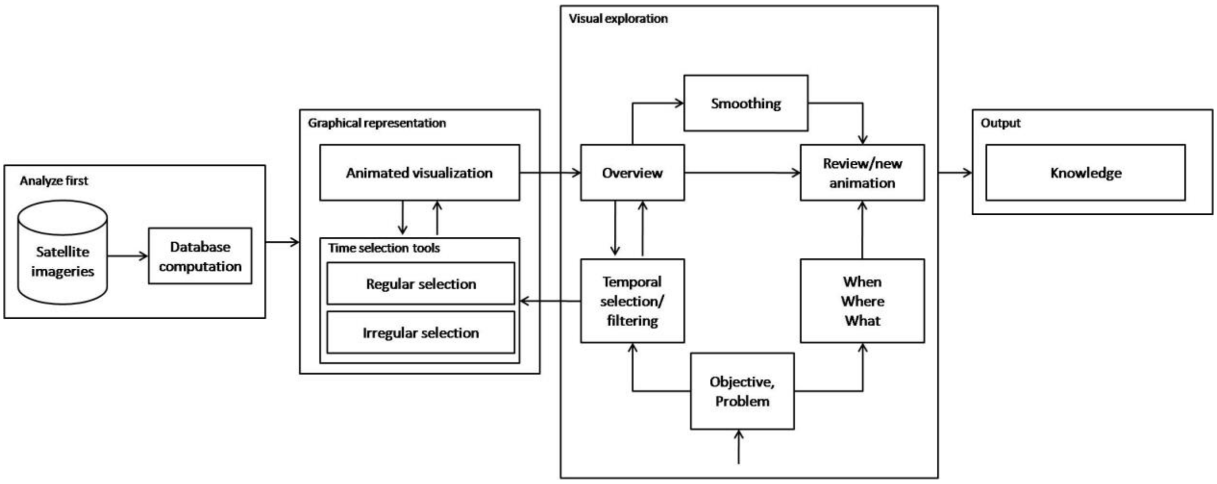


Figure 3.1 Conceptual framework

Combining Shneiderman's and Keim's mantra in visual exploration, first performed an analysis of satellite data is performed. Given large amounts of satellite data, users must first perform a database operation and computation (analyse first), before applying visualization (show the important). Therefore users will interact with the visualization of secondary data, not with raw data.

After applying the visualization, according to Shneiderman (1996), users need to understand general overview or information of the whole dataset. This knowledge is gained from looking at the animation and supporting information obtained from other tools.

The objectives, the formulation of the problem, and the general overview of data are used to determine the spatial and temporal scale that are required, temporal extent, and aggregation level of time. Next users can do filtering to reduce amount of data. Since this study focuses on time selection, users can do temporal selection/filtering to get a new required time unit using time selection tools that are provided for further processing.

The visual exploration activity then continues to answer questions relating to what – where – when. For example, NDVI users might be interested in the questions of when the growing and dry seasons are; where there is drought, what happening in particular area over time. By knowing the needs and tasks, the users can interactively use tools to adapt the visualization according to their needs. Interactive tools will be described to perform visual exploration, to reduce the effects of information overload, and MTU problems, and to select required temporal units.

3.2. Time selection tools

3.2.1. Time legend and graph

In order to understand any temporal animation, a time legend is required to interpret the meaning of temporal sequence and pacing of the animation (Kraak et al., 1997). Besides its function as interpretation tool, a time legend can also be used as a navigation tool and allows users to manipulate the time. There are several types of time legend; an analogue clock, time bar, and numerical (Kraak et al., 1997). In an analogue clock, time is described by the orientation of the hands. The side bar represents time by a sign on the line/bar indicating the time span of the animation. And the numerical time legend indicates the time position without showing the time scale and position of the time on the animation, making it hard to interact with time. The analogue clock is more suitable for displaying cyclic time while the time bar is more suitable for displaying linear time, but the time bar has an advantage in representing time extent and it facilitates users to interact with time.

Before doing temporal unit selection, information about time extent and the value contained is needed. For example, if using NDVI data, then the NDVI value in the observed area is needed. Monitoring NDVI performance can be used to detect the occurred change, particularly for land covered by vegetation. For more advanced conclusions, additional data is required such as crop calendars, type of land cover, land use, and others. Information of the starting and ending of season can be obtained from other supporting tools such as a time legend and a graph, as already mentioned.

For a first overview, information about the NDVI value during the observation time can be shown using a graph over time as in Figure 3.2. The figure shows a time bar that is used in aNimVis (Blok, 2005). Besides as a time legend, the time bar is equipped with a graph that shows average NDVI value per frame at the related time. The graph shows increase and decrease of the average NDVI value per frame. These values can be used as an indicator of the season such as the growing season and end of season. However, it must be noticed that the value does not give the full information of what really happens in the field. It is just an indicative of when and what. This value is an indicator or guideline for further investigation, in this case, for further temporal unit selection. The information can be used as basic information for time selection, time extent, start and end time.

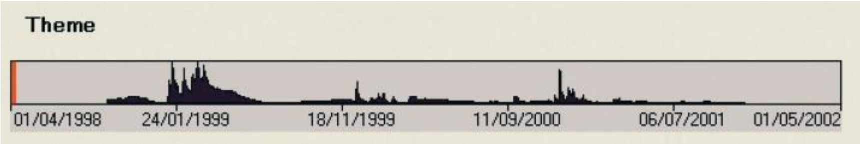


Figure 3.2 Time legend and hydrographic graph in aNimVis (Blok, 2005)

According to the information seeking mantra (Shneiderman, 1996), users might need filtering to remove parts of data from the view for further activities. Users might need to get understanding of a particular area within the given study area. By default, NDVI values that will be shown in the graph are the averages of NDVI values in a given area per frame. Then it requires a tool to allow users to select the area they want to observe and generate NDVI value graph for the selected area. A bounding box can be employed to select an area of interest.

Related to time unit selection, filtering is done by reducing the number of images that do not help in performing visual exploration. Reducing the number of images to be displayed can also be done by aggregating of some images.

3.2.2. Regular temporal unit selection

3.2.2.1. Time sampling

Time sampling is used for time unit selection; it is a simple method of selection without requiring any calculations. The selection is done by selecting images in the time series data with a certain time interval. The number of images that are included in the time interval will be used to select the new time unit. Practically, this selection requires a simple interface that allows the user to select the images included in the dataset that will be visualized as animation.

3.2.2.2. Time aggregation

Time aggregation is useful to observe general events that occur in a specified time interval. Time aggregation summarizes events that occur in the desired time interval. It will be useful to study distributions and dynamics of longer term. It also can be used to reduce the number of images in time series observation in order to reduce information overloads.

But temporal aggregation is a computationally costly operation (Zhang et al., 2008). Have to deal with large amounts of data, calculation of temporal aggregation takes longer time than other time unit selection methods. Therefore, animation that is generated by performing aggregation on the fly will probably take a long time. Different from other proposed methods, the time aggregation operation will produce new images before they are displayed in animation; the new images will be generated from the aggregation process.

3.2.3. Irregular temporal unit selection

3.2.3.1. Time brushing

With the development of using animation as an exploration tool, interaction with the data in animation becomes very important in visual exploration activities. A time slider (figure 3.4) is an interactive tool available in almost all animation environments, it enables time brushing. It is used to interact with a time legend by clicking and dragging the slider to go back in selected time, by clicking and dragging the slider, users can simultaneously set the animation speed, and repeat the selection of time. Hand-eye coordination is a basic skill to perform data manipulation (Ware, 2004). Provided that there is a time legend added to the time slider, users can easily select particular times to be observed and flexibly move the slider in accordance with the animation speed they need.

Figure 3.3 Time brushing

3.2.3.2. Threshold

The selection of time based on the threshold can be performed to find the anomalies. For example, by knowing the average historical value, this value can be used as threshold to find deviations, like wet and dry seasons. Although wet and dry season can also be seen from the NDVI value graph mentioned in the previous section, the addition of selecting time by threshold value will make it easier to observe more precisely the phenomena or events.

3.3. Summary

This chapter discussed how users can interact with the temporal dimension using different selection methods and also supporting tools. Different selection methods have each advantages and disadvantages. Before performing the time selection, users should understand the purpose of their activities. And prior to selection of time, they should know the general overview of the data to determine the time extent, the start and the end time, and the level of aggregating (if users are going to use aggregation methods to perform the time selection). Supporting tools (time legend and graph) can assist users to understand the general overview of the data. Hence the time selection tools can better support visual exploration activities.

4. DESIGN AND IMPLEMENTATION

Different methods of time unit selection are identified in Chapter 3. This chapter is about design and implementation of the methods in The Integrated Land and Water System (ILWIS), GIS software developed by ITC. In order to implement the methods in ILWIS, it is important to know the existing functions related to time selection in ILWIS. NDVI data is used for the implementation phase as a case study. This chapter starts with brief description of data used (Section 4.1). Then the existing time unit selection functions/tools in ILWIS are described in Section 4.2. The process of how users do time selection is described in Section 4.3. The chapter continues with a section on the design and implementation of the time selection methods including the user interfaces (Section 4.4). Discussion about what have been done in implementation is described in Section 4.5. And after all, a brief summary is in Section 4.6.

4.1. Data used

SPOT4 VEGETATION and MODIS Terra land product data are used for design and implementation. The SPOT VEGETATION data are available continuously from March 1998 onwards. There are daily and ten-day synthesis products available. Daily products contain more cloud problems than 10-day products. Furthermore, 10-day images are free to download through VITO (2011). In this study, 10-day NDVI products, composite of daily images over 10 day periods using the maximum value composite (MVC) method/algorithm, are used. The 10 day data refer to the 1st-10th day, 11th-20th, and 21th to the last day of the month.

MODIS Terra dataset can be obtained free of charge at the LPDAAC (2012). Vegetation indices datasets are available at the following spatial resolutions: 250 m, 500 m, and 1 km. These products are offered as 16 day and monthly composites. In this study, 1 km spatial resolution with 16 day temporal resolution will be used.

