

A Conceptual Design for Visualisation of Spatio-temporal Data using Animation with Linked Graphics

Sarmistha Biswas

December 2004

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by

Sarmistha Biswas

This thesis submitted to the International Institute for Geo-information Science and Earth Observation in partial fulfilment of the requirements for the degree of Master of Science in Geo-informatics.

Thesis Assessment Board

Chairman: Prof. Menno J. Kraak (ITC)
External examiner: P.S. Acharya (DST)
IIRS member: P.L.N. Raju (IIRS)
Supervisor: Shefali Agarwal (IIRS)

Thesis Supervisors

Shefali Agarwal (IIRS)
Drs. Connie Blok (ITC)



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**INTERNATIONAL INSTITUTE FOR GEO-INFORMATION SCIENCE AND EARTH OBSERVATION
ENSCHEDE, THE NETHERLANDS**

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... Dedicated to my father...

I certify that although I may have conferred with others in preparing for this assignment, and drawn upon a range of sources cited in this work, the content of this thesis report is my original work.

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Disclaimer

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Acknowledgement

I would like to convey my sincere gratitude and appreciation to my supervisors Shefali Agrawal and Drs. Connie Blok for their invaluable advice, guidance and support throughout the research period. I am grateful to Mr. P.L.N. Raju, Head of the Geoinformatics Division, for giving me an opportunity to join the masters' degree course of Geoinformatics at IIRS. I appreciate the support that I received from Dr. Sameer Saran at the starting phase of my thesis work. I am greatly thankful to Harish Karnataka, Sudhir Kumar and Giri Babu (Scientist Of RRSC) for their guidance regarding the development of my prototype.

Success of my thesis would not be complete without to the participants of my usability evaluation phase. I am indebted to their advice and criticism that have enormously contributed to my research work. For this I am thankful to C. Jeganathan, Minakshi Kumar, Yogesh Kant and Dr. P.K. Joshi and all others who have helped me to arrange user testing. Though I might not be able to name all of these people by name, I dearly extend my thanks to each one of them.

I also appreciate the friendship of my all classmates of Geoinformatics and EADM course. It was a great opportunity to go ITC, The Netherlands and stay with all my friends and classmates. Special thanks go to my roommate Anusuya Barua for her immense cooperation during the stay at IIRS. Special thanks also go to my classmates Amit, Gaurav, Badri, Sudhira, Nagi, Ashwini, Mishraji and Chhabraji. Their friendship, openness and availability to discuss about so many things and listening music will be greatly missed.

Finally I like to say that I am immensely grateful to my husband, Abhik who gave me a tremendous support and encouragement during my study days and research periods at IIRS.

Last but not the least, I thank my parents, my in-laws and my brother for their support and encouragement over the years.

Abstract

In the field of geovisualization, animation technique for the representation of spatio temporal data has emerged as an effective tool to explore the hidden pattern of raw datasets. However it is seen that simple animation is not always able to address all forms of spatio temporal pattern. Hence, interactive animation is an alternative approach to represent the changing pattern in a more expressive way. A number of interactivity can be added with animation. Animation with linked graphics is such an approach. For enabling the effectiveness of this tool, the research outlines the conceptual design framework for the representation of spatio temporal data. The temporal NDVI of Indian subcontinent is considered for demonstrating the prototype 'TEMPVIZ'. Through animation an attempt has made to represent the changing pattern of vegetation and the linked graphics techniques combined with static maps has considered for change identification and measurement purpose. For the usability study of this technique focus group combined with questionnaires method is considered and applied. The usability evaluation session is conducted in two parts. Changes were implemented in response to first group results and final assessment revealed that animation with linked graphics had high impact on users and the combined approach of dynamic and static map had little impact on users. But overall, users expressed that combination of animation with linked graphics along with static map is an effective approach for change detection and change measurement studies.

Key words: geovisualization, animation with linked graphics, spatio-temporal analysis, focus group, and usability evaluation

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1. Introduction

“The purpose of visualization is insight, not pictures”.

- Willam Ribarsky

1.1. Visualization of Geospatial Data

Scientific discovery has opened up numerous approaches to the representation of wide range of data. Scientific visualization is such an approach. It is for observation, interpretation and explanation of the datasets. It has emerged, as an effective way to explore graphic representation of data that may enrich the process of scientific discovery and understanding of raw data sets. Scientific visualization can be defined as “the use of sophisticated computing technology to create visual displays, the goal of which is to facilitate thinking and problem solving. Emphasis is not on storing knowledge but on knowledge construction” (MacEachren & Kraak, 1997).

Visualization in Scientific Computations ‘studies the mechanisms in humans and computers, which allows them to perceive, use and communicate visual information’ (McCormick et al., 1987). This way of visualization when deals with geographic data it becomes geovisualisation. “Geovisualisation integrates approaches from scientific visualization, exploratory cartography, image analysis, information visualization, exploratory data analysis and geographic information system to provide theory, methods and tools for visual exploration analysis, synthesis and presentation of geospatial data”(MacEachren & kraak, 2001). Geovisualization involves transferring the information about characteristics and nature of data to human brain by exciting the sensory system through the proper use of graphics. Hence to study the geospatial datasets in detail geovisualization is one of the way. The main concept of geovisualization can be illustrated as under:

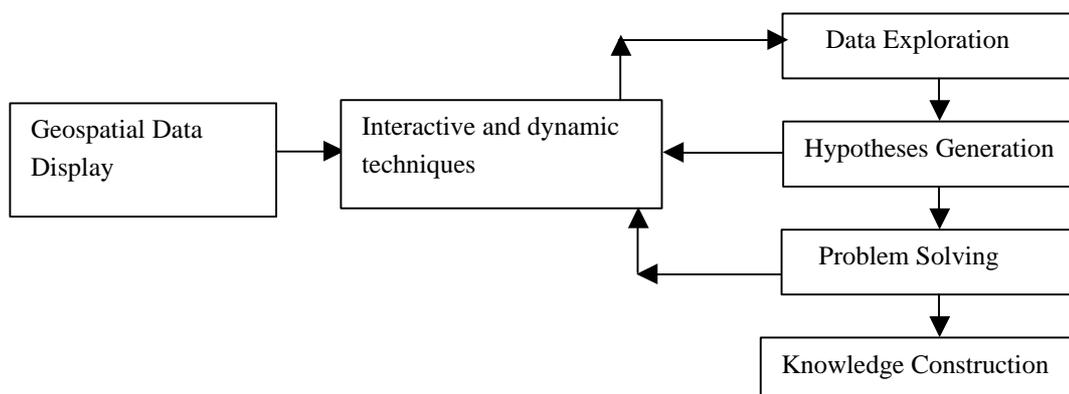


Figure 1.1: Conceptual Diagram of Geovisualization

The above figure implies that user can access geospatial data through graphical representations and through interactive and dynamic techniques, which allows user to explore the characteristics of the data. One can also generate hypotheses, which is essential for problem solving and knowledge con-

struction. It is not a one-way process, based on user's requirement for knowledge construction the process continues.

To study the complex phenomena in natural and social sciences geospatial data is essential. Geospatial referencing provides a fundamental mechanism for linking the diverse forms of data needed to study those phenomena. But in GIS environment there is no fully developed, integrated model of complex human and environmental systems. Data integration is not enough to study those complex systems. Geovisualization has make room to represent the complexity of phenomena and processes through innovative scene construction (MacEachren & kraak, 2001). Hence to make an innovative visualization, cartographic technique is essential. Cartographic techniques and methods are mainly applied to translate the data into graphics, which include map like products (Kraak, 1998).

Traditional maps only display the geospatial data but interactive maps offer more exploration options. Thus geovisualization environment allows alternative representational methods with new insights and different perspective. In this environment it enables the user to study the data from different perspectives like combine map with other graphics, diagrams, photographs and videos and then nature of the data will be better appreciated (Kraak, 2002). In this geovisualization environment data representation is not only restricted within two dimensions but four and five dimensions can also be mapped. All these representational techniques are the result of integration of techniques of computer science and GIS. The multivariate representations of geospatial datasets by different creative graphics have more impact than traditional mapping methods. In this context it can be said that maps are the tools for thinking about the characteristics of geospatial data.

In the world many geographic data are dynamic in nature (e.g. weather data) and many users are interested to view the changes over time. The users not only want to view the changes but also to analyse the phenomena. This calls for interaction with the data. Series of interactive static maps is one of the ways to visualize such changes, but in this case the sense of dynamics is very limited, it has to be constructed in the mind of the user. Animation seems to be a suitable technique to represent the dynamism. It is a subject of great interest among the computer graphics. It facilitates the function for seeing the whole process of change. The study aims at integration of graphics with animation and, in effect, developing an effective tool for exploring spatio-temporal data.

1.2. Background

To discover dynamism usually large volume of data are needed and it can be best visualized through animation. In animated maps temporal characteristics of change can be viewed in a running animation mode in display time. This type of dynamic representation seems helpful for visual exploration of the data and domain expert can explore the processes, relationship, trends, and causes using associated interactive tools. Dynamism and interactivity became the most identifying traits of visualization tools. Interactive techniques allows user to explore the more information. The most common visualization tools for interaction are zooming, panning, rotating, layers on off can be considered as the basic display tools. Orientation and navigation tools help user to know the location of the view and the meaning of symbols. Querying is the most important tool to interact with data which enables the user to answer queries like when, what, and where clause. Apart from these, multiscale, re-expression, multi-

ple dynamically linked views are also very effective tools for interactivity. Animation can also be considered as an important tool for the analysis of complex dynamic phenomena. All these tools are essential for interactive techniques.

Interactivity can be ranked in various way, e.g. according to functional complexity. In a geovisualisation environment five levels of interactivity tasks can be seen: examination, comparison, reordering, extraction and testing cause and effect (Crampton, 2002). Usually when user start to look at the object from multiple perspectives it indicates that he is examining or inspecting something. Comparing includes simultaneous data display like “small multiples”(Crampton, 2002). In the case of reordering user can dynamically allocate data according to some threshold value. “Extracting or highlighting and suppressing or filtering the data occurs when the user identifies a subset of data and wishes to highlight or delete it”(Crampton, 2002). In the case of exploring the cause and effect relationship user can dynamically manipulate the datasets. For example relationship between vegetation and rainfall data can be visualized through dynamic linking (like scatterplot with map) interactive technique. In this case change in one dataset will reflect change in another dataset.

Crampton (2002), identified four types of interactivity

- Interaction with the data representation (e.g. orientation of data, rescaling)
- Interaction with the temporal dimension (e.g. Navigation, Toggling)
- Interaction with the data (e.g. Querying, Brushing)
- Contextualizing interaction (e.g. Multiple views, Linking)

Most of these type of interactivity are applicable for dynamic or animated maps. All interactivity is related to the elementary components of spatial data: location, thematic attributes and time.

Although different types of interactive techniques can be applied in a geovisualisation environment, integration of these techniques with animation for the representation of temporal data is not common yet. If we want to investigate their usefulness in relation to animation, we must realize that interactive tools can support information exploration only when tools support user tasks and users are able and willing to utilize those tools properly. Therefore effectiveness of visualization tools is also an important issue.

1.3. Problem Definition

In the present scenario (e.g. on the web), animation is mainly embedded with basic media player functionality like, play, pause, backward and forward. But those techniques are not enough to answer a number of common questions about spatio temporal data. For example during the animation mode if user wants to know-‘How did the value of a pixel change from one moment to another moment?’ or ‘How do characteristics of change vary from one moment to another moment?’ In some application like “Earth Systems Visualizer” temporal focusing and temporal brushing have been added to animation techniques for the exploration of linear and cyclic time. Blok (2005) concentrates on interaction with the variables of the temporal dimension. Research on linked graphics, valuable for exploration of static maps, is still missing for animation.

1.4. Prior Work

There were a number of researches about interactive techniques. An attempt is made to review some of the selected research regarding dynamic visualization tools and usability of those tools.

Symanzik et al (1996) made a prototype to achieve a linking between maps and statistical graphics by using Arc View and X-Gobi. In his prototype an analyst can brush points in either Arc View or X-Gobi an corresponding points highlighted using same colour in another application.

William Acevedo and Penny Masuoka (1997) also describes Time Series Animation Techniques for Visualizing Urban Growth in which landuse changes for Baltimore-Washington region were generated by showing a series of images in sequential order. They made sophisticated animation by interpolating between the original data in order to create a smooth continuous change. They made three types of animation for visualizing the urban growth, those are two-dimensional planimetric, three dimensional perspective animation with a fixed viewpoint and with a moving viewpoint.

Gennady L. Andrienko & Natalia V. Andrienko (1999) made a software called DESCARTES which support automated presentation of data on maps and interactive manipulation of these maps. The system designed to support visual exploration of spatially referenced data. In this system user can manipulate the data according to their needs. This system provides number of data presentation methods that are suitable for user selected data. It supports different spatial objects and attribute data. It represents dynamic choropleth maps. The main utility of this software is that it is designed for the people from various disciplines.

Mark Harrower (2000) made a prototype called VoxelViewer, which support exploration of the effects of temporal and spatial scale in multi-temporal satellite imagery. It is also designed to support visual exploration of the data and observation of changing features over time and space. It is built in Macromedia Director 8. The system incorporates two types of dynamic spatial and temporal tools through users are able to adjust pixel size from 10 to 250 km and temporal interval from 10 to 80 days.

Mark Harrower, Alan MacEachren & Amy L. Griffin (2000) made a geographic visualization tool to support Earth Science Learning. It is designed to support learning about global weather. In this tool they used temporal focusing and temporal brushing. It shows both linear and cyclic changes by producing dynamic and interactive map animation. The tool provides an opportunity to explore the complex spatial and temporal aspects of continuous changing phenomena. They assessed their tool based on focus group results.

Patrick Job Ogao (2002) in his PhD addressed a theoretical concept about effective exploratory temporal cartographic animation, which enable user to extract geospatial information. He made an attempt to define the functionalities in cartographic animation. His work addressed inference based animation, which represents the cognitively modelled interactive animation. He has also mentioned a formal evaluation methodology for identifying users thought process.

In the above mentioned researches focuses mainly on cartographic animation or dynamic mapping with statistical graphics. Still in each case use of interactive techniques play a major role. But little attention was focussed on the combination of animation with different graphical techniques.

1.5. Motivation

Based upon the problem definition, the research is focussed on integration of interactive techniques with animation for the exploration of spatio temporal data. The main focus is to develop a method and associated tools to support animation with linked graphics, and build and evaluate a prototype. As a case study it will be applied on temporal data.

Temporal data are widely used in monitoring purposes. In digital image processing temporal data are generally used for change detection. The changes are generally visualized using static maps. In this research an attempt has been made to develop an interactive animation technique includes animation with linked graphics for the representation of spatio-temporal data.

1.6. Objective

The main objective is to develop

- A method and tools for the use of graphics linked to animation,
- To build prototype and
- To evaluate its usefulness to support visual exploration of NDVI time series.

1.7. Research Questions

- Which aspects of data are best represented in the graphics?
- How to represent these data graphically?
- Which interactive tools can support exploration of the linked graphics?
- How should the animation and linked graphics be designed in a common interface?
- What kind of interactivity can be added to the interface to enable visual exploration?
- How to evaluate the effectiveness of a proposed system?

1.8. Research Methodology

The following methodologies would be used to help answer the research questions stated above:

Conceptual level:

1. Initial phases of the research will be to review the characteristics of spatio-temporal datasets and identification of a particular temporal data for the study.
2. Comprehensive literature review would be used to investigate the types of exploratory visualization techniques for analysis and representation of spatio-temporal datasets.
3. Selecting existing interactive techniques, which can be useful for solving the user tasks.
4. Investigating the probable software, which is suitable for interactive visualization of spatio-temporal data.

Operational level:

1. Designing effective interactive technique with emphasis on animation with linked graphics using existing tools.
2. And also assessing all these techniques, which support the elementary task.

Implementation level:

The third phase encompasses the creation of a prototype that shows interactive functionalities identified in the operational level. It will be designed for exploration of complex natural phenomena.

Testing level:

Assessment of the method/tool by a suitable usability evaluation method.

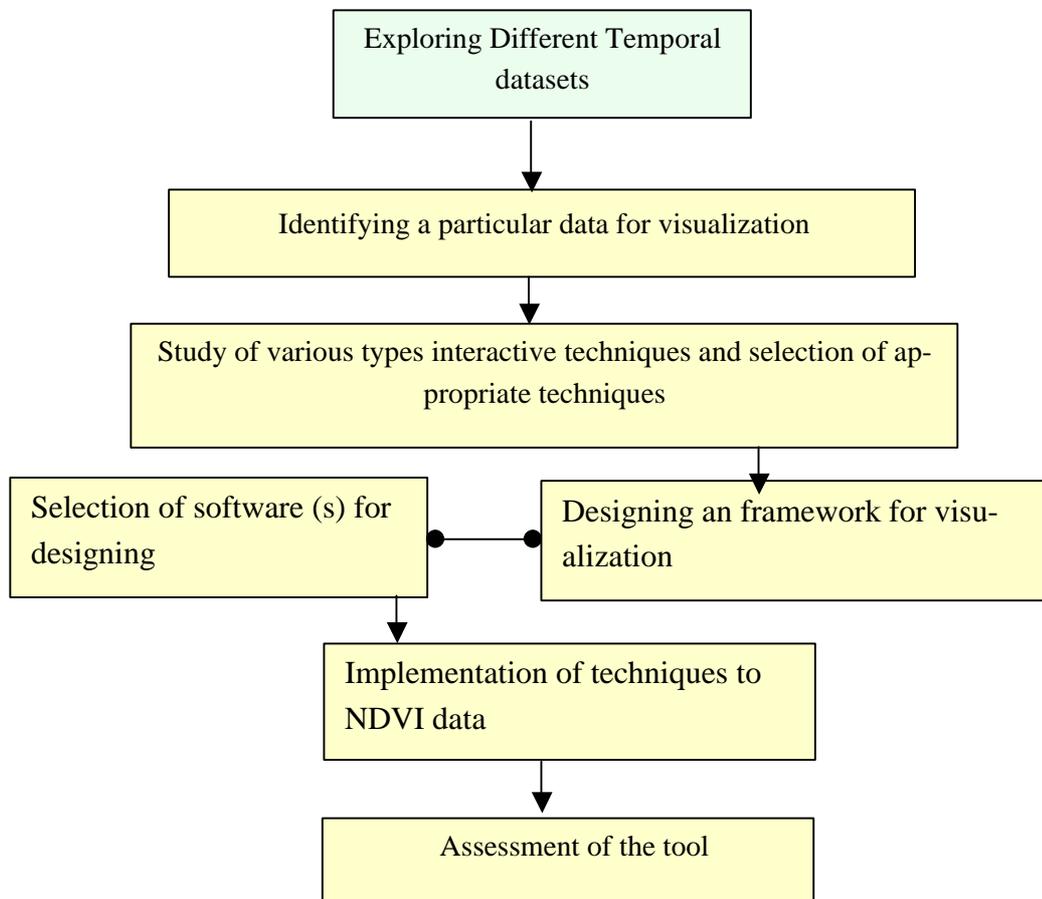
Diagrammatic Representation Of Methodology

Figure 1.2: Methodology Flowchart

1.9. Structure of the Thesis

The thesis is organized as follows:

Chapter1. Introduction gives an overview of research work, problem definition, motivation, research questions, and methodology and thesis structure.

Chapter2. Representation of Spatio-Temporal data describes the review about characteristics of spatio temporal data, users requirements and different way to represent those datasets, assessing the utilities of all those techniques.

Chapter3. Animation as visualization presents the significance of animation and place of animation in cartography. In additional to this different form of animation and application of those forms for the representation of spatio temporal data has also described.

Chapter4. Application of animation with linked graphics for the representation of spatio-temporal vegetation data includes nature and characteristics of spatio-temporal vegetation data and representation of different aspects of this data. In this chapter a conceptual framework has designed for the representation of temporal vegetation data using animation with linked graphics.

Chapter5. Prototype Design includes development and design of ‘TEMPVIZ’ using animation with linked graphics for the representation of temporal vegetation data.

Chapter6. Usability Evaluation includes prototype evaluation using combined methods of focus group and questionnaires. The combinations of these two methods help to evaluate the usability of the prototype ‘TEMPVIZ’ in a qualitative as well as quantitative manner.

Chapter7. Conclusion and Recommendations.

2. Representation of Spatio-Temporal Data

2.1. Introduction

This chapter highlights the characteristics of spatio-temporal data, which represents the spatio temporal phenomenon of the earth surface. The use of spatio-temporal data is increasing day by day specially for monitoring and change detection studies, hence different techniques to visualize such type of datasets is also evolving. The changing distributional pattern of object is not easy to represent through traditional cartographic methods. Thus different techniques have emerged in the field of cartography and geovisualization. The study deals with representation of spatio temporal data and the different exploratory technique for visualizing the changing phenomena is discussed in this chapter in detail.

2.2. Characteristics of Spatio-temporal Data

On the earth surface each phenomena is dynamic that is changing from time to time, some phenomena takes shorter period (e.g. vegetation growth) and some are longer (e.g. geological change). All these phenomena involve number of complex physical processes. These processes vary spatially and temporally. To study these complex processes advanced statistical and computational modelling were used by geographers to explore and understand how geographic system function.

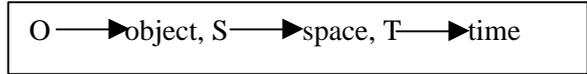
In today's world effort is being made to collect the information about these complex processes through earth observation satellites. To monitor, explore and analyse different geographic phenomena, spatio-temporal data plays a major role. The analysis of spatio-temporal data helps to predict the future, analyse the changes, do trend analysis, model generation and effect estimation (Blok, 2000). Numbers of analytical and computational functions are used for the analysis of spatio-temporal data. Graphic representation is one of the ways to analyse and explore the data. In geovisualization environment graphic representation (e.g. static maps, maps combines with graphs, dynamic maps etc.) of spatio-temporal data is based on two aspects. One is characteristics of the data and other being users needs which is an important aspect.

A comprehensive understanding of spatio-temporal phenomena is necessary before representing the complex geographic phenomena. Geographic phenomena are dynamic in nature and it is related to space and time. Dynamism can be conveyed by change in the states of objects.