The NDVI datasets used in this study span the period from 1st January 2002 to 31st June 2011 (altogether 342 images for SPOT4 VEGETATION and 219 images for MODIS Terra). The data provided is accurately georeferenced. In order to facilitate interpretation of vegetation conditions, the NDVI data are kept in decimal values between -1 to 1. Both datasets have 1 km spatial resolution. It is suitable to get a quick overview of change in a large area.

The area included in the case study images is the Netherlands and part of Germany. Most of the area is lowland. Located in the northern hemisphere, July – August are the warmest months and December – February the coldest months. Rainfall is relatively the same throughout the year. The intensity of rainfall in summer and autumn tend to be a bit more than in other seasons (KNMI, 2012). There is no different season in this area.

4.2. ILWIS

ILWIS is remote sensing and GIS software developed at the ITC. Since 2007, ILWIS is available as “Open Source” under the 52 North initiative (North, 2011). ILWIS provides analytical image processing functions. This includes functions such as image visualization, animation, re-projection/resampling, interpolation, filtering, clustering, overlay and statistics. ILWIS is easy for an end user to learn and use (Blok et al., 2011). The way how ILWIS classifies the available operations allows its users to easily find the interaction tools they need. In addition, it is open source software, and its further development is important and useful, especially for users in developing countries (Blok et al., 2011; Mannaerts et al., 2009). ILWIS contains an animation environment. Figure 4.1 shows the user interface of the animation environment in ILWIS 3.8 beta 2.

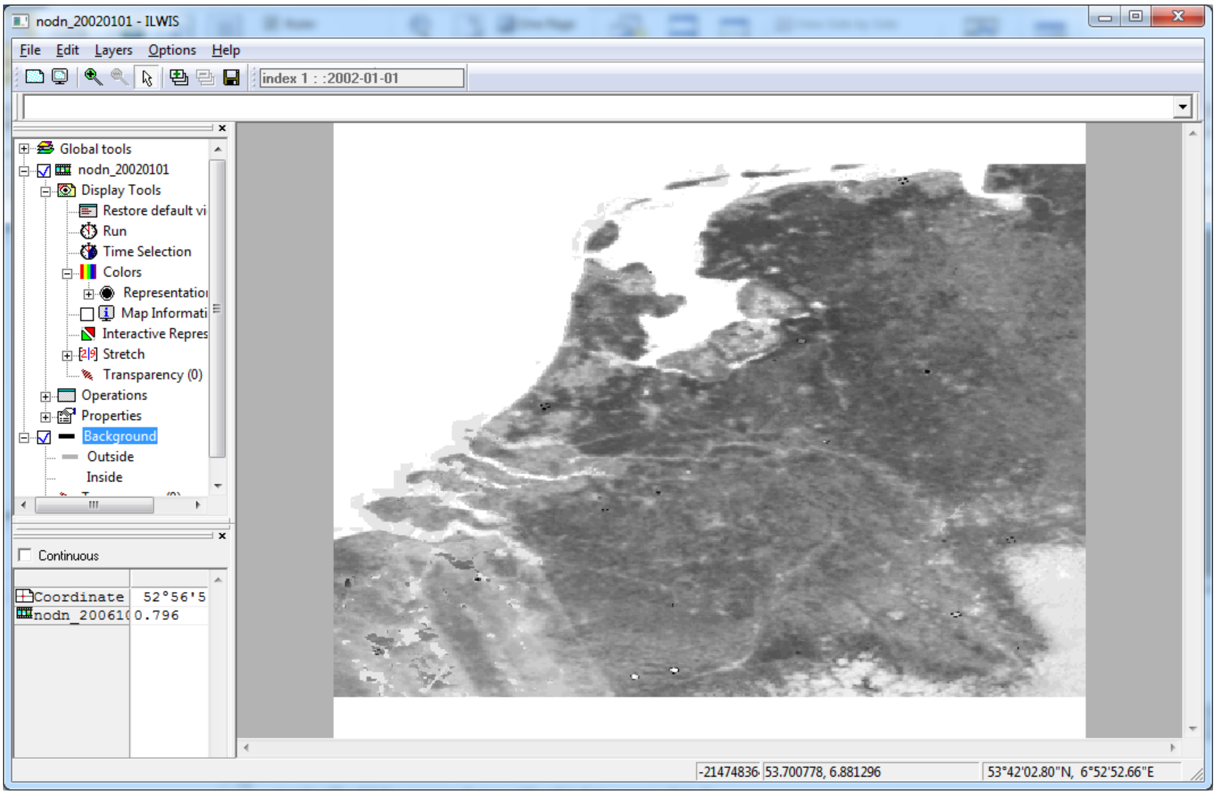


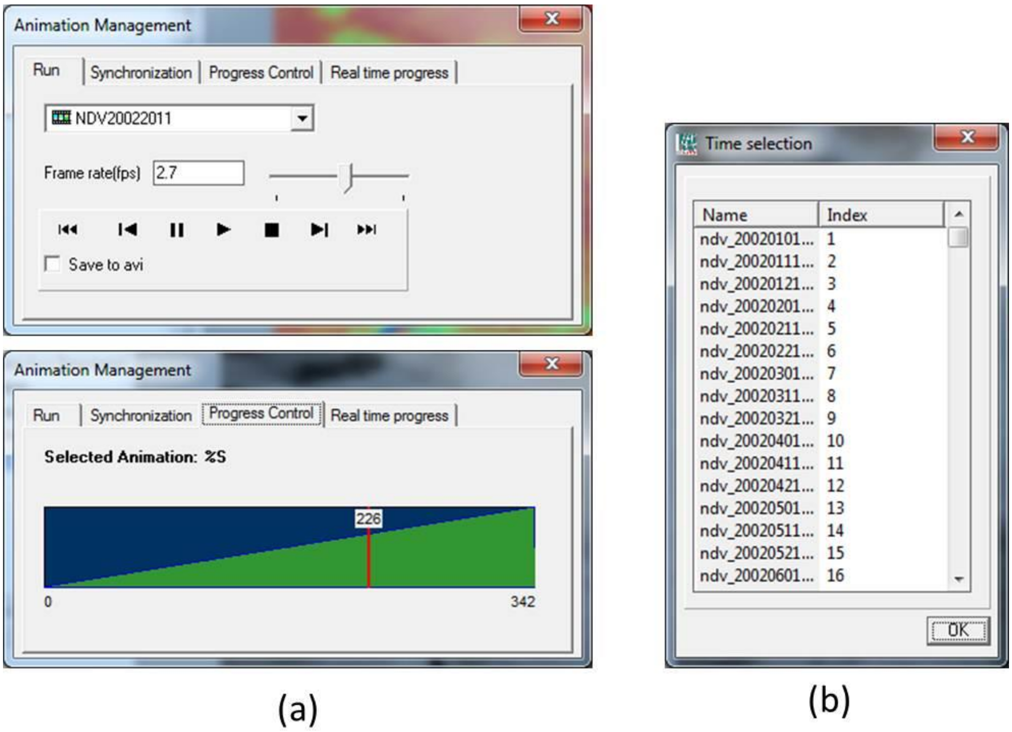
Figure 4.1 Animation environment interface of ILWIS 3.8 beta 2

Temporal selection tools in ILWIS 3.8 beta 2

The newest version of ILWIS, ILWIS 3.8 beta 2, was released in October 2011. An important improvement in this version was the development of animation tools which were adapted from aNimVis (Blok et al., 2011; Metaferia, 2011; North, 2011). ILWIS 3.8 beta 2 added some user interaction to the animation. For instance, the previous version of ILWIS did not have timelines that allows users to interact with the animated data shown. ILWIS 3.8 beta 2 has some controls for users for time unit selection.

Before getting into the time unit selection tools, how ILWIS handles animations will be describe. In ILWIS, before animating multiple raster maps, these maps should be combined in a maplist. A maplist is a container object which stores the names of a set of raster maps; they can be the names of multi-spectral bands of a satellite image to be classified or the names of several raster maps of a time series (Schouwenburg, 2012). Using a slide show technique, ILWIS displays the maps included in a maplist, one after the other.

In the ILWSI animation environment, there are two main tools to control the animation, “run” and “time selection”. Selecting the “run” icon will bring up a control window that gives control over the animation called animation management (Figure 4.2). Animation management contains multiple tabs: *run, synchronization, progress control, and real time progress*. The first tab, *run,* provides basic animation control which includes speed, stop, start, pause the animation, etc. Second tab, synchronization, is used to synchronise the display of two different animations. On the third tab, *progress control*, there is a graph with a moving progress line (red line in Figure 4.2(a)) that shows the index of the image that is being shown in the animation. The time unit selection methods are particularly related to the first and third tabs. Instead of providing information about the data, the graph shows the number of images included in the animation. The progress bar control already has a function of time brushing users can click a point in the graph to select the image to be shown. But users can only select a point at which the animation starts; users cannot select a point or time to end it. Selecting a point as starting time and clicking on the start button on the *run* tab, start the animation from the selected point/image to the end of the data.



NDV20022011

Frame rate(fps) 2.7

☐ Save to avi

Selected Animation: %S

Name	Index
ndv_20020101...	1
ndv_20020111...	2
ndv_20020121...	3
ndv_20020201...	4
ndv_20020211...	5
ndv_20020221...	6
ndv_20020301...	7
ndv_20020311...	8
ndv_20020321...	9
ndv_20020401...	10
ndv_20020411...	11
ndv_20020421...	12
ndv_20020501...	13
ndv_20020511...	14
ndv_20020521...	15
ndv_20020601...	16

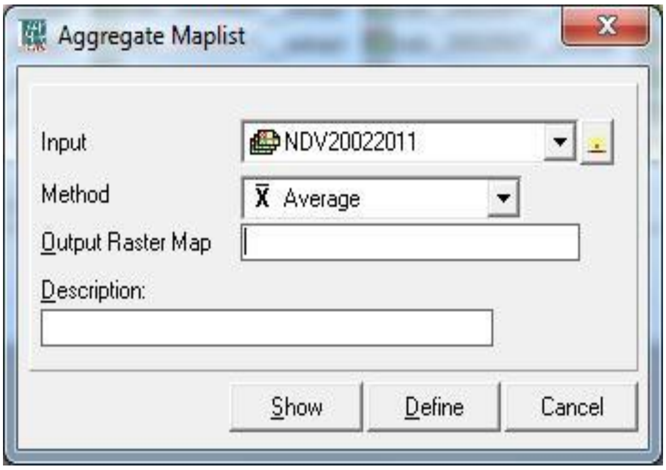
(a) (b)

Figure 4.2 (a) Animation management in main operation “Run” and (b) time selection tool in ILWIS

Another tool, the time selection (Figure 4.2(b)), is used to select images to be displayed in the animation. The time selection tool can be used for both regular and irregular selection. For irregular selection, users can select images related to the time they want to display.

Regular time selection is related to regular time sampling. For example, users may want to display one out of three images. But in the existing time selection tool, in order to perform a regular time sampling selection, users should manually select the images they want to display. Manual selection might lead to errors if the selected time interval is long: users might get lost in the selecting, resulting in a different time interval, or users might accidently cancel the selection they made. So the user should redo the selection.

Furthermore, there is a tool named aggregate maplist under the raster operation functions (Figure 4.3). It is used to aggregate maps that are incorporated in a maplist. By applying aggregation calculations: average, maximum, or median, the aggregate maplist operation merges the maps included in a maplist into one map. Like the method of time unit selection, the aggregate maplist function is related with time aggregation as time selection method. Given time series data, users may want to perform time aggregation to support their visual exploration activities. With the existing aggregate maplist tool, users should first create several maplists within a selected time unit and perform maplist aggregation for every maplist they created. New maps will result from the maplist aggregation operations. Next, the resulting maps should be re-incorporated into a new maplist, before being displayed in an animation. This way is possible, but same as the manual time selection mentioned before, mistakes resulting from human errors might happen. This function will be improved to be used as time aggregation tool. Besides error in selecting raster maps to be included in a maplist for further aggregation, manually creating maplists may also result in user error in naming the output of the raster maps.



Input: NDV20022011

Method: Average

Output Raster Map:

Description:

Figure 4.3 Aggregate maplist in ILWIS

Time handling in ILWIS 3.8 beta 2

Time series data should be named systematically (Groten et al., 1999). The names should give information about the images and indicate area, theme, and most important, time should be included in file names so that the data can be sorted by time. This rule is related to the time sequence of data collection and the sequence of images that are shown in the animation. Involving the time aspect for naming time series data assists users in selecting the first image/time that will be used for further time selection processes.

In satellite images, information about the acquisition time can often be derived from the file name and from the header file. The format of header file depends on the sensor/agency. For example in the data used, the hearer file of SPOT VEGETATION is in a text file format (.txt). The information related to time is written as:

```
SYNTHESIS_NOM_DATE          20020101
SYNTHESIS_FIRST_DATE        20011231221302
SYNTHESIS_LAST_DATE         20020110235000
```

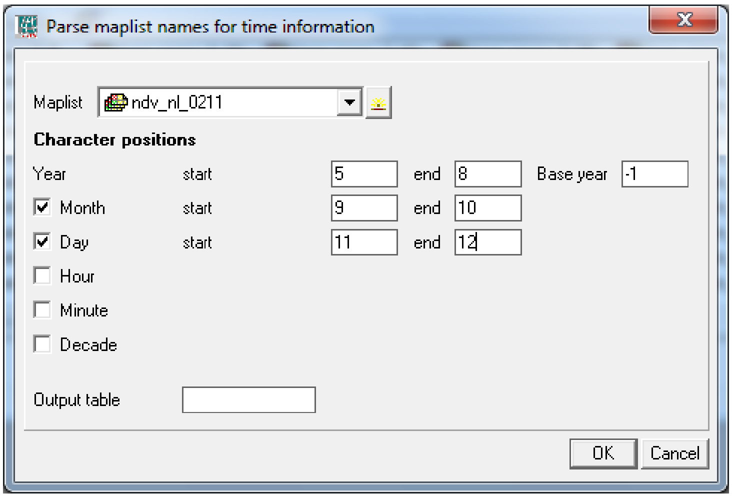
MODIS datasets use .xml files for the header file. And the following is the information about the time contained in the header file:

```
<RangeDateTime>
      <RangeEndingTime>23:59:59.0000000</RangeEndingTime>
      <RangeEndingDate>2002-01-16</RangeEndingDate>
      <RangeBeginningTime>00:00:00.0000000</RangeBeginningTime>
      <RangeBeginningDate>2002-01-01</RangeBeginningDate>
 </RangeDateTime>
```

The difference of each dataset in providing information regarding the acquisition time, make the automatic handling of time more complicated. ILWIS uses time information included in the file name to handle the problem. ILWIS provides a function to retrieve the information concerning the time named create time column under table operation (Figure 4.4)

With the tool, the user can enter a sequence number of characters in the file name that indicates the time (year, month, date, hour, minute, and decade). This operation produces a table with image index and time columns. However, this tool is not able to handle all the datasets. For SPOT VEGETATION datasets, information on the time of the year, month, and date can be obtained, since the file name of the dataset has information about it. Hence the operation works for SPOT VEGETATON, but not for MODIS Terra. MODIS Terra also includes time in its file name. But the time involved in the file name in not based on the date, but the year and the Julian day.

Different ways in which data providers stored the time information makes the time handling becoming complicated. Currently, ILWIS can only handle the time from datasets that involve the date as its name. The ways in which MODIS Terra stores the time information cannot be handled by ILWIS.



Parse maplist names for time information

Maplist: ndv_nl_0211

Character positions

Year start 5 end 8 Base year -1

☑ Month start 9 end 10

☑ Day start 11 end 12

☐ Hour

☐ Minute

☐ Decade

Output table:

Figure 4.4 Create time column interface

4.3. Process of time selection

How the user does time selections with the proposed tools is illustrated in Figure 4.5. To display the animation in ILWIS, first, users must create a maplist that contains the time series data. Having a maplist, users can display the maps one after the other as an animation. After having the maplist users should generate two tables: attribute table and time table. Attribute table contains values that represent every image included in the maplist and some statistical calculation that further can be used as threshold. Time table contains the time information about every image. The two tables then are merged to generate the time series graph in order to provide general overview about the data.

Next, users can perform time unit selection according to their needs. From four different time selection methods that are proposed, time aggregation is somewhat different from the others. The time aggregation operation produces a new maplist that contains new images. Therefore users need to re-perform the calculation of the attribute table and time table for the new maplist. While for other time selection methods, the animation resulting from the operations will be displayed on the fly by simply selecting/querying the images that meets the conditions. In time sampling, the condition refers to the time interval that is chosen; in selection by threshold, the condition refers to the selected threshold values, while in time brushing, the condition refers to where the point in the time legend is clicked by users.