According to Baher El-Geresy and Christopher Jones (2000), “ three possible types of change can be distinguished,

- I. Spatial change in which spatial properties of an object transforms from one state to another state.

i. $ST1 = (O1, S1, T1) \Rightarrow ST2 = (O1, S2, T2)$



- II. Non-spatial change where non-spatial properties of an object transform from state to state.

i. $ST1 = (O1, S1, T1) \Rightarrow ST2 = (O2, S1, T2)$

- III. Total change where both spatial and non-spatial properties of an object transforms from state to state.”

i. $ST1 = (O1, S1, T1) \Rightarrow ST2 = (O2, S2, T2)$ (Geresy & Jones, 2000)

In the first case of change object is same only its spatial property has changed in time. For example movement of vehicle changes its position from time to time. Pedestrian movement is another example. In the second case object has changed in time but its spatial property is same. For example changes in sea surface temperature, where temperature is the object, which changes in the same sea surface that is spatial property in different time periods. In the third case object changes both with reference to space and time. For example a specific type of forest cover has changed after deforestation of that area. Changes occurred on the earth surface in different geological era is also an example of this type of change.

According to Yattaw “geographic phenomenon may change aspatially, spatially or in both attributes”. All such changes are related to temporal and spatial dimensions. In temporal dimension changing pattern can be homogenous, majoritative, occasional and wholistic (Yattaw, 1999).

Homogenous changes are continuous changes where without any abrupt interruption the pattern of change is same. For example sea surface temperature is a continuous event but sometimes due to global warming the pattern of change varies from place to place. Majoritative and occasional changes are noncyclical processes where changes appeared in two time periods are totally different from each other. Wholistic change is a single time change.

According to Yuan, (1995) there are six major types of spatial and temporal changes can be observed:

- “1) For a given site where occurrences and duration of events change from time to time.
- 2) For a given point in time where a certain phenomenon change its characteristics from site to site.
- 3) For a given period of time where attributes change from site to site.
- 4) For a given event where its characteristics or processes change at sites.
- 5) For a given area where attribute changes site to site and from time to time.
- 6) For a given event where its location changes from time to time.” (Yuan, 1999)

According to Peuquet spatio temporal data involves space (where), time (when), and objects (what) (Peuquet, 1994, cited in Andrienko et al., 2002). It can be explained as, during a specific time at a particular place an object can change its characteristics or an object can change from time to time at dif-

ferent places. The other one is object and location both is changing from to time. It can be explained as:

When + where → what
 When + what → where
 Where + what → when (Andrienko et al., 2003)

Based on this, the questions can be framed as:

- What is the object present at location ‘l’ during the time ‘t1’?
- Where is the location of object ‘o’ at time ‘t1’?
- When the object ‘o’ occupied the location ‘l’?

All these questions are very common while dealing with the analysis of changing spatial distributional pattern. Hence to answer these questions a proper visualization is essential which can be helpful for monitoring the dynamics of the object.

Changes of spatial objects and phenomena can be either discrete or continuous. When a phenomena moves uninterrupted it is said to be continuous, when it is discontinuous and stops periodically it is said to be intermittent and when frequency of the movement is predictable then it is said to be cyclic (Yattaw, 1999). All discrete and continuous phenomena can again be classified according to the occurrence of an object at a particular place, time of occurrence and nature of occurrence.

Thus changes in the spatio-temporal datasets can be categorised according to spatial domain and temporal domain.

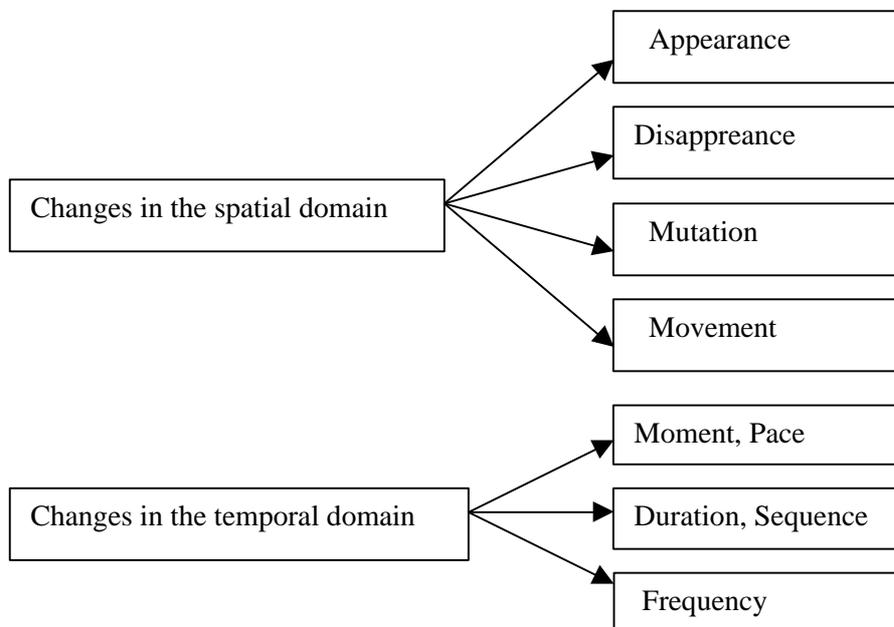


Figure 2.1: Characteristics of Change in Spatial and Temporal Domain (Source: Blok, 2000)

In the spatial domain an object may appear or disappear within a certain a time period, it may change its characteristics from time to time and may move at different positions. But the natures of all these changes are different in different time periods. It can change at a particular moment and the rate of

change also varies in time. While duration of changes between two time periods varies. On the other hand sequence of change is also varies spatially (Blok, 2000). All these types of spatio temporal dynamics are important for monitoring a particular event. For example to monitor the forest cover, study of vegetation growth rate, changing number of different species, area covered by forest all are important aspect. The changing patterns of all these phenomena are not equal. But certain spatio temporal characteristics are same for all types of datasets, which are dynamic in nature.

Then spatio-temporal data can be classified according to temporal properties:-

- a) Existential changes
 - Appearance (e.g. new settlement, tornado)
 - Disappearance (e.g. changing coastline)
 - b) Changes of spatial properties
 - Location (e.g. vegetation growth, urban growth)
 - Geometry (e.g. extension of an urban area)
 - c) Changes of thematic properties
 - Attribute (e.g. changing NDVI value, population growth)
- (Andrienko et al., 2003)

All these properties of spatio-temporal data are significant for studying the geo phenomena. After exploring the above aspects of spatio-temporal changes, it is clear that only three aspects of spatio-temporal data are important for designing the visualization tool, which are:

- a) Nature of object
- b) Location of the object
- c) Time of change

Numerous dynamic geophenomena can be observed over the earth surface, which has all these three aspects. Each phenomenon has its own characteristics and importance, such as landslide, earthquake, changing river course, vegetation growth, changing coastlines, tornadoes, flood, urban sprawl etc. Significant amount of research in the field of remote sensing has been carried out to study all these dynamic phenomena, which are relevant for monitoring and generally analysed by using computational functions. The alternative way to explore and analyse the data is graphic representations. In this case geographic visualization plays a role to visually explore the data. While designing a visualization tool for visually exploring and analysing of spatio-temporal data it is necessary to understand all the above facts in addition to users requirements.

2.3. User's Requirement for Exploration of Spatio-temporal Data

To study the spatio-temporal data users have different and distinct needs. It varies between presentation and exploration of data. "The needs are made up of series of tasks or a list of processes that are undertaken and invoked within the confines of the users thought processes"(Ogao, 2002). For example, in the field of forestry a user would like to use the spatio temporal NDVI data for monitoring the vegetation growth, for understanding the phenological pattern of different vegetation species and to discriminate them, for calculation of biomass, to classify the land cover and to identify the cropping pattern etc. (From a discussion with faculty and researchers working in the field of forestry at IIRS).

In this case the user may use different statistical operations in order to achieve the above objectives. In the field of geovisualization to explore these events numerous techniques could be applied for the exploration of spatio-temporal characteristics.

As the needs of users stretches into the exploratory paradigm the nature of the representational techniques are also changing and exhibiting more interactive operations (Ogao & Kraak, 2002). “For exploratory purposes there should be some techniques that allow the user to look at data in any combination, at any scale or resolution with the aim of seeing or finding hidden spatial patterns”(Ogao & kraak, 2002). The same type of datasets could be visualized by a number of techniques and user’s task may not be limited by one or two techniques.

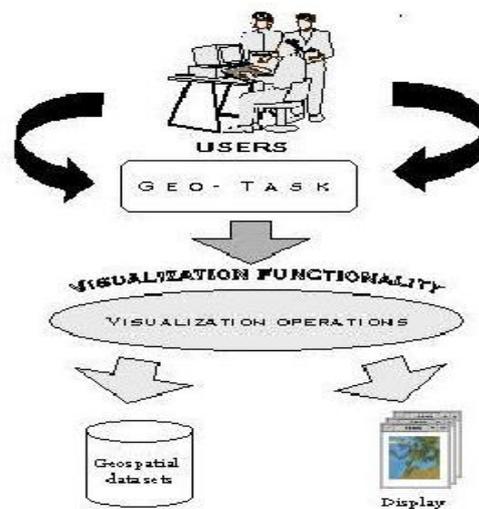


Figure 2.2: The Role of User Task in an Exploratory Visualization Process (Source: Ogao, 2002)

Figure3 illustrates the role of user’s task, where these tasks are based on visualization functionalities for exploring the datasets. It may require the use of a number of visualization operations or combinations with other alternative tools to explore the datasets. For example to explore the temporal datasets static techniques may not be able to fulfil the user’s task. Alternative techniques (like linking between maps and different datasets, interactive manipulable maps etc.) could be applied for this type of datasets. “Identify, locate, associate and compare form the basic visualization operations that are widely used for analysing spatio-temporal datasets”(Ogao, 2002). All these operations enable users to explore and analyse the datasets with the help of a definite process and find some conclusion.

Hence user’s requirement for studying the dynamic events using spatio-temporal datasets is an important aspect along with data characteristics during the designing phase of visualization tool. For example, if a tool is developed for visualization of temporal NDVI data using animation, without considering some of the user’s need like extensive query operations related to locational and attributinal changes, linking with other climatic database, then the visualization tool would be simply an attractive animation movie with all kinds of basic display functionalities but will be of no use to the user, in terms of applicability.

2.4. Exploratory Techniques

Before designing visualization tool a proper understanding of exploratory technique is required. There are numerous techniques for representing geospatial data but applicability of all these techniques are based on nature and type of data. In the field of modern cartography ‘interactivity’ and ‘dynamics’ are the new term for the development of computer based visualization tool for the representation of spatio temporal events (Andrienko et al., 2003). Hence to represent and analyse the spatio temporal events number of techniques can be applied.