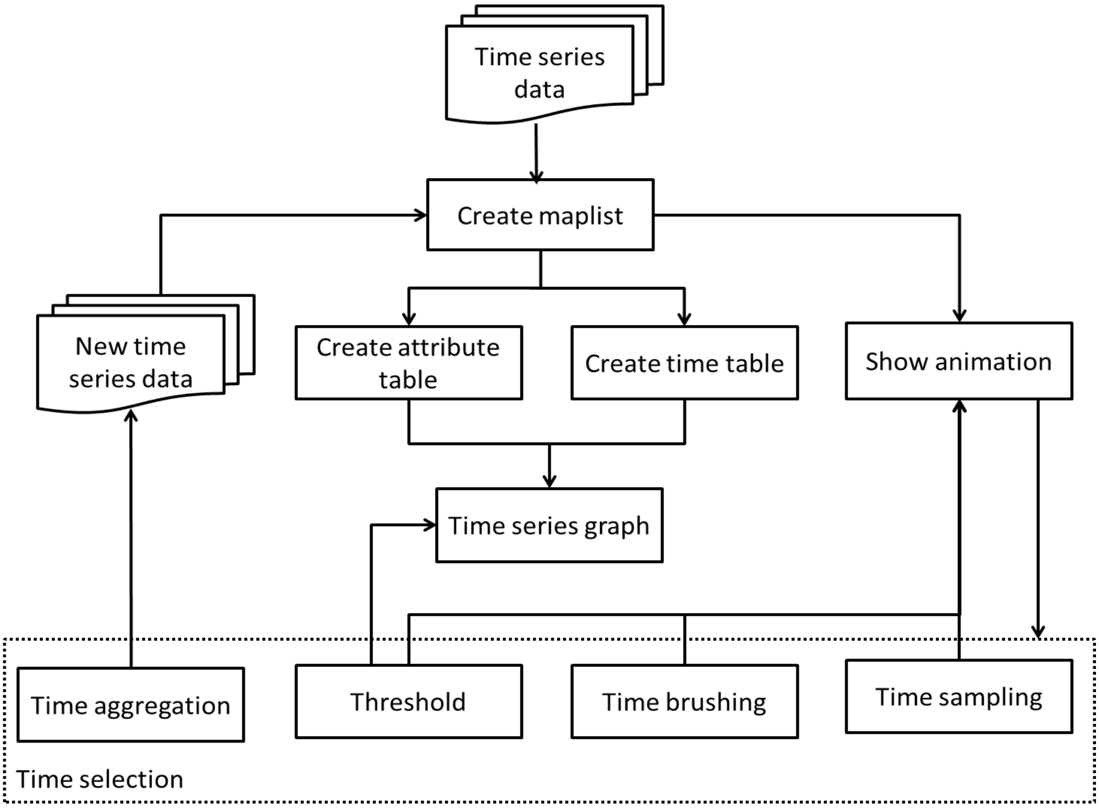


Figure 4.5 Process of time selection

4.4. Design and implementation

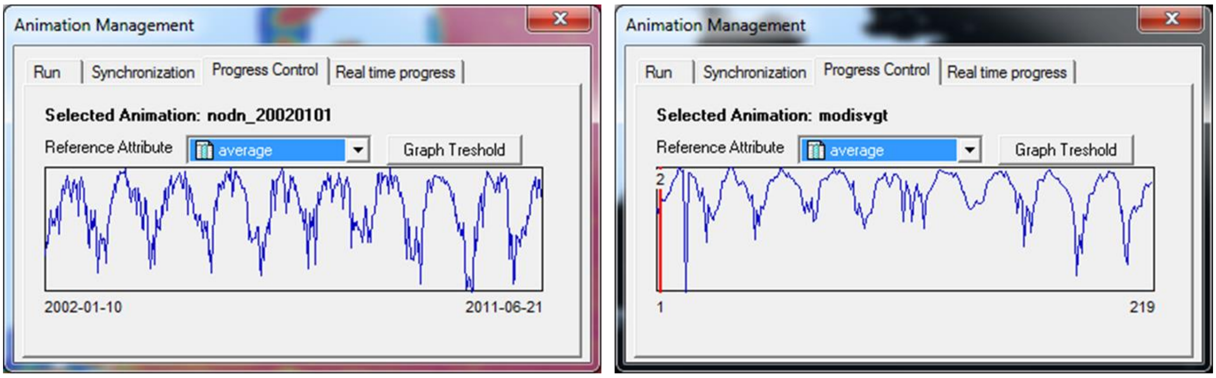
Interaction refers to controls that allow users to interact and manipulate data elements that have an effect on the image display through a user interface (Blok, 2005). User interface design is important to support the productivity if any system (Edsall & Peuquet, 1997). Poor user interface design can cause delay in interacting with a system and increase the cognitive overloads that reduce the information that can be received by the user (Ware, 2004). User friendly interface is needed to allow users to concentrate on the task, and not on how they interact with the interface. Furthermore, instead of designing a totally new user interface, Ware (2004) suggest that it is better to design an interface based on already common practice to do things. In this study, because the methods will be integrated into ILWIS, the implementation of the proposed methods will be approach from the ILWIS user interface.

4.4.1. Time series graph

A general overview about the data is required before performing the time unit selection activities that have been described previously. A time series graph is proposed as a tool to provide the general overview.

In this study, 10 day composite NDVI data is used. Since the objective is to get a general overview and not to investigate the spatial variations, a single NDVI value is used per image by simply averaging all the pixel values in the area of study (Alexandridis et al., 2008; Myneni et al., 1998). There is a fairly wide area that is covered by water in the study area. It decreases the average NDVI value in the area and will also influences an anomaly event observation, which will be described in Section 4.4.5, where pixel values that represent water are converted to undefined value so they will not be considered in the calculation. The average NDVI values of every image are recorded in a table and presented in a graph (Figure 4.6).

In order to show the relation of event and time, the graph is linked to the progress control bar. First, information about time should be included as the x-axis of the graph, since the progress control bar in the current version of ILWIS shows the image number. Time information to be applied as x-axis in the graph is derived from the table discussed in Section 4.2. The x-axis of the graph shows the start and the end of the time series. Information of the time within the interval is attached to the progress bar. Thus the user can get the time information when an event (displayed image) occurs.



Selected Animation: nodn_20020101
Reference Attribute: average

Selected Animation: modisvgt
Reference Attribute: average

(a) (b)

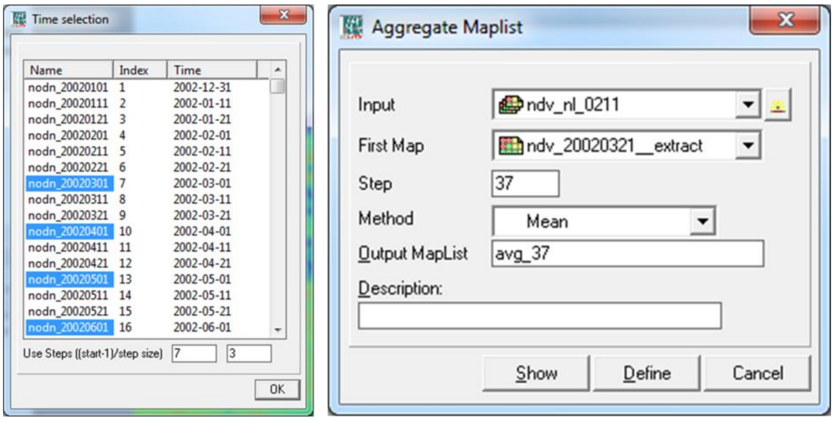
Figure 4.6 Time series graph from (a) SPOT VEGETATION dataset, (b) MODIS Terra

4.4.2. Time sampling

Regular time selection includes regular sampling of time and time aggregation; these are developed by improving the exiting function, time selection, described in section 4.2. For displaying an animation, users are expected to be able to select the time interval (starting time and time extent), and determine the temporal granularity. To create an animation, the user can do this by producing new images or can do it on the fly from the existing data (Kuhn et al., 2011). Time sampling is a simple temporal query that can display a new animation on the fly, using existing images in the maplist of ILWIS. For aggregation, that requires calculations, featuring a new animation on the fly will be a high cost operation. Therefore the time aggregation operation that will be implemented in this research will produce a new maplist containing new images before animating it. Section 4.3.3 describes the time aggregation.

For the regular time sampling selection method, automation is applied for improving the existing function. Users can simply select the first image and any number as intervals between images they want. In the proposed tool, if the first image for regular time sampling is selected, the previous images are ignored. As shown in Figure 4.7a, to select 7th image as the first image, the user can simply enter 7 as the first images to be shown. Selection of the number of images as interval is related to the choice of a new time unit.

Satellite data have different characteristics, especially for temporal resolution and the number of images in an interval of time. For example, to get a month as the new temporal unit, in this study, using a temporal composite of 10 days, the user should select an interval of three images.



Name	Index	Time
nodn_20020101	1	2002-12-31
nodn_20020111	2	2002-01-11
nodn_20020121	3	2002-01-21
nodn_20020201	4	2002-02-01
nodn_20020211	5	2002-02-11
nodn_20020221	6	2002-02-21
nodn_20020301	7	2002-03-01
nodn_20020311	8	2002-03-11
nodn_20020321	9	2002-03-21
nodn_20020401	10	2002-04-01
nodn_20020411	11	2002-04-11
nodn_20020421	12	2002-04-21
nodn_20020501	13	2002-05-01
nodn_20020511	14	2002-05-11
nodn_20020521	15	2002-05-21
nodn_20020601	16	2002-06-01

Use Steps ((start-1)/step size) 7 3

Input: ndv_nl_0211
First Map: ndv_20020321__extract
Step: 37
Method: Mean
Output MapList: avg_37
Description:

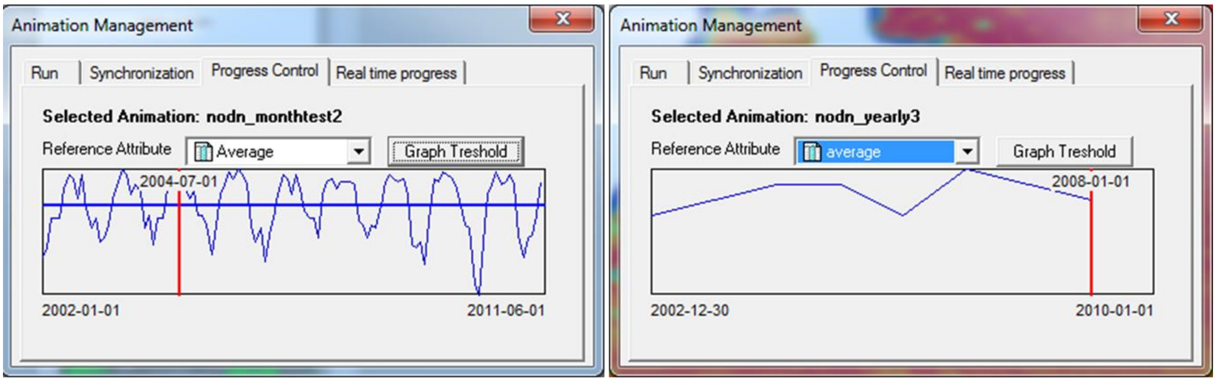
(a) (b)

Figure 4.7 Regular time unit selection interface (a) time selection (regular time sampling). (b) aggregate maplist (time aggregation)

4.4.3. Time aggregation

A second option for regular temporal unit selection is temporal aggregation. Similar to the time selection, temporal aggregation is developed by improving the existing maplist aggregation tool, named aggregate maplist. However the new animation generated from the time aggregation operation is not displayed on the fly, a new maplist with new images is generated from the operation. The input of the existing aggregate maplist function is a maplist (Figure 4-3). Then by performing an aggregation calculation, a new raster map will be produced. Slightly different from the existing aggregaste maplist, the input of the proposed time aggregate tools are a maplist, aggregation calculation, first image to be proceed, and number of images for each aggregation. Result of monthly aggregation of SPOT VEGETATION dataset is illustrated by time series graph in Figure 4.8.

In the existing aggregate maplist function, all images in the input maplist will be merged into one new image. In the proposed time aggregation, there are some aggregation functions that generate new images in a maplist. The resulting new images are grouped in a new maplist to be displayed as an animation. Users should also input the first image as start time, and the number of images for the time interval that will be merged.



Selected Animation: nodn_monthtest2
Reference Attribute: Average

Selected Animation: nodn_yearly3
Reference Attribute: average

(a) (b)

Figure 4.8 Time series graph resulted from (a) monthly aggregation and (b) yearly aggregation of SPOT VEGETATION

For instance, having a 10-day composite dataset that spans from January 2002 to June 2011; users may want to perform time aggregation for each month, starting from March 2002. Then the user should enter the March image 2002 which can be determined from filenames as input for the first image. For the monthly period, the user enters the number of 3 which means the number of images contained in a single month. The time aggregation will produce a new image resulting from aggregating 3 images using the chosen aggregation method. The time aggregation does not have an option to select the end of the selection. Therefore, iterations are conducted until the last image in the maplist that can still be aggregated.

Also different from the existing tools is that if the output of the existing tool is a raster map, the output of the new maplist aggregation is a new maplist containing raster maps that are resulting from image/temporal aggregation. Users just need to enter a maplist file name as the output. Also, the names of the images produced by the time aggregation operation are automatically generated. The way how to name the new images follows the way in which data providers named the data. The beginning of a composite time period will be included as the file name. For example, SPOT VEGETATION uses “date” to be included in the file name; 20020201 represent the first-10-day and 20020211 represents the second-10-day of February 2002. For a MODIS Terra dataset, it does not use the date, but the number of day of a year; the rules are quite the same. For example 2002001 to represent the first-16-days in 2002 and 2002017 to represent the second-16-days in 2002.

To provide a common understanding of what is usually given by the data providers, the resulting images from the time aggregation operation will also involve the time information. The time information will be obtained from the first image to be involved in the process of aggregation. In this study, resulting images will use the entire first image file name involved in the time aggregation and calculation method that is used. Besides to arrange the time series images in sequence, file name can also be useful for storing the history of the operation process. By its naming rule, the user is expected to recognize that an image is produced from the aggregation process with a certain calculation method. Information about the time interval can be obtained from the distance between one image and another.

With respect to the tracking process history, there is a function named dependency in ILWIS. If there are images used to create another image, such as the maplist aggregate operation, the operation (or expression) and input image file names will be stored with the new image. So that the users can trace how an image is made from its properties. In the time aggregation, the input and the output is a maplist and the expression of the operation will be:

```
output_maplist=MaplistAggregate(input_maplist,first_map,step,method)
```

where step is number of images for every iteration operation; method is aggregation method (here is mean, and maximum value). The expression to the right side of the equals sign is called main expression.

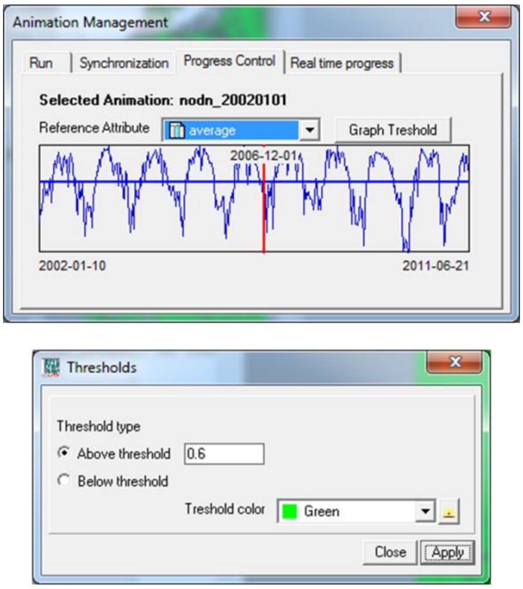
After preforming time aggregation, to show the animation supporting tool and time series graph, the user should create an attribute and time tables for the new maplist. The attribute table contains tabular information about the average value of each image that will be generated as the graph. The attribute table also contains some statistical calculation that further can be used in conducting the time selection by a threshold. The time table is used to generate the x-axis of the graph as a time legend.

4.4.4. Time brushing

Not much has been done for the time brushing as it already exists. But the progress bar has been replaced by a time series graph. Users can select a point on the graph and combined with the run tab, users can initiate and control the animation speed.

4.4.5. Threshold

Another proposed method is time selection by threshold. Threshold selection includes an option to define values below or above a threshold and input text for users to enter their desired threshold value. The interface of threshold selection is shown in Figure 4.9. Users can explore interesting events by selecting a threshold. The use of a threshold as time selection method will be particularly useful to observe anomalous events. A threshold, as a condition that can be considered as an anomaly, might be different for different cases. In order to support it, users can fill a threshold according to their need. Values that might be used as a threshold can be obtained from the attribute table of the maplist that have been made previously. From the average pixel values of every image, some statistical calculations such as mean, median, and standard deviation are also performed. Users can simply select the mean as long term average or do calculation to get another value as the threshold.



Selected Animation: nodn_20020101

Reference Attribute: average

Threshold type

● Above threshold 0.6

○ Below threshold

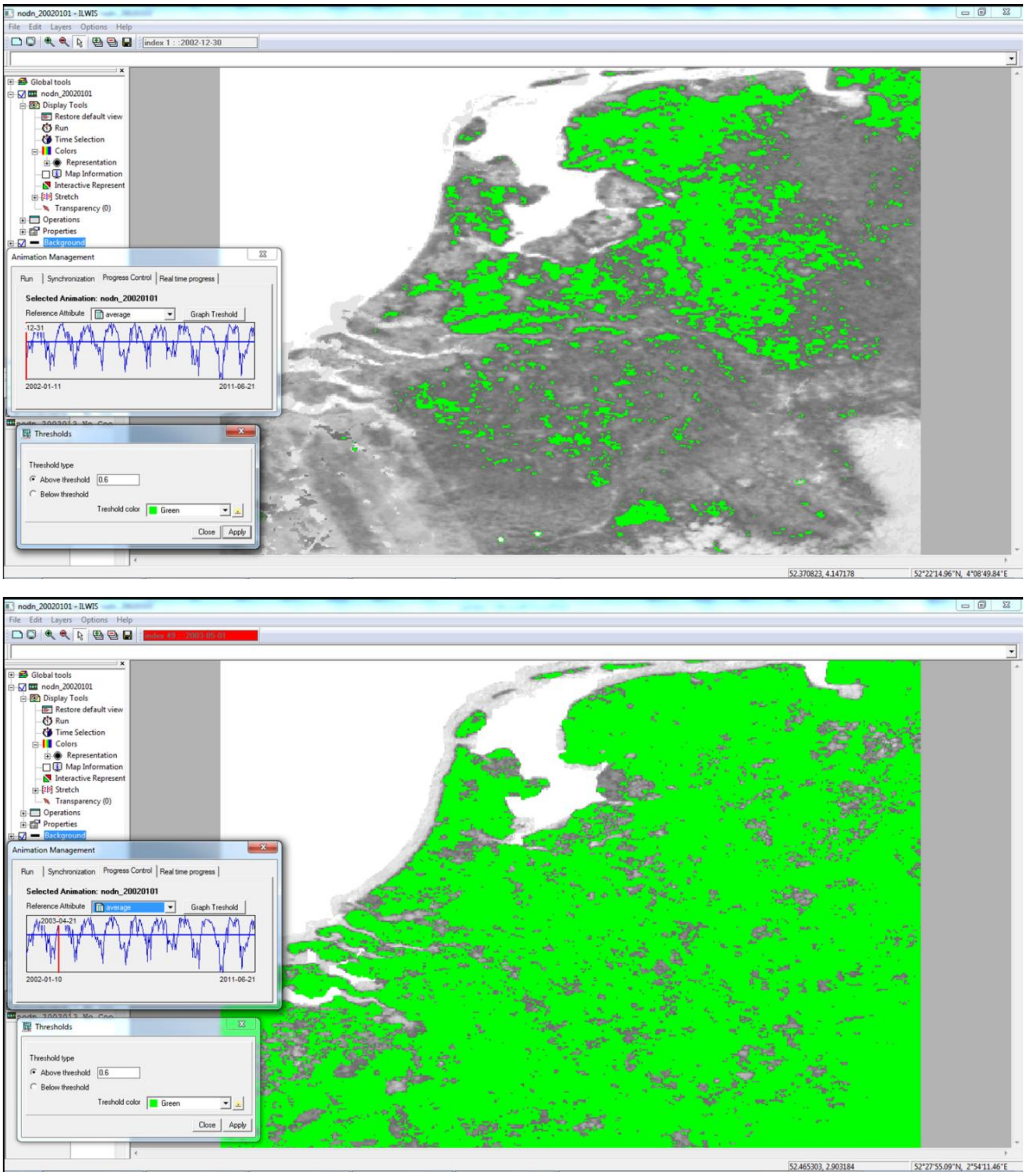
Treshold color 🟩 Green

Figure 4.9 Threshold selection

After selecting the threshold, a line representing it will be displayed in the time bar (Figure 4.4a). Users can choose for values above or below the threshold. The animation will display all images in the maplist, whether they meet the condition or not (Figure 4.10).

When the average pixel value meets the condition; there will be a red signs above the animation indicating that the displayed image satisfies the given constraints. Then a different colour will be applied for the pixel values of the images that meet the condition. As it is shown in Figure 4.8, green indicates the pixel values (area) that have values above the threshold, and grey below the threshold. It is expected that users can easily gain knowledge and see the process of change which is displayed in the animation, especially for area with anomalous events.

There is an operation named slicing in ILWIS (Figure 4.11). This is an adapted tool from aNimVis (Blok, 2005). Users can define a threshold, two thresholds, or an interval in a value range. Threshold here refers to the pixel value. The pixels that have a value that meet the condition are displayed in animation in different colours. In case of one threshold, the animation will display the images in two different colour representing above and below the threshold. In case of two thresholds, the animation will display the images in three different colours, for pixel values above, below, and between the two thresholds.



Selected Animation: nodn_20020101
Reference Attribute: average

Threshold type
● Above threshold 0.6
○ Below threshold
Treshold color: 🟩 Green

Selected Animation: nodn_20020101
Reference Attribute: average

Threshold type
● Above threshold 0.6
○ Below threshold
Treshold color: 🟩 Green

Figure 4.10 Display resulting from selection by threshold. Above: display of an image that does not meet the condition. Below: display of image that meets the condition

4.5. Discussion

For conducting visual exploration, especially to observe the process of change, users can employ animation. Visual exploration activities to get the knowledge about patterns and relationships between events and time is done mainly by answering the questions when, what, and where. But animation often has some limitations related to the cognitive information processing by users.

In order to answer the questions and overcome the limitations, animation should be completed with some supporting tools and be well designed. The addition of time selection tools are expected to support the activity. The tools are developed to allow users to actively interact with the animated display of time. Users can repeat the display and focus on the interesting events they want to observe. Animation and its supporting tools should be well designed. Using the animation environment should not be complicated. Users do not need to do complicated task to perform visual exploration tools and spend their time in finding out how they use the tools.