(a) Techniques applicable for the representation of all types of time series data

Mapping of time series data means “mapping change”(Kraak & Ormeling, 2003). To demonstrate the changes in a map in terms of feature, attribute or both, static and dynamic both types of techniques are applicable. Different graphic variables and symbols are used to show the changes in case of static mapping. According to Bertin (1983) basic graphic variables are size, value, texture, colour, orientation and shape. Some other researchers have added saturation, transparency and fuzziness. For example in case of urban area, development of new area could be represented by darker colour and older one by lighter colour or different symbols can also be used. According to DiBiase et al. (1992) and Koussoulakou & Kraak (1992), if dynamic variables used in individual frames of an animation the images will effectively communicate the cartographic message to the user while the movement of animation gives the information by an extra dimension (cited in Kobben & Yaman, 1995). Alternatively temporal events can also be represented by series of static maps. But this method is not useful in case of large datasets. It is useful for comparing the two state of change at different time moments. Temporal events can be represented in the form of animation where changes can be perceived in a single frame by displaying several snapshots one after the other (Kraak & Ormeling, 2003). In case of animation graphic variables and dynamic variables both play a major role to represent the data. According to DiBiase and MacEachren the dynamic variables are display time, duration, order, frequency, rate of change and synchronization (cited in Blok, 1998). In creating animation using geodata both graphic variables and dynamic variables are used to represent the data. Three-dimensional maps are also useful for the representation of temporal datasets.

Time series data have been traditionally represented with statistical diagrams, with time as the horizontal axis and a single variable as the vertical axis (Mark Monmonier, 1990). Monmonier addressed number of visualization strategies for the representation of time series data. Such as Cartographic cross classification array can be used where instants of time and number of attributes are small, b) Point symbols or glyphs can be used for a single variable observed at different periods of time, c) Isochronic lines are well suited for showing the trend, d) Flow maps are used to show the movements, e) arrow symbols are useful for showing migration streams. Apart from these techniques the most widely used techniques are scatter plot and line graphs. Other alternatives are box plots, parallel coordinate plots and chernoff faces (Kraak & Ormeling, 2003).

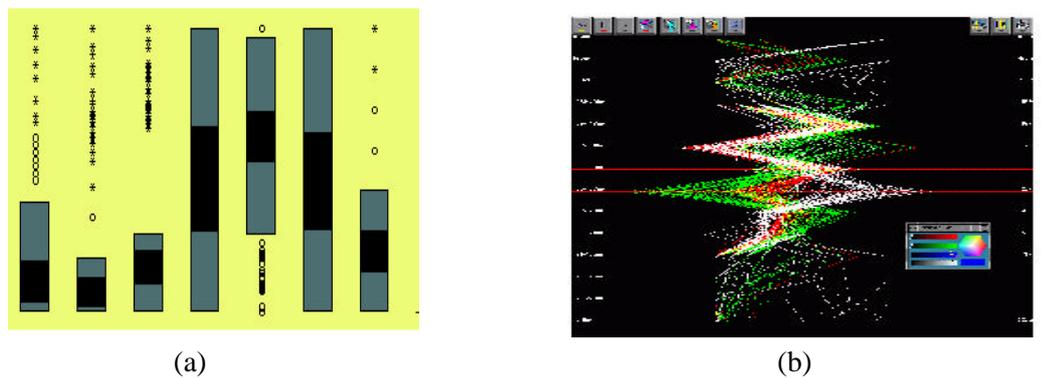


Figure 2.3: (a) Box plots (b) Parallel co-ordinate plot (Source: Taken from technical report by Wilhelm et al.)

Box plots give a graphic summary of the distribution of a phenomenon and parallel coordinate plots are able to display multi-dimensional data in a single representation. Chernoff faces are also used to visualize multivariate data. All these graphic techniques are more useful when they are linked with maps.

(b) Techniques applicable for the analysis of time series data

The analysis of time series data is based on characteristics and nature of the data. Various types of techniques are applicable for the analysis of time series data. The major techniques are Querying, Animation, Focusing, Linking Views, Small multiples, Juxtapositioning of several maps, Multiscale and Reexpression.

- Query tool is capable of answering user's questions concerning data under analysis. It works based on two principal ways one is look up and second one is filtering. Look up means to provide requested information in addition to present information on the screen. Filtering means to remove the data from the user's view that do not satisfy the query constraints (Andrienko et al., 2003). Direct look up technique is another way to query in the datasets. Change measurement can be achieved by using this method. In this case the user points on an object/location on the map with the mouse cursor and corresponding values are displayed on the screen. Apart from this user can directly access the database through simple querying.
- Animation is most suitable for depicting trends and processes and provides insight into spatial relationships. It is much more useful when the number of functionalities increased. Minimum functionalities like forward, backward, slow, fast, pause sometimes are unable to show the spatial relationship in a proper way.
- Juxtapositioning of maps is one of the techniques for representing change. "In this case different windows may be juxtaposed in order to view multiple perspectives on the data"(Crampton, 2002). But it is insufficient to measure the amount of changes in different period of time.
- Dynamically linked views help the user to view and interact with the data in different windows. It is most valuable for the analysis of changing spatial and temporal properties of data. One can incorporate maps but video, sound, text using linked views (Kraak & Ormeling, 2003). In this case clicking an object in a particular view will show the corresponding spatial relationship in other views.

- Brushing is a useful technique to explore correlations between statistical and geographic patterns. It can be temporal, geographical and statistical. Geographical and statistical brushing is linked with each other. In this a brush like feature is used across the map and when it brushes over an area the corresponding values are highlighted either in scatterplot or any other graph. Temporal brushing is useful to see the temporal patterns.
- Toggling is useful to see changes between different time periods. It is just like switching back and forth between time periods (Crampton, 2002).
- Small Multiples are array of simple graphics. Maps or graphs of different time periods can be shown by this technique. It is helpful for comparison of nature of change between different time periods.
- Re-expression is another technique to represent the same datasets in a variety of way. For example population growth can be shown either by simple bar graphs or by choropleth map or by 3d bar graphs. It is helpful to explore the datasets in different combination and different scale. The combination of all views improves the understanding of datasets.

The study concentrates on design a visualization tool using animation with linked graphics, hence understandings of all the above-mentioned techniques is important. From the above discussion it is clear that different aspects of spatio-temporal data can be represented through use of different exploratory techniques for making it effective tool. For a designer/cartographer it is important to know what he is designing and for whom he is designing. After proper understanding of nature of datasets cartographer or tool developer will be able to select a suitable exploratory technique to create an effective visualization tool.

2.5. Summary

The chapter outlined the nature and characteristics of spatio-temporal data. It varies within different datasets. Different events have different characteristics and hence ways of representation of all these events are not same. Hence, this research also concentrates on understanding of the temporal datasets before designing the visualization tool. In the field of geovisualization number of techniques are exists for representation of all those phenomena. But the applicability of all these techniques are depend on nature of datasets and users requirement for analysis the data. This research focuses on animation for visualization of spatio-temporal data, hence different animation technique and its significance needs to understand before going to develop a visualization tool.

3. Animation As Visualization

3.1. Introduction

The spatio-temporal data provides information related to locational, attributinal and geometrical aspects. One such visualization tool, which can be used to visualize the above data characteristics, is through animation. The chapter highlights the significance of animation as a visualization technique its applicability in the field of cartography and different types of animation techniques. The possibility of using animation for representing geospatial data in a temporal dimension is also discussed in detail.

3.2. Why Animation?

The word animation means, “motion” or “to give life to”. It is an attractive graphic art that creates a time sequence or series of graphic images together to give an appearance of continuous movement. The benefit of graphic is that, it is easy to comprehend, easy to learn and gives insight about the object. “An object’s position and orientation are obvious candidates for animation”(Ogao, 2002). According to Halas & Manwell (1968) “animation is a technique in which the illusion of movement is created by photographing a series of individual drawings on successive frames of film”(cited in Ogao, 2002). This technique describes the motion of an object and its behaviour. The motion of an object can also be represented through static form. But it represents one moment at a time. For example trend of sea surface temperature can be shown by static form but in this case number of static maps are required. It is not a feasible way of representation. To view such continuous change or trend, animation can be used realistically. In today’s world it has become an important tool in the field of geovisualization. But here lies the question, what are the salient features of animation? Holistically:

- It provides a unique method of visual communication.
- It is more effective in understanding trends and processes as it represents complex system in a simpler way.
- It has narrative character.
- It provides detailed information about the fine structure of the processes.
- It is useful for displaying continuously varying phenomena.
- It has an aesthetic appeal.

All the above-mentioned characteristics create a niche to represent events, facts and phenomena of earth surface. In the field of geovisualization it has become an important technique to represent the geospatial datasets. Even though it is based on computer graphics, its significance in geographic information system especially in cartography is increasing day by day.

3.3. Animation in Cartography

Historically the production of animated maps witnessed three eras: 1) manual, 2) computer assisted and 3) computer based (Harrower, 2004). Pioneered by Waldo Tobler, the first computer assisted map was created in 1970, in which he represented simulated urban growth in the Detroit region. With the development of numerous digital technologies computer based mapping came into existence. The evolutions in computer animation are as follows:

- In 1963 first computer animation started.
- In 1970 super computer digital animation created.
- In 1980 workstation digital animation started.
- In mid 80s shelf animation software came into existence.
- In 1990 desktop digital animation started.

The use of animation in the field of cartography started in the year 1960. Proper cartographic animation started in the year 1980. At present it is tied up with GIS technology, as animation can be very useful for depicting and analysing trends and processes as well as in providing insight into spatial relationships. “In GIS environment animated cartography deals with processes as a whole and it is not just visualization methods and techniques but also database issues as well”(Kraak & Ormeling, 2003).

At times, the potentiality and evolution of animated mapping has been described by Thrower (1961), Moellering (1972-1980), Tobler (1970), Campbell & Egbert (1990), Peterson (1994, 1995), Acevedo & Masuoka (1997) and Mark Harrower (2000). For example Moellering used animation to show the growth of population in United States. His work addressed two kinds of use of display time, one was real time display and another was changing viewing perspective. His work was related to animating traffic accident data of Detroit. Peterson highlighted the use of java script, hypercard, animated gif for the development of animated map. Thrower mentioned possibilities of animated mapping which is not a substitute of static mapping (Harrower, 2004). Acevedo & Masuoka highlighted the interpolation method for creating smooth frame based animation in case of representation of long time periods where some datasets are missing between certain time intervals (Acevedo & Masuoka, 1997). Conceptual design and use of animation in cartography has been formulated by Monmonier (1990), DiBiase et al. (1992), Kraak & Ormeling (1995), MacEachren (1995) and Blok (2005). For example Monmonier proposed graphic scripting mechanism and DiBiase proposed the use of dynamic variables for cartographic animation (cited in Peterson, 1994). According to Blok et al., “animated mapping allows a person to see the data in a spatial as well as a temporal context”(Blok et al., 1999).

Major research in this field has been carried on animation of time series data, methods for animating attribute data, representation of uncertainty and data quality in animated maps, interactive animated legends, use of dynamic visual variables in temporal dimension and methods of temporal interpolation for smoothing the sparse datasets and use of temporal focussing and brushing with animated maps.

Some of the above researches have emphasized on representation of change in temporal dimension. Cartographic animation can visualize changes of geospatial components. It is a useful technique to depict the changing interrelationship between two variables (e.g. causal relationship between rainfall and vegetation), changing pattern of environmental phenomena (e.g. vegetation growth, sea surface temperature), changing landuse due to encroachment of settlement. In addition to all these researches cartographic animation can be classified as under.