Several types or interaction with time (further called time selection methods) are discussed in this study. This study focuses on temporal zooming out. Time aggregation and time querying are the possible ways to be implemented as the temporal zooming out methods. Time aggregation is done by the maplist aggregation tool, while time querying can be done by time sampling and time selection by the threshold. Besides those two tools, time brushing can also be considered as time querying. According to the choice of the time unit, the proposed tools are grouped into two categories: regular and irregular time unit selection. Regular time unit selection includes time sampling and time aggregation while irregular time unit selection includes time brushing and time selection by threshold.

Different methods are developed to assist users performing different tasks. Regular selection can be employed to get the display of cyclic events or to get a summary of events in a time interval for long term observation. And irregular selection can be used to display interesting events, such as a threshold to observe anomaly events. Also time brushing can be used when users need to repeat the display because they miss some scenes or they need to get more understanding about interesting events of particular times. Besides the time selection methods, time series graph is developed to support the activity of time selection.

4.5.1. Time series graph

The time series graph shows the average value of every image in time series data. The use of the graph provides patterns and relationships of events in the given area over the time. Hereinafter, to understand the specific area where the events occur, users need to inspect the animation display.

In studying vegetation conditions, the graph shows the peaks, the length of the growing seasons, etc. The fluctuation of graph that indicates the seasons is also useful to find out the time interval of the seasons. The time interval can be used for further time unit selection.

This time series graph is used as an active time legend and a progress control. There is a line to indicate where the current image being shown is. But a disadvantage of the time series graph is its design. First, time information in the progress line covers the graph. Currently limited space of the interface does not allow y-axis values to be placed. To get the values of the y-axis, users should need to look into the attribute table that is generated before. This activity, looking at the graph, opening the attribute table, and finding the particular value in the table lead to cognitive overloads caused by complex interaction of many elements. Many elements in the interface that are needed to perform the activity will also cover the main display of the animation.

The user interface should be redesigned to be able to display the y-axis. It can be done either by increasing the window size or decreasing the size of the graph. In redesigning the user interface, the window size should also be taken into consideration in order not to cover the main animation view. But the work of redesigning the user interface has not been performed in this study.

As the default, the time series graph shows the general overview by displaying the average of pixel value (NDVI) of the study area. The Netherlands and its surrounding are used as the study area in this study. Since it is quite small area without any difference season, the average of NDVI value can represent the condition of the area. But simply averaging all pixel values in the study area will not appropriate to represent larger area which has different seasons, such as Africa. The average of entire area will eliminate the character of different area with different seasons. So that an additional tool to select and calculate the average value of the interest area is needed. Thus time series graph can show the general overview of a particular area.

4.5.2. Time sampling

With the time sampling, the animation will only display the selected images, and simultaneously the progress bar will show the position in time of an image that appears. But the progress bar only shows the position of the displayed image, there is no information about any image that has been selected and will be displayed in animation. This causes that users will face difficulty in remembering any image that appears. It might be better if there is a sign of the position of displayed image in the graph or a new graph is produced after performing time sampling.

4.5.3. Time aggregation

Time aggregation provides a summary of events that occur in an area in a time interval, which might be useful for observing long term variation. It is also reducing the number of images to be displayed in animation.

However, users might forget how an image is produced and from which images it is from. Keeping the history of the process is important. As it has been described, the dependency function only stores the operation or expression and the input of the operation in the output. From the expression, only the main expression will be stored in the output maplist. Although the time aggregation operation will also produce a number of maps to be included in the output maplist, the images production is not the main expression; it is the internal function of the time aggregation operation. The dependency function does not store the history in the resulting images. The history of the process on how an image is produced is stored only in its file name. This is the simplest way to do.

The use of the number of an image as time unit is less precise for defining the new time unit. For SPOT VEGETATION, it might not lead to a problem because there is the same number of images in a time interval. In MODIS Terra dataset, there are 23 images in a year and the interval between images is 16 days. The problem is coming, for instance if users want to get the summary of events (aggregate) for every month. Since it only has 23 images for every year, it means that there is one month with only one image, and that is October or November. Therefore selecting 2 images to represent a month will result in a shift in the result.

Time aggregation for NDVI data using regular time intervals might have a negative effect. The effect of aggregation will increase if an aggregation is conducted over different seasons. The study area has four different seasons, aggregating one year means aggregating four different seasons. Figure 4.8 (b) shows the result of yearly aggregation of SPOT VEGETATION dataset. Compared to Figure 4.6 (a), one cycle in the graph indicates one year period. Aggregation over different seasons eliminates the characteristics of each season. The pattern of vegetation condition in a year cannot be seen anymore. Different with Figure 4.8(a) as the result of monthly aggregation, the inter-annual pattern still can be seen, because there is no extreme change of vegetation condition in a normal condition.

The seasons do not change in a fixed time. If time aggregation is used to aggregate each season, it will be difficult to determine the time interval for an aggregation operation. The aggregation effect will increase if the transition of seasons occurs within time interval. It might be useful if the selection of the start and the end time is based on values that indicate the slope of growing and end season so the effect of the time aggregation as mentioned before can be reduce. Time aggregation in this way can be categorized as irregular time unit selection.

The evaluation to assess the quality of the result of time aggregation is not performed in this study.

4.5.4. Time brushing

The use of different tabs (run and progress control) to control the animation might lead to delay in interacting with the animation. Too much tools to interact increase cognitive overloads and decrease the information that can be retrieved by the users. Redesigning its user interface by merging the two tabs into one should be considered. The y-axis as mentioned in Section 4.5.1 also needs to be considered to redesign the user interface.

4.5.5. Time selection by threshold

The use of a threshold is useful to find when anomaly events occur. Time selection by threshold is in this study grouped under irregular time unit selection. But the result of the implementation is actually regular time interval. All images (which are in same time interval) in the maplist are displayed in the animation. The indication of whether images meet the condition is shown by the threshold line in the time series graph and the red colour above the animation display. This is useful because even in images that do not meet the condition (threshold) as a whole, there are some areas in the image which has values that meet the condition. It is shown by putting different colour for pixel values that meet the condition, and gives useful information about a specific area with has the events.

To differentiate the images which do not meet the condition or not, there is the red band that appears and disappears above the main animation display. The use of the red band may cause inattentional change blindness. Users may fail to notice the red band that suddenly appears because their attention is engaged on another task, looking at the main animation display.

Combining the two functions, selection of the threshold and slicing will be useful to understand the time at which the average conditions of an area is above, at, or below the specified conditions. It can also be used to determine areas with anomalous events.

4.5.6. Time handling

Most of the implementations of proposed methods are done by looking at the file name to handle the time. Even though SPOT VEGETATION NDVI data is used for implementation, the proposed tools are expected to be useful for all the time series satellite images.

However, there are still some shortcomings of the use of file name for the time handling and how ILWIS retrieve the time information. The use time as part of file name ends up depending on the data preparation (analyse first phase). As an example, for MODIS Terra datasets, it has been mentioned that the data provider involves time information of the year and number of days in Julian calendar. But currently, ILWIS only can retrieve time from the file name including the data, not number of days in Julian calendar. In this study, SPOT VEGETATION already includes the year, month, and date in its file name that already can be handled by ILWIS. While in MODIS Terra datasets, ILWIS has not been able to handle its time information. As the result, it can be seen in Figure 4.6, the x-axis that represent time shows the date for SPOT VEGETATION time series graph, though it shows number of images being shown for MODIS Terra time series graph. It is necessary to adjust the file name that involving the year, month, and date so that it can be handled by ILWIS.

While performing a time unit selection, users should select the first time to define the time extent. This first time is selected from the file name of image or the time information (in time sampling and time aggregation), the graph (in time brushing). It is simple to implement compared to time selection that commonly used by various applications, that is based on a calendar. Time selection by calendar allows users to easily input the date/time from a dropdown calendar. Applying such a date picker will be quite complicated since different datasets have different characteristics including temporal resolution and they use different rules regarding including time in the names. SPOT VEGETATION includes the date in its name, but not all the dates, because there are only three images in every month. The images use 1, 11, and 21 representing 10 days in each composite. Selection of a date on a calendar might be conducted by applying some condition. For example, if users select the 25th of a month, then the operation will choose the 21th that represents the date that most close to 25. But again, this way is quite complicated because the condition will be different for each dataset, not forgetting to mention cases in which there are datasets with multiple images on one day.

Defining the new time unit, users select the number of images included in a time interval. This way is acceptable for time interval with the same number of images, such as performing monthly aggregation for SPOT VEGETATION which has 3 images for every month. MODIS Terra has 23 images within year. It means that there is one month with only one image which occurs on October or November. Using the number of images will not be precise in performing monthly aggregation. In case there is one image in October in the first year; the operation will aggregate the October image and one November image, and another November image with one December image. So on until the iteration reach the month with one image in the next year. Therefore the time handling is important to be improved.

Proposed methods are implemented in the prototype to be integrated on ILWIS. But some error occurs. For example, in the time table operation, the dataset (SPOT VEGETATION) only has 3 images for each month and they are represented by date 1, 11, and 21. But as can be seen in Figure 4.7a and 4.8, there are dates that are not expected in the first image. But the time table operation generates the appropriate data for the rest of data.

4.5.7. Monitoring vegetation

Used to capture same phenomena in the same area, SPOT VEGETATION and MODIS produce similar long term pattern (Figure 4.6). With 10 days temporal composites SPOT VEGETATION provides more detail pattern and more fluctuate than MODIS Terra with 16 day composite. From the time series graphs, it is known that yearly vegetation condition trends are similar over the time spans. But there is a difference that can be seen in the end of 8th and 9th periods. From the animation display, it is because of the clouds. It is identified by a big difference condition that is shown in animation between the image in particular time with the image before and after it. A big difference happens when there is a disaster or there is a cloud interfere the observation by sensor.

The graph shows that the vegetation growth occurs from February and reaches its peak around June or July for every year. And it is in the lowest point on December to January. The animation display and time brushing tool are used to inspect the vegetation growth over the area in the particular time. Seasonal patterns of vegetation growth can be seen in the centre of the area from 11 February to 21 July 2003. But there is still cloud disturbance in the SPOT VEGETATION dataset, monthly aggregation is done to reduce the effect of the cloud. By monthly aggregation, seasonal pattern in the study area is clearly displayed over the time spans.