3.4. Classification of Cartographic Animation

The classification of cartographic animation is based on two aspects: one is representation of time and another is creation of animation.

- In case of first category it is classified as temporal and non-temporal animation. In temporal animation “display time is used to visualize real world time in a temporal sequence”(Kraak & Klomp, 1995). Examples of these animations are changing river course. This animation mainly shows changes of all components of geospatial data in time. “Temporal animation can be used to view environmental transitions as they happen in time as opposed to simply viewing the snapshots of the processes or their end states”(Ogao, 2002). Temporal animation is limited to the display of change over time. Time series animation is a visualization technique in which each image represents one moment in time. It can be classified into two dimensional planimetric animation, three dimensional perspective animations with a fixed viewpoint and three-dimensional perspective animation with a moving viewpoint (Acevedo & Masuoka, 1997).
- Non-temporal animation consists neither of movement nor change through time. “It shows change that is caused by factors other than time”(Peterson, 1994). Here display time is not related with world time. Fly-through is an example of non-temporal animation. According to Dransch (1992) (cited in Kraak & Klomp, 1995) non-temporal animation can again be subdivided into time series animation, successive build-up and changing representations. The complex environmental processes can be represented by successive build up animated frames. In changing representation the same data can be represented in a number of way like it can be represented through different symbols or by different classification methods. Non-temporal animation can include all forms of cartographic animation.

Cartographic animation can be created into two ways:

- Frame based animation in which individual frames can be created by graphics, mapping or GIS program (Peterson, 1994). In this case many frames are required for a few seconds of animation and illusion is created by displaying those frames quickly.
- “Cast based animation is based on the concept of the ‘cel’. A cel is an individual layer of a frame of animation and a frame can be composed of many layers. A frame of an animation can consist of a background cel and a series of foreground cels containing an object that can be made to move on the background”(Peterson, 1994).

Among the above mentioned techniques frame based animation is most easy to create and cast based animation is time consuming but can be use for a display of large datasets.

3.4.1. Different Cartographic Animation Techniques

The simple animation technique is to display the original cartographic data sequentially and sophisticated animation techniques used interpolation method to create the intermediate frame for better visual perception (Acevedo & Masuoka, 1997). In both the cases the purpose is to represent the data in such a way that viewer can able to get “an impression of continuity if the difference between successive frames is not too large and the correct display speed is chosen”(Blok et al., 1999). Simple anima-

tion is embedded with basic media player functionality like play, backward, forward and pause. It is interactive but limited only to basic functions. While in the first case, viewers can modify the sequences or frames, interactive animation employs an environment where user can control, manipulate the animation in different combination. To add more interactivity it includes number of functionalities of geovisualization like basic media player functionality, active legends, switch off-on layers, additional controls like zoom in, zoom out, panning in the form of buttons with simple animation. Another type is dynamically linked views where “main view is supplemented by alternative synchronized views of either the thematic or geospatial attributes of the subject”(Ogao, 2002). Temporal focussing and brushing are also the tools that can be used with animation. Temporal focussing helps to represent the linear characteristics of time and temporal brushing brings out the cyclic characteristics of time. In Earth System Visualizer these functionalities have been added (Harrower et al., 2000). The use of sound, text and video also play an important role in case of interactive animation. In addition to all these interactive techniques dynamic and visual variables also has an important role for designing the effective animated maps. Changing graphical variables can be used to represent the changing characteristics of data in individual animation frames (Blok et al., 1999).

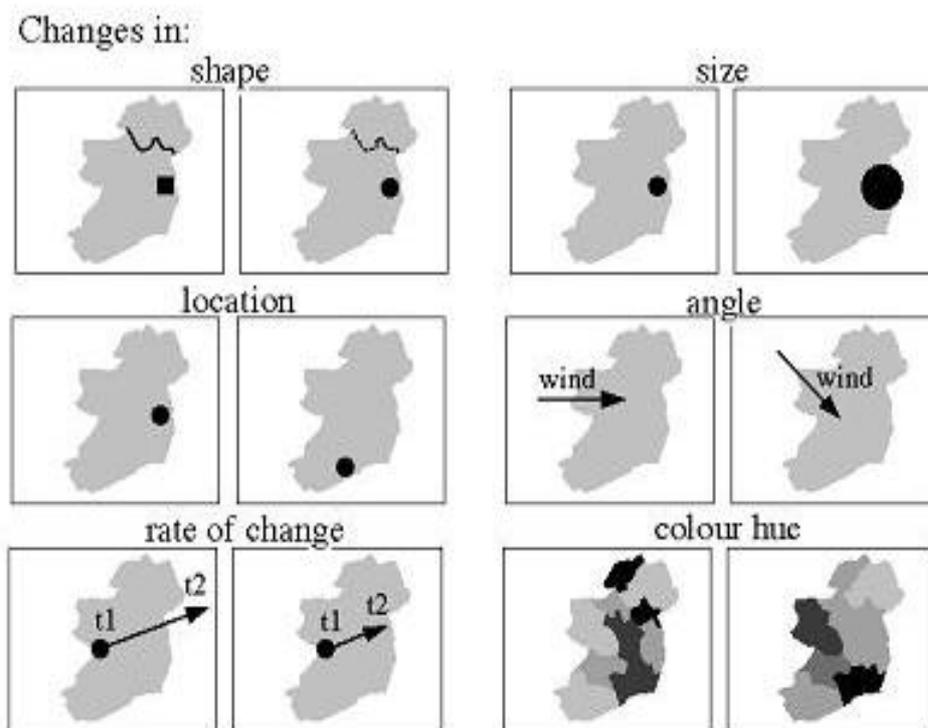


Figure 3.1: Visual Variables (Source: Hayward, 1984. cited in Ormeling, 1995)

Major visual variables are size, shape, position, viewpoint, distance, texture, pattern, colour, and orientation. To represent the changing features that are basically related to object's size, shape, position these variables are taken into account. These variables added more visual impression to the animated maps.

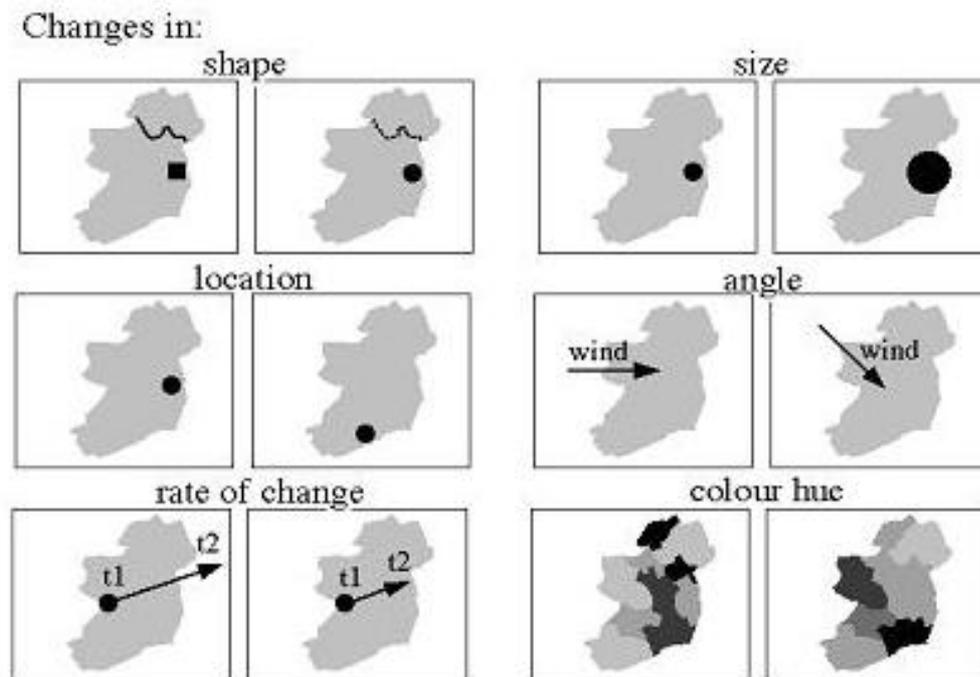


Figure 3.2: More Visual Variables (Source: Hayward, 1984. cited in Ormeling, 1995)

Sometimes only changing images fail to portray the pattern of change in those cases visual variables play an important role. For example to show the changing direction of wind number of arrows can be used to show the directional changes. In this case the symbol “arrow” acts as a viewpoint variable. Applications of these variables are based on nature of changes and characteristics of datasets. These visual variables can again be subdivided into more specific categories like colour; it varies in hue, value and saturation. Texture changes according to directionality, size and density. While pattern consists of shape, element, texture, size, and arrangement. It implies that some variables are composite of other variables. Crispness, resolution and transparency are another type of visual variable (Blok, 1998). All these variables can be effectively use for the representation of change and also uncertainty in animated mode. For example, changing NDVI value can be visualized better by using different colour varies in hue, value and saturation.

Beside these visual variables dynamic variables are also important in cartographic animation. Those are display date, duration, frequency, order, rate of change and synchronization and are defined by MacEachren (1995) (cited in Blok, 1998). Display date implies the moment of change where order is nothing but the sequence of frames displays the change at particular time. While duration indicates the length of time, frequency indicates number of identifiable states per unit of time, rate of change implies magnitude of change and synchronization indicates the temporal correspondence of two or more time series (Blok, 1998).

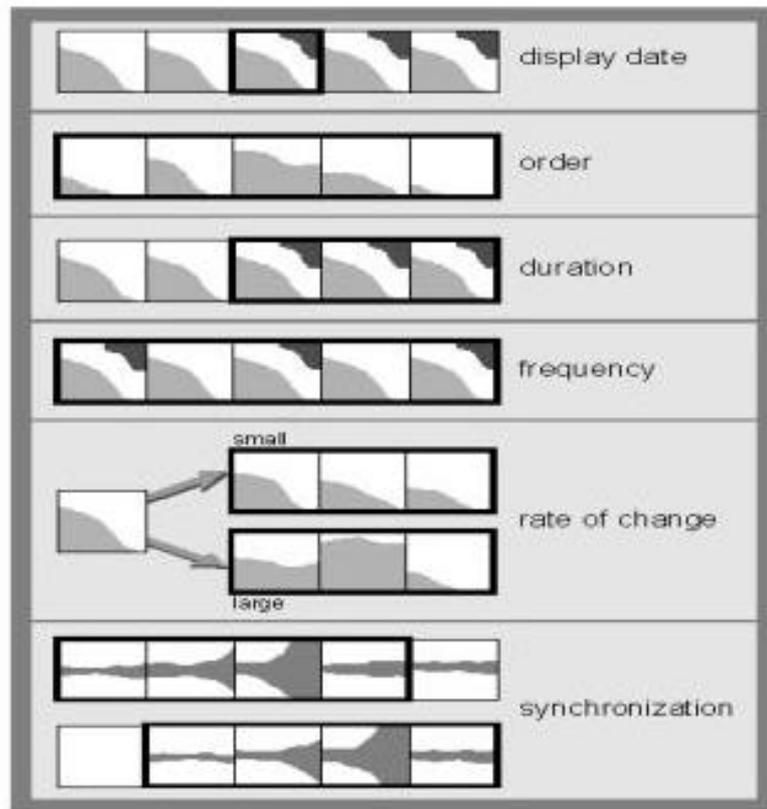


Figure 3.3: Dynamic Variables (Source: Blok, 1998)

By using all these graphic and dynamic variables animation can be more effective in terms of exploratory purposes. The most important are duration and order which have a strong impact on animation. All these variables can stimulate users thinking for more exploration. Sound can also be considered as another variable, which can relieve users from the monotonous visual attention. It can be used in animation to add more interactivensess during representation of data.