Combination of time brushing and time selection by threshold allows detection of vegetation stress in the study area from date 21 November 2002 to 21 January 2003. Long term average is chosen as the threshold. For the other years, the vegetation stress also occurred in almost the same area and time with in the end of 2003. Especially for the end of 2009 and 2010, the vegetation condition cannot be observed because of the cloud.

4.6. Summary

This chapter describes the design and implementation of the time selection methods. The time selection can be done after the user understands the overview of the data, especially the relationship between time and events are further illustrated by the graph to help understanding. This graph is adopted from aNimVis. With a general overview of the data, a general pattern of the data, and starting and ending time of events which can further beexplored can be used as a reference of the time selection. Thus it is expected that the negative effects of the MTU can be minimized. Users interact with data through the user interface.

Appropriate user interfaces are required to get results. A user friendly interface that is easy to interact with will keep users to concentrate on their tasks. In this study, since the time selection methods are integrated in ILWIS, the ILWIS user interface is adapted for the proposed method implementation. Time selection methods and supporting tools have been designed and implemented in a prototype. They are time sampling, time aggregation, time brushing, and time selection by threshold. The use of the methods should be conducted in accordance with the purpose of observation.

For example time sampling would be better used to observe recurrent events at the same time interval, time aggregation to give summary of event in the time interval, time brushing to observe and repeat the events of interest, and the threshold to observe anomaly events. Time selection tools are expected to assist users to gain knowledge about the pattern of events, the relationship between the event, time and area, and the process of change. The combination of the time series graph and time selection tools allows the user to answer visual exploration questions related to attribute (what), location (where), time (when, how long, how often). Although there are still many weaknesses in the proposed methods, such as time handling and especially the user interface.

5. CONCLUSIONS AND RECOMMENDATIONS

The main objective of this research is to design an animation environment equipped with tools that enable users to modify the temporal unit in order to support visual exploration of time series data, especially data that is derived from satellite imagery. To achieve the objective, geovisualization and potential time unit selection methods are studied. Based on the study, the development of the visualization environment that is integrated in existing software (ILWIS) is carried out. In the next section, the results of the study and the development of the visual environment is summarised by answering the research questions. This is followed by recommendations for future work.

5.1. Conclusions

Conclusions will be formulated by revisiting the research questions:

1. What methods can be used to do time selection of animated time series for visual exploration?

There are several types of interaction with time. They are temporal panning, temporal querying, temporal zooming, and data transformation. Similar with spatial zooming, there are also temporal zooming in and zooming out. From those types of interaction with time, temporal querying and temporal zooming can be used to select the time unit

2. Which methods are potentially suitable for implementation in a prototype?

In this study, the implementation of temporal querying and temporal zooming, particularly zooming out, are conducted. The time unit selection can be done according to several methods: time sampling, time aggregation, time brushing, and selection by putting a value as threshold. Further these are categorized in two categories, regular and irregular time selection methods. The regular selection method includes regular time sampling and time aggregation, while the irregular time selection method includes time brushing and time selection based on a threshold.
The time selection methods need to have the support from another tool, a time series graph. Therefore it is necessary to implement a time series graph which is then placed on the time legend to provide general overview of the data, and the relationship between events and time.

3. What are user requirements?

While performing visual exploration activities using temporal animation, users need to understand the information concerning time. This can be obtained from the time legend. From the time legend, users can interpret the meaning of the sequence. In addition, users also need an interactive tool, then the time series graph is employed, to help them to explore the information and interact with the data and display in order to get the information and knowledge they need. Focussing on modifiable time unit selection tools, several methods that allow users to modify the time unit are proposed. But before modifying/selecting time units, users need information related to data over the time. Unfavourable interaction, such as switching between different tools to perform an activity may cause users to spend a long time in performing their activities. Users need a better tool to directly interact with the respective tools in performing a task to reduce their time in interacting with the data and display the animation.

4. How to design and implement the potentially suitable method(s) in a prototype?

Time selection methods are implemented in ILWIS. Before applying the methods, review of the tools that already exist should be conducted. Existing tools that might be used can then be further developed into the time selection and its supporting tools. Time sampling is an improvement on time selection, time aggregation is an improvement on the function aggregate maplist, and the time series graph and time brushing on the time progress control. Time selection by threshold is a new tool because there is no similar tool to be improved in ILWIS.

5. Which case studies can be used to demonstrate the methods/tools?

NDVI data from SPOT VEGETATION and MODIS Terra that represents the condition of vegetation is used for the implementation. Different datasets have different characteristics and ways of handling the time. Different datasets are used to determine whether the proposed tools can handle the different datasets or how the data should be adapted with the requirements of the tools.
The Netherland and its surrounding are used. The whole study areas have the same seasons at the same time, so that the condition of vegetation is the same. The general overview of the area can more easily be derived by averaging the pixel values than the general overview of larger areas (for example Africa).

5.2. Summary

Proposed tools to support visual exploration can help users to understand the general pattern of phenomena. It can also be used to identify the relation between event, area, and the time. File name must be considered in the data preparation phase so that the time information can be read and applied to the time legend. Then the general patterns and trends can be easily seen on the time series graph.

From the case study that are done to inspect the vegetation growth and vegetation stressed, it is shown that the use of time selection tools and their combination can be used to see inspect occurring events that occur in a particular area in particular time. Time series graph provides the general overview of the data. Time aggregation provides summary of an event in time interval. Time selection by threshold allows users to indicate the incidence of vegetation stressed. Time brushing allows users to instantly choose a time and loop over into a temporal extent. It is useful to review the animation and look into the information that may be missed before. The combination of the proposed tools (time series graph, time legend, and time selection tools) allows users to answer the visual exploration questions related to where, what, and when.

5.3. Recommendation

The following recommendations for future work can be made.

1. Currently, the selection of end time for time selection, especially for regular time sampling, time aggregation, and time brushing has not been implemented. It is necessary because the end time is the end time is to be considered relevant in interacting with the animation, especially to select the time extent.
2. The temporal legend is an active temporal legend. It allows the user to choose the time by clicking at a particular point in it. But to start the animation, another tool, the start button on a different tab is needed. It might be better if the user can select a particular point by clicking while holding the mouse and dragging it to display the animation. By clicking, holding, and dragging the cursor in the time legend, besides for selecting the images that the user wants to be displayed, the user can simultaneously control the animation speed according to his/her needs.

3. There are too many windows and tabs to conduct a time selection. For example to control the animation, its speed, and looking at the time series graph, users should move from the tab run to progress control. Many works and eye movement that are needed while switching the different tabs will increase the cognitive overload and users may miss some scenes that are being displayed in the main animation window. It will reduce the information from the animation that can be perceived.
4. Currently, the progress control with a time series graph is used as the time legend. Time information about the image that being displayed is attached in the moving progress line. But then it covers the time series graph. The limited place in the progress control point does not allow the placing of the y-axis values. Related to the points in recommendations 2 and 3, it is necessary to re-design the animation time management, so that information about time, the values along the y-axis of graph, and also animation control can be put in one place.
5. Currently the file name plays an important role for selecting the time. It is necessary to handle time in a way that can be used by all datasets for some purposes: selecting the time, keeping history, also naming of image files produced from time aggregation. What has been done is the input filename is used as the name of new images produced from operation. If the input file name is long enough, it is not easy to do selection based on a long file name.

   Data preparation is important in naming the time series data. If an import file is needed from another data type, the import maplist from ILWIS does not allow users to put the original file name in the importing files. Information about the time might be lost. The use of time as file name depends on data preparation. The use of the file name, or giving another option for users to choose the file name, should be reconsidered.
6. The implementation phase is carried out using a dataset of the Netherlands, which is a relatively small area. For monitoring a larger area which has much vegetation variability and variability in the seasons, then giving the overview by simply calculating the average value of the entire image of a given area on the graph will be less informative. For that reason, it might be better if there is a tool that allows users to select a particular area of interest and calculate the pixel values contained in the selected area and then generate the graph. Then the graph will provide a more precise overview of the area.
7. Currently there is no smoothing technique available in the animation environment. Smoothing techniques applied to animation could also help in providing insight about the process of change. Lack of cloud free data causes problems in time series data since there are vacancies between images to be displayed in animation. Smoothing might overcome such events, so there are no uninformative images between the displays. Smoothing may be able to describe the process of change in more detail.
8. For the time selection by a threshold, a sign that an image is displayed in the animation above the main window, apart from the animation, may interfere in making observations. Therefore another way to indicate whether an image meets the condition or not is needed.
9. There is no user evaluation conducted to test how effective and efficient the proposed tools are. A user evaluation is necessary to improve the dynamic interaction tools (here the time unit selection) and also the user interface design.

LIST OF REFERENCES

Alexandridis, T. K., Gitas, I. Z., et al. (2008). An estimation of the optimum temporal resolution for monitoring vegetation condition on a nationwide scale using MODIS/Terra data. *Int. J. Remote Sens., 29*(12), 3589-3607. doi: 10.1080/01431160701564618

Andrienko, G., Andrienko, N., et al. (2008, 28 - 30 May 2008). *Interactive visual interfaces for evacuation planning.* Paper presented at the Proceedings of the working conference on Advanced visual interfaces, Napoli, Italy.

Andrienko, N., & Andrienko, G. (2005). *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach.* New York: Springer-Verlag New York, Inc.

Andrienko, N., Andrienko, G., et al. (2003). Exploratory spatio-temporal visualization: an analytical review. *Journal of Visual Languages & Computing, 14*(6), 503-541. doi: 10.1016/s1045-926x(03)00046-6

Anyamba, A., & Eastman, J. R. (1996). Interannual variability of NDVI over Africa and its relation to El Nino Southern Oscillation. [Article]. *International Journal of Remote Sensing, 17*(13), 2533-2548.

Bar-Noy, A., Nisgav, A., et al. (2001, August 2001). *Nearly optimal perfectly-periodic schedules.* Paper presented at the Proceedings of the twentieth annual ACM symposium on Principles of distributed computing, Newport, Rhode Island, United States.