Hence cartographic animation is changing its way of presentation in a more effective way. Although number of graphical techniques can also be applied in animation which are present with static mapping techniques. Like linked graphics, database connections are important tool, which are presently available with static maps.

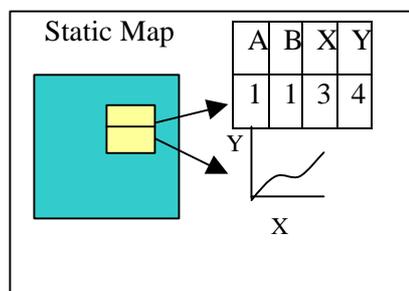


Figure 3.4: Static map with linked graphics

In the above figure it shows that a graph and database can be obtained from a static map. From a single static map the information of change area can be obtained either by using the visual variables or by linked graphs or databases. To represent the socio-economic changes this technique is highly useful. This same technique can be applied in animated map for the representation of complex geophenomena but based on nature and characteristics of data are important to apply this technique. The study is mainly concentrate on this aspect.

3.5. Discussions

The above mentioned animation techniques and types are very useful for the representation of spatio-temporal data but animation does not give an analyst an opportunity to directly compare the different state of change at different moments of time. It is sometimes too complex or too fast to be accurately perceived. According to Tversky & Morrison “the drawback of animation may not be the congruence between the conceptual material and the visual presentation but rather perceptual and cognitive limitations in the processing of a changing visual situation”(Tversky et al., 2002).

All these limitations can be overcome by using different interactive techniques with animation. Animation is suitable for representing the continuous changes rather than discrete changes. Sometimes animated graphics represent more information than static graphics. The choice of using animation to represent different aspect of environmental system is based on their resources to enhance learning, acclaimed preference to other graphical representations and ability to search operations (Ogao, 2002).

Therefore while making animation certain things are important for designing visualization those are display speed, number of animation frames, image size and animation file size. For making the impression of continuity display speed is important and it also helps user to interactively select the display speed. According to principle of apprehension “animation should be slow and clear enough for observers to perceive movements, changes and their timing and to understand the changes in relation between the parts and the sequence of events”(Tversky et al., 2002). But sometimes it is difficult to decide the number of frames and display speed. On the other hand more frames smoothen the visual perception of change and movement.

To make an effective animation the purpose of making animation and nature of datasets also plays an important role. For developing a visualization tool using animation technique the characteristics of data in terms of temporal and non-temporal dimension is to be considered. If a visualization tool is designed for a dataset having temporal dimensions with the use of techniques meant for non-temporal dataset then the tool developed will not display the actual aspects of datasets. Animated graphics is more informative than static graphics. In this case same information can be represented in different way and it will be better than static graphics. At last it can be concluded that effectiveness depends on characteristics of datasets and animation platform over which the cartographic animation is being developed.

3.6. Summary

This chapter outlines the place of animation in cartography as a new dimension to the erstwhile mapping pattern. Hence different techniques of animation help to represent the complex geophenomena in a simpler manner and which can be more informative than static representation for designing a visualization tool. Animation combined with different variables and interactivity is the best way to represent the changing phenomena. But sometimes this technique is too complex for exploring the phenomena. All these above facts helped to design the prototype in this research.

4. Application of Animation with Linked Graphics for the Representation of Spatio-temporal Vegetation Data

4.1. Introduction

This chapter illustrates the nature and characteristics of spatio-temporal vegetation data and representation of different aspects of this data. It also includes the concept for designing the interactive animation. Representation of spatio-temporal data and animation techniques has already been discussed in the previous chapters. A conceptual framework for representation of spatio-temporal data using animation with linked graphics is described in this chapter.

4.2. Temporal Data

Remotely sensed data plays a significant role for monitoring the different environmental phenomena. The data obtained through earth observation satellites plays a significant role in monitoring landuse/landcover changes as they enable direct observation of the land surface at repetitive intervals and therefore allow mapping of the extent at different time frame. Everything on the earth surface is dynamic in nature and for observing this dynamism earth observation satellites plays a pivotal role. In order to study the land use land cover changes, climate change, cropping pattern, deforestation, coastline changes, river course changes and other earth atmospheric events, spatio-temporal data is important. Data from different earth observation satellites such as, NOAA- AVHRR, Landsat TM, SPOT series of satellites (1-5), IRS-1C/1D, TERRA AQUA MODIS etc. provide useful land cover information from regional to global level. All these datasets are important to detect the changes on the earth surface.

4.2.1. Application of Temporal Data

The main application of temporal data is to identify and detect the changes in different geospatial phenomena. On the earth surface geospatial changes are either natural or man-made. Natural changes can be seasonal, cyclic, continuous, discrete and abrupt. Vegetation grows according to diurnal, seasonal and annual cycles and temporal images helps to find out the phenological variation of vegetation. Man made changes can be continuous and discrete. For example construction of dams is a sum of number of events, thereafter it can be said as a continuous change. While other examples of man-made changes are deforestation, desertification, construction of buildings etc. In this field considerable amount of research has been made about the mapping of land cover or ecosystems using

multitemporal satellite imagery. In INDIA a significant effort has been made for the mapping of landuse classification in South Central Asia using multitemporal SPOT vegetation data (Roy et al., 2000). In this time series NDVI data was used to generate the landuse/landcover map, which is in static mode. In this study an attempt is made to visualise this time series NDVI data in order to highlight the changes in vegetation pattern/cropping pattern etc.

4.3. Data Used

In this study temporal NDVI images have been used. It is derived from SPOT 4 VEGETATION data for the year 1999-2000. It has four spectral bands –blue (0.43-0.47 μm), red (0.61-0.68 μm), infra-red (0.78-0.89 μm) and short wave infrared (1.58-1.75 μm) at a spatial resolution of 1 km and temporal resolution of 1 day. It is one of the first sensors designed specifically for global vegetation monitoring. The plant pigments chlorophyll a and b absorbs wavelengths of 0.66 μm and 0.65 μm respectively in the red region and infrared wavelength reflected in the wave region 0.78 – 0.89 μm is not interfered by water absorption. This gives precise information of vegetation calculated as ratio of red and infra-red wavebands in NDVI. In this research the NDVI images generated for entire INDIA for the month of November, December, January, February, March, April, May, October and December (Roy et al., 2000). Those are used along with the landuse/ landcover map for the same region generated from the above NDVI images.

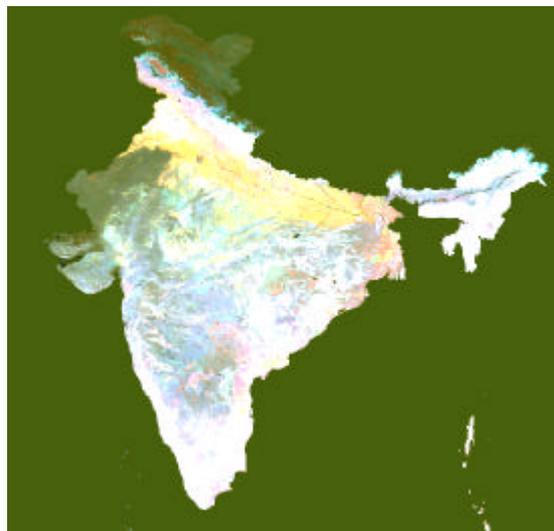


Figure 4.1: Stacked NDVI Images of Nine Months (Source: IIRS)

The dataset is in geographic latitude/longitude co-ordinate system with WGS 84 datum and spheroid. The composite images provide maximum information of vegetation and also phenological variation of different vegetation types.

4.4. Characteristics of Data

Vegetation index is a number that is generated by two or more spectral bands and indicates the amount of vegetation in an image pixel. The NDVI indicates the amount of green vegetation on the earth surface measured by a satellite. Vegetation has a low reflectance in red part and very high re-

flectance in near infrared part. When the difference between the near infrared and red reflectance is bigger the vegetation is more.

Therefore it represents the ratio of

$$\left[\frac{NIR - RED}{NIR + RED} \right]$$

The values range from -1 to $+1$. Negative values indicate water, zero indicates bare soil and positive value indicates healthy vegetation. In this study NDVI values are rescaled from 0 to 255. These are the general characteristics of the data. The specific characteristics of temporal NDVI data are:

- It is a ratio type data.
- Vegetation growth is a discrete phenomena.
- Vegetation growth takes longer time so the duration of this change event is long.
- Magnitude of change is different at different places.
- Magnitude of change is different in different season.
- Number of physical factor is responsible for changing for example climate, physiography, soil etc.

4.5. Use of NDVI

NDVI gives a measure of the vegetation cover on the land surface over wide areas. Dense vegetation appears strongly in the imagery and areas with little or no vegetation are also clearly identified. NDVI has proved to have extremely wide range of applications. It is used to monitor vegetation conditions and therefore provide early warning on droughts and famines. The NDVI data in the temporal domain helps in studying the phenological variations of different vegetation types and thereby helps in discriminating different vegetation species. The NDVI is useful in analysing the temporal and interannual behaviour of surface vegetation and developing surface background characteristics for use in-

- Climate modelling
- Global land cover classification
- Desertification studies and drought monitoring
- Terrestrial environmental monitoring
- Global water and energy balance studies
- Biodiversity characterisation.

In brief it is useful to calculate the percentage of ground cover, the total green biomass for a given vegetation types, calculation of leaf area index for crop modelling and observation of photosynthetic activity of the vegetation (Windisp manual, 1999).

4.6. Review of Different Aspects of Spatio-temporal Vegetation Data

On the earth surface all geographic phenomena is continuously changing like, atmospheric motions, sea surface temperature, socio economic events all are ongoing changes and it is difficult to identify the exact point of start and end of these processes (Harrower, 2002). These different techniques of digital image processing are valuable for change detection. Those techniques are effective to study discrete and sudden changes. For example study of change areas before and after earthquake or flood.

The final output is static. But representation of continuous phenomena in a static form is not effective. For example sea surface temperature changes can be effectively shown using animations rather than static image display. In case of monitoring the vegetation growth static image is not effective. Because through static images only one time event can be represented. The vegetation growth event is discrete but landcover changes are continuous. On the earth surface growth rate of vegetation is not equal but varies from place to place and from species to species. However summation of all such changes represent a continuous change over land. Thus representation of such continuous changes can be viewed more effectively through animation.

The data used in this research contains the vegetation reflected value. The values are not constant but changing from time to time and area to area. The values are indicated by NDVI.

For example in case of time t1 the pixel values of an area is same, in time t2 a portion of the area has changed(in the figure-7 it showing by x1 value). In time t3 more changes can be seen like in the figure7 from x, x1, x2.

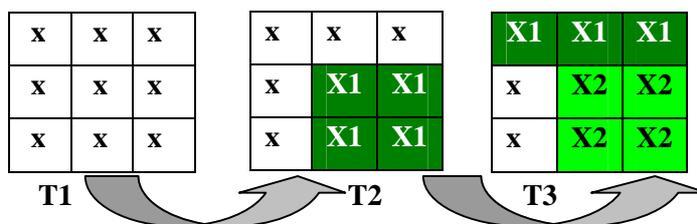


Figure 4.2: Pixel Values are Changing from Time to Time

In each successive time period changing values are not uniform and changing pattern is not uniform. In spatio-temporal data the changes are generally locational, thematic and attribute in nature. In present temporal data the changing pixel values indicate the locational changes and amount of values indicates the attribute changes. In the above figure nine cells are representing nine pixels. It is a case of SPOT-4 images. Each pixel are representing 1 km area. If one area have same type of species then it will reflect same values (e.g. in the figure 7, 4 cells are showing x1 values in t2.) and that values may change from time to time (e.g. in t3 the previous x1 values become x2) due to the chlorophyll concentration. It is applicable for other areas also. In reality different types of vegetation cover can be there within 1km area. Therefore growth rate also varies within one kilometre area. All these changes are depend upon physiography, species, climate and chlorophyll concentration. In this research the main emphasis is to represent the locational changes and attribute changes through animation.

Table 4.1: Possible Methods to show Locational and Attribute Changes

To show change or trend	Location	Attribute
Temporal Images contain NDVI	Map iteration (Animation with statistical information and positional information)	Numeric change (pixel value and spectral profile of temporal images)

In this dataset geometrical aspect is not considered. NDVI images showing complex phenomena where shape and size is not easy to identify. The main focus is to study the changing spatial distribution of objects. Changing spatial distribution is related to three basic questions. According to Pequet (Peuquet, 1994, cited in Andrienko et al., 2002) these are when, what and where. In this research dataset the where is stressed on positional aspect (at where vegetation growth rate is changing?), what indicates landuse including agriculture and vegetation type or specific species of vegetation and when indicates time and in this study it is mainly related to seasons. This study determines the detection and identification of changing spatial distributional pattern of landuse by using NDVI value at a given season.

4.7. Conceptual Framework

To fulfil the above mentioned task an attempt is being made to design a prototype for the visualization of changing NDVI. The concept is to detect the locational changes of vegetation growth rate at a given time moment and thereafter identify the spatial characteristics of vegetation. Finally evaluation of the quantum of change has also been incorporated in the prototype.

As vegetation growth rate is a continuous phenomena and its changing aerial extent is not definite therefore in this study aerial changes is not considered in case of representing the locational changes. The study concentrates mainly on about the representation of changing vegetation growth rate at different locations due to chlorophyll concentration. Hence pixel wise changing growth rate has to determine.

The concept is when one is able detect the landuse changes by changing pixel value then it becomes easier to identify the types of changing landuse by the changing nature of pixel value of particular land class. Thereafter measurement of changing vegetation growth rate is important to explore the datasets. The design concept is described in flow chart Figure 8.

The concept is detection, identification and measurement simultaneously should be incorporated with animation though the significance of these three tasks are different. Through animation locational and geometrical change (landuse change) can be recognised. While attributinal change (vegetation type, species, landuse class) can be recognised through statistical information and changing property of object (changing chlorophyll concentration) can be visualised through direct look up technique. An option should be there that functioning of these three steps (mentioned in Figure4.3) also present in static mode. Thus the combination of dynamic and static approach can reveal more information through visualization.

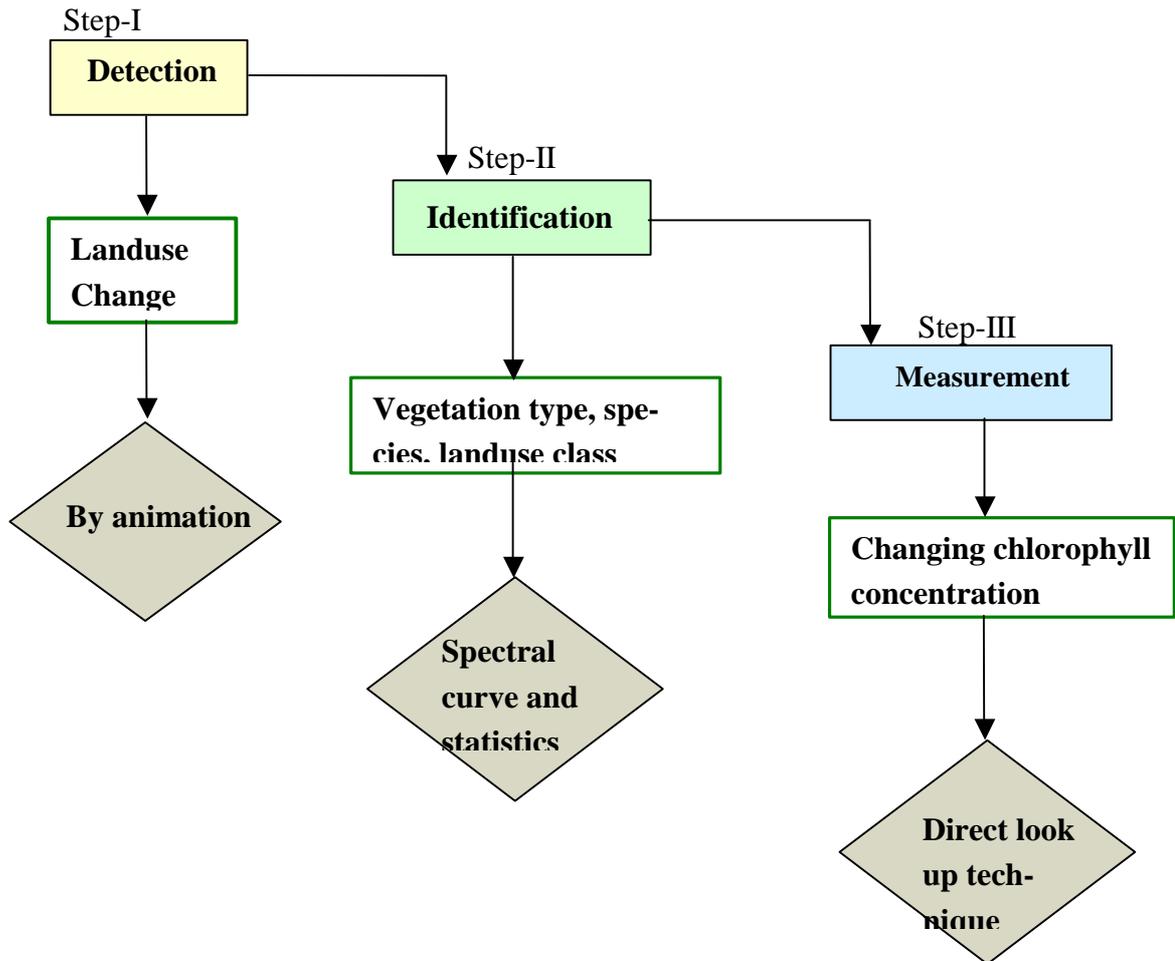


Figure 4.3: Conceptual Framework for the Design of Prototype

4.8. Summary

The study aims to represent the different aspect of temporal vegetation data. The task is to visualize the changing spatial distribution of vegetation. Regarding this animation with linked graphics technique has been applied to detect and identify the changes or trend. Finally a conceptual framework of representational technique has been discussed.

5. Prototype Design

5.1. Introduction

The primary objective of this research is to develop a prototype, which supports the use of animation with linked graphics for visual exploration of spatio-temporal data (NDVI). Prototype design is based on literature review (chapter 2 and 3) and characteristics of datasets (chapter 4). The user's requirement for exploration of this dataset is manifold, but in this study, emphasis has been given mainly on detection and identification of changing spatial characteristics of NDVI images at different time period. Thus, the development of the prototype "TEMPVIZ" is an attempt to illustrate the concept of animation with linked graphics for the visualization of temporal NDVI data.

5.2. Design Concept

The visualization of complex geophenomena in itself is a challenging issue pertaining to the number of parameters involved in any kind of geophenomena, either hazardous or of natural cycle. Landuse change is one of such complex phenomena, e.g. vegetation growth is one of the most important factors for landuse changes.

In the present study, the approach is to construct a design for the visualization of temporal vegetation data. The task is to design a prototype to make it useful for detection and identification of temporal changes of vegetation primarily due to change in chlorophyll concentration. Animation technique is useful for visualizing the changes but in present digital environment it is mainly embedded with basic media player functionalities. In some GIS software (like IDL, Macromind director) interactivity is in vogue. IDL is useful for interactively analysing the data and it support mapping, image processing, statistical calculation, surface and volume visualization and animation (Dungan, 1994). Macromind Director's graphic interface and graphic programming language make basic animation simple and intuitive and it supports raster-based animation (Weber, 1994). IBM's data explorer has functionality for the animation of time series data (Knapp & Carron, 1994). Other visualization software has also certain facilities of animation. (AVS, Spyglass, Khoros etc). Some of these software (e.g. AVS, Khoros) are not useful in GIS application. Hence number of research software has designed basically for cartographic visualization purpose. Such as Voxel Viewer, DESCARTES etc. DESCARTES developed by Andrienko and Andrienko, supports visual exploration of all types of spatially referenced data and dynamic manipulation of data (Andrienko & Andrienko, 1999). Voxel Viewer developed by Mark Harrower (Harrower, 2002); supports dynamically controlled spatial and temporal resolution of a raster-based animation. Keeping in mind all these researches in the geovisualization arena current research prototype has concentrated on application of animation with linked graphics for the study of temporal NDVI datasets.

The design concept used is based on spatial and temporal characteristics of data. In this dataset all changes are mainly determined by pixel value. Thus, to view the trends, animation with linked graphics techniques have been applied. It has already been mentioned that changes in spatio-temporal data mainly consider location, attribute and geometrical changes. The approach used in designing the prototype is such that it would support to explore locational and attribute changes with the help of animation and linked graphics. Linked graphics is present with static map for analysing the spatial data. But it is still missing with animation. It is well known fact that animation is suitable for the representation of dynamic events but for intensive analysis purpose interactive animation is more effective. Hence a conceptual design has made based on the study of nature and characteristics of data and thereafter interactive techniques and tools are selected for the development of linked graphics with animation.

5.3. Software selection

To make an effective design for the development of prototype , number of softwares are being used for different purposes.

Table 5.1: Outline of the Different Software used in Designing Stage

Software used	Purpose
ErDAS IMAGINE 8.6	For making pseudo colour image For exporting the image to jpeg format (layer by layer) For extracting image based on specified region of interest For Point map generation wherein each point indicates single pixel Statistical calculation
ArcGIS 8.2 Arc map	For exporting vector map (Arc coverage format to *.ai format)
Macromedia FlashMX	For making animation For making interactive buttons, zoom, pan function and linked graphics For making static image and graph with statistics summary for a month State wise animation
Visual Basic 6.0	Main display window Toggle windows File opening buttons
Microsoft Excel	For graph generation
SPSS	For statistics and graph generation

The reasons for selecting software for the development of prototype have been illustrated herewith: First, the NDVI images were transformed into pseudo colour using ErDAS Imagine 8.6. NDVI gives single layer grey scale image. Grey scale image is not effective for animation and changes cannot be shown properly. To show the changes different colours are being used according to hierarchical pixel

value (low to high NDVI value). All these processes is carried out in ErDAS Imagine 8.6. The given image is already rescaled from 0 to 255.