Batista, G. T., Shimabukuro, Y. E., et al. (1997). The long-term monitoring of vegetation cover in the Amazonian region of northern Brazil using NOAA-AVHRR data. *International Journal of Remote Sensing, 18*(15), 3195-3210. doi: 10.1080/014311697217044

Becker, T. (2009). *Visualizing time series data using web map service time dimension and SVG interactive animation.* MSc, ITC, Enschede.

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

Blok, C. A., Turdukulov, U. D., et al. (2011). *Development of open source functionality for the analysis and visualization of remotely sensed time series : extended abstract + powerpoint.* Paper presented at the GeoViz Hamburg 2011 : Linking geovisualization with spatial analysis and modeling, Hamburg, Germany.

Broich, M., Hansen, M., et al. (2011). Remotely sensed forest cover loss shows high spatial and temporal variation across Sumatera and Kalimantan, Indonesia 2000–2008. *Environmental Research Letters, 6.* doi: 10.1088/1748-9326/6/1/014010

Carranza, E. J. M. (Ed.). (2008). *Geochemical anomaly and mineral prospectivity mapping in GIS* (Vol. 11). Amsterdam,: Elsevier.

Çöltekin, A., Sabbata, S. D., et al. (2011). Modifiable Temporal Unit Problem.

de Jong, R., & de Bruin, S. (2011). Time series of vegetation indices and the modifiable temporal unit problem. *Biogeosciences Discuss., 8*(4), 8545-8561. doi: 10.5194/bgd-8-8545-2011

Edsall, R., Andrienko, G., et al. (2009). Interactive Maps for Exploring Spatial Data In M. Madden (Ed.), *ASPRS Manual of GIS* (pp. 837-858).

Edsall, R. M., & Peuquet, D. (1997). *A Graphical User Interface for the Integration of Time into GIS.* Paper presented at the Proceedings of the 1997 American Congress on Surveying and Mapping Annual Convention and Exhibition, Seattle, WA.

FAO Global Information and Early Warning System. (2003), from http://www.fao.org/giews/english/windisp/windisp.htm

Field, A. P. (2009). *Discovering statistics using SPSS.* Los Angeles: SAGE.

Forsell, N., & Eriksson, L. (2011). Influence of temporal aggregation on strategic forest management under risk of wind damage. *Annals of Operations Research*, 1-18. doi: 10.1007/s10479-011-0966-4

Galvão, L. S., Ponzoni, F. J., et al. (2004). Sun and view angle effects on NDVI determination of land cover types in the Brazilian Amazon region with hyperspectral data. *International Journal of Remote Sensing, 25*(10), 1861-1879. doi: 10.1080/01431160310001598908

Groten, S. M. E., Immerzeel, W., et al. (1999). *Monitoring of crops, rangelands and food security at national level : + an introductory tutorial using WINDISP on CD - ROM.* Enschede ; Rome: ITC ; FAO.

Harrower, M. (2001). Visualizing Change: Using Cartographic Animation to Explore Remotely-Sensed Data. *Cartographic Perspectives, 39*, 30-42.

Harrower, M., & Fabrikant, S. (2008). The Role of Map Animation for Geographic Visualization *Geographic Visualization* (pp. 49-65): John Wiley & Sons, Ltd.

Harrower, M., MacEachren, A., et al. (2000). Developing a Geographic Visualization Tool to Support Earth Science Learning. *Cartography and Geographic Information Science, 27*(4), 279-293. doi: 10.1559/152304000783547759

Holben, B. N. (1986). Characteristics of maximum-value composite images from temporal AVHRR data. *International Journal of Remote Sensing, 7*(11), 1417-1434. doi: 10.1080/01431168608948945

Hornsby, K., & Egenhofer, M. J. (1999, 1 - 3 September 1999). *Shifts in detail through temporal zooming.* Paper presented at the Proceeding of Tenth International Workshop on Database and Expert Systems Applications,, Florence , Italy

ITC. (2010). *GI science and earth observation : a process - based approach : also as e-book*. Enschede: University of Twente Faculty of Geo-Information and Earth Observation ITC.

Kachigan, S. K. (1986). *Statistical analysis: An interdisciplinary introduction to univariate and multivariate methods.* New York: Radius Press.

Keim, D. A. (2001). Visual exploration of large data sets. *Commun. ACM, 44*(8), 38-44. doi: 10.1145/381641.381656

Kirsh, D. (2000). A few thoughts on cognitive overload. *Intellectica, 1*(30), 19-51. doi: citeulike-article-id:845791

KNMI. (2012). Royal Netherlands Meteorological Institute Retrieved 1 February 2012, 2012, from http://www.knmi.nl/index_en.html

Kraak, M.-J., Edsall, R., et al. (1997, 23 - 27 June 1997). *Cartographic Animation And Legends For Temporal Maps: Exploration and or Interaction.* Paper presented at the Proceedings of the 18th ICA International cartographic conference, Stockholm, Sweden.

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

Kraak, M. J., & Ormeling, F. (2010). *Cartography: visualization of geospatial data*: Prentice Hall.

Kross, A., Fernandes, R., et al. (2011). The effect of the temporal resolution of NDVI data on season onset dates and trends across Canadian broadleaf forests. *Remote Sensing of Environment, 115*(6), 1564-1575. doi: 10.1016/j.rse.2011.02.015

Kuhn, M., Pfitser, S., et al. (2011). *Timeline: A Tool for Video Analysis and Visualisation of Geographic Phenomena Over Time.* Paper presented at the 25th International Cartographic Conference, Paris, FR. http://www.zora.uzh.ch/54261/

LPDAAC. (2012). Land Processes Distributed Active Archive Center, January 25, 2012, from https://lpdaac.usgs.gov/

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

Malamed, C. (2009). *Visual Language for Designers: Principles for Creating Graphics that People Understand*: Rockport Publishers.

Mannaerts, C. M., Maathuis, B. H. P., et al. (2009, July 12-17, 2009). *The ITC GEONETCast toolbox : a geo capacity building component for education and training in global earth observation and geo information provision to society.* . Paper presented at the IGARSS 2009 : Proceedings of the 2009 IEEE international geoscience and remote sensing sympsosium : Earth observation, origins and applications, Cape Town, South Africa.

Meentemeyer, V. (1989). Geographical perspectives of space, time, and scale. *Landscape Ecology, 3*(3), 163-173. doi: 10.1007/bf00131535

Metaferia, M. T. (2011). *Visual enhancement of animated time series to reduce change blindness.* MSc, University of Twente Faculty of Geo-Information and Earth Observation ITC, Enschede.

Monmonier, M. (1989). Geographic Brushing: Enhancing Exploratory Analysis of the Scatterplot Matrix. . *Geographical Analysis, 21*, 81–84. doi: 10.1111/j.1538-4632.1989.tb00879.x

Myneni, R. B., Tucker, C. J., et al. (1998). Interannual variations in satellite-sensed vegetation index data from 1981 to 1991. *J. Geophys. Res., 103*(D6), 6145-6160. doi: 10.1029/97jd03603

NASA. (2011). Measuring Vegetation (NDVI and EVI) Retrieved 15 November 2011, 2011, from http://earthobservatory.nasa.gov/Features/MeasuringVegetation/measuring_vegetation_2.php

North. (2011). 52 North home Retrieved 30 December, 2011, from http://52north.org/

Nowell, L., Hetzler, E., et al. (2001). *Change Blindness in Information Visualization: A Case Study.* Paper presented at the Proceedings of the IEEE Symposium on Information Visualization 2001 (INFOVIS'01).

Oldfield, S. J. (2001). A critical review of the use of time sampling in observational research. . *Nursing Times Research, 6*, 597–608. doi: 10.1177/136140960100600206

Oxford Dictionary. (2012). Oxford University Press.

Repp, A. C., Roberts, D. M., et al. (1976). A Comparison of frequency, interval, and time-sampling methods of data collection. *Journal of Applied Behaviour Analysis, 9*, 501-508.

Reynolds, H. (1998). *The modifiable area unit problem: empirical analysis by statistical simulation.* PhD.

Schouwenburg, M. (2012). 52 North Blog, 2012, from http://blog.52north.org/category/communities/ilwis/

Shneiderman, B. (1996, 3 - 6 September 1996). *The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations.* Paper presented at the Proceedings of the 1996 IEEE Symposium on Visual Languages, Boulder, CO , USA.

Simons, D. J., & Levin, D. T. (1997). Change blindness. *Trends in Cognitive Sciences, 1*(7), 261-267. doi: 10.1016/s1364-6613(97)01080-2

Sweller, J., van Merrienboer, J., et al. (1998). Cognitive Architecture and Instructional Design. *Educational Psychology Review, 10*(3), 251-296. doi: 10.1023/a:1022193728205

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

University of New Hampshire. (2010). MODIS Animated Time Series, from http://www.cooa.unh.edu/data/satellites/modis/movies/index.jsp

van Leeuwen, W. J. D., Huete, A. R., et al. (1999). MODIS Vegetation Index Compositing Approach: A Prototype with AVHRR Data. *Remote Sensing of Environment, 69*(3), 264-280. doi: 10.1016/s0034-4257(99)00022-x

Vancutsem, C., Pekel, J. F., et al. (2007). Mean Compositing, an alternative strategy for producing temporal syntheses. Concepts and performance assessment for SPOT VEGETATION time series. *International Journal of Remote Sensing, 28*(22), 5123-5141. doi: 10.1080/01431160701253212

VITO. (2011). Free Vegetation Products Retrieved November, 2011, from http://free.vgt.vito.be/

Ware, C. (2004). Interacting with visualizations *Information Visualization : Perception for Design* (2 ed., pp. 317-350). San Diego: Academic Press.

Wyatt, P., & Ralphs, M. (2003). *GIS in land and property management*: Spon Press.

Yang, W., Yang, L., et al. (1997). An assessment of AVHRR/NDVI-ecoclimatological relations in Nebraska, U.S.A. *International Journal of Remote Sensing, 18*(10), 2161-2180. doi: 10.1080/014311697217819

Zhang, J., Roy, D., et al. (2007). Anomaly detection in MODIS land products via time series analysis. *Geo-Spatial Information Science, 10*(1), 44-50. doi: 10.1007/s11806-007-0003-6