Second: Animation was built using Macromedia Flash MX. Flash software allows rapid development of animation by inserting frame-by-frame images. Flash supports images only in gif, jpeg, bitmap and *.png format or tiff format. Images used for animation are in jpeg format. Other interactive tools are also built in Flash MX. These are zoom in, zoom out, pan, full extent, pixel information buttons, state wise animation, static image and graph. All these tools and functionalities made in action script.

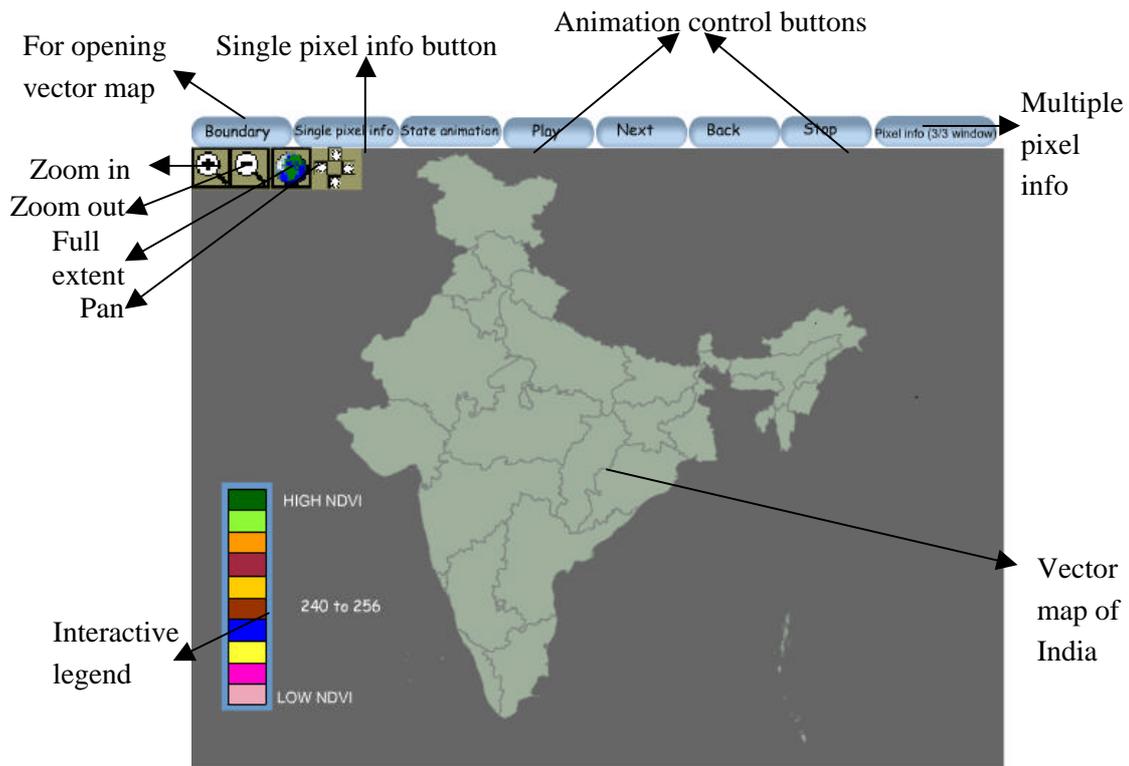


Figure 5.1: Animation Display Window built in FlashMX

Third: The main environment is designed in Visual Basics 6.0 that supports the concept of multiple views. In VB shockwave component and image box component has been used for animation and image reading respectively. The reason being that in VB interface, number of windows can be simultaneously opened and toggled in between. The same dataset has been designed in a different way. One window displays only animation and linked graphics another shows static images with static graph for entire image, in other window one can open one tiff image and can read pixel info (presently it reads only RGB value). All these are designed to provide different views of data representation. It supports the concept of combined approach of static and dynamic representation of same datasets. It allows user to see the changes in different combination.

According to user's choice all these windows can be maximized, minimized and toggled in between.

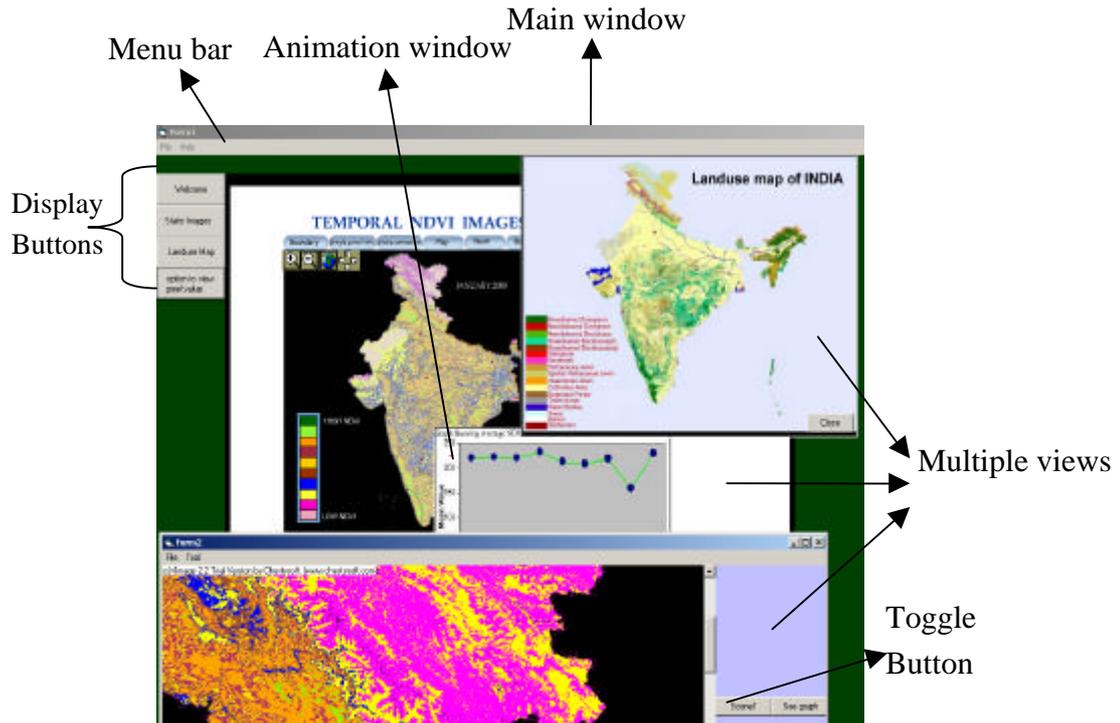


Figure 5.2: Main display window built in Visual basics6.0

Shockwave component used for animation. Landuse map of India is static map. The third window is for pixel information from tiff image of NDVI. Pixel information can also be obtained from animation window. In the main window maximum three windows can be open simultaneously.

Fourth: Spectral profile for all nine images has been generated using Microsoft Excel. Statistical data has been derived from SPSS and ErDAS Imagine8.6

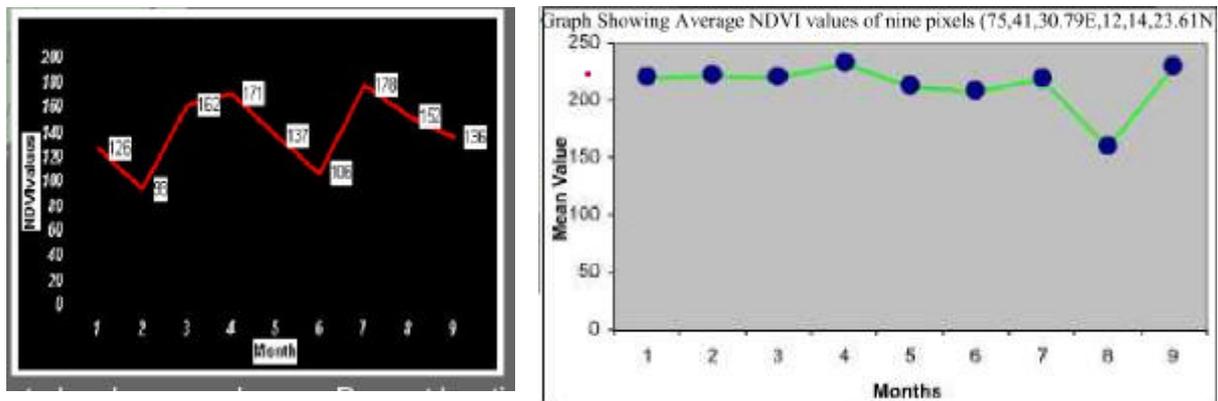


Figure 5.3: Different Graphs for Single Pixel and Multiple Pixels has generated in Excel Spreadsheet

Fifth: TWO vector maps have also been used in TEMPVIZ and to import them in flash environment, Arc map has been used.

5.4. Functionality of 'TEMPVIZ'

TEMPVIZ is designed for representation of temporal images showing NDVI values. Here nine datasets have been used. Some data are missing. Datasets of July, August and September are not used due to presence of cloud cover. To detect and identify the changes simple animation has been used. It is a frame based animation and is built in Macromedia FlashMX. Action script is used to make all basic functionalities like zoom, pan, play, back, stop and other buttons. The size of animation window is 800/600. The lay out is made first and then frame by frame images has been inserted. The animation rate is 12 frames per second. No interpolation is made for making animation. Legend in the map is also interactive. By clicking on any of the colour it will show the corresponding pixel value. Movie showing state wise changes, selection of static images and graph movie is also made in flash using action script. The reasons for making all these views has illustrated as under:

- From literature review it has been found that simple view only animation is not very effective to detect and identify the complex changes. It is also not useful to quantify the changes. Thus combination of linked graphics and animation can be a good approach to solve this problem. Graphics is nothing but images such as symbols, drawings, diagrams, photographs and clip art (URL1). It is basically a visual representation of information of any specific theme. Therefore if such graphics can be linked with animation then representation of complex phenomena can be easily understood. In the present prototype 'TEMPVIZ' spectral profile, histogram and textual information are the main graphics linked with animation. A single pixel for all nine images is important for change detection and identification for the present datasets. On the other hand information of a single pixel value and how it changes with time is useful for studying the phenological variation of the particular landuse category, however to take into account the variability of the pixels within a particular class the pixels in the spatial neighbourhood should also be considered. Hence an option to generate the profile using the nearby 3*3 pixels is also provided. The main objective being that while animation is running user can interact by clicking at any pixel and it will give information in terms of spectral profile of a particular landuse class/pixel. This mouse clicking functionality is present with static mode as well as dynamic mode. A separate window is also present in 'TEMPVIZ' which provide rgb value and xy coordinate of points. (In order relate the pixel to the geographic location). To increase the user interactiveness a window provides a facility so that the user can select any image and is able to get statistical information like mean, median, mode and the histogram plot of whole month. It can help to compare the statistical information from month to month. Thus the combination of animation and static view of same datasets can help to analyse the phenological variation in detail.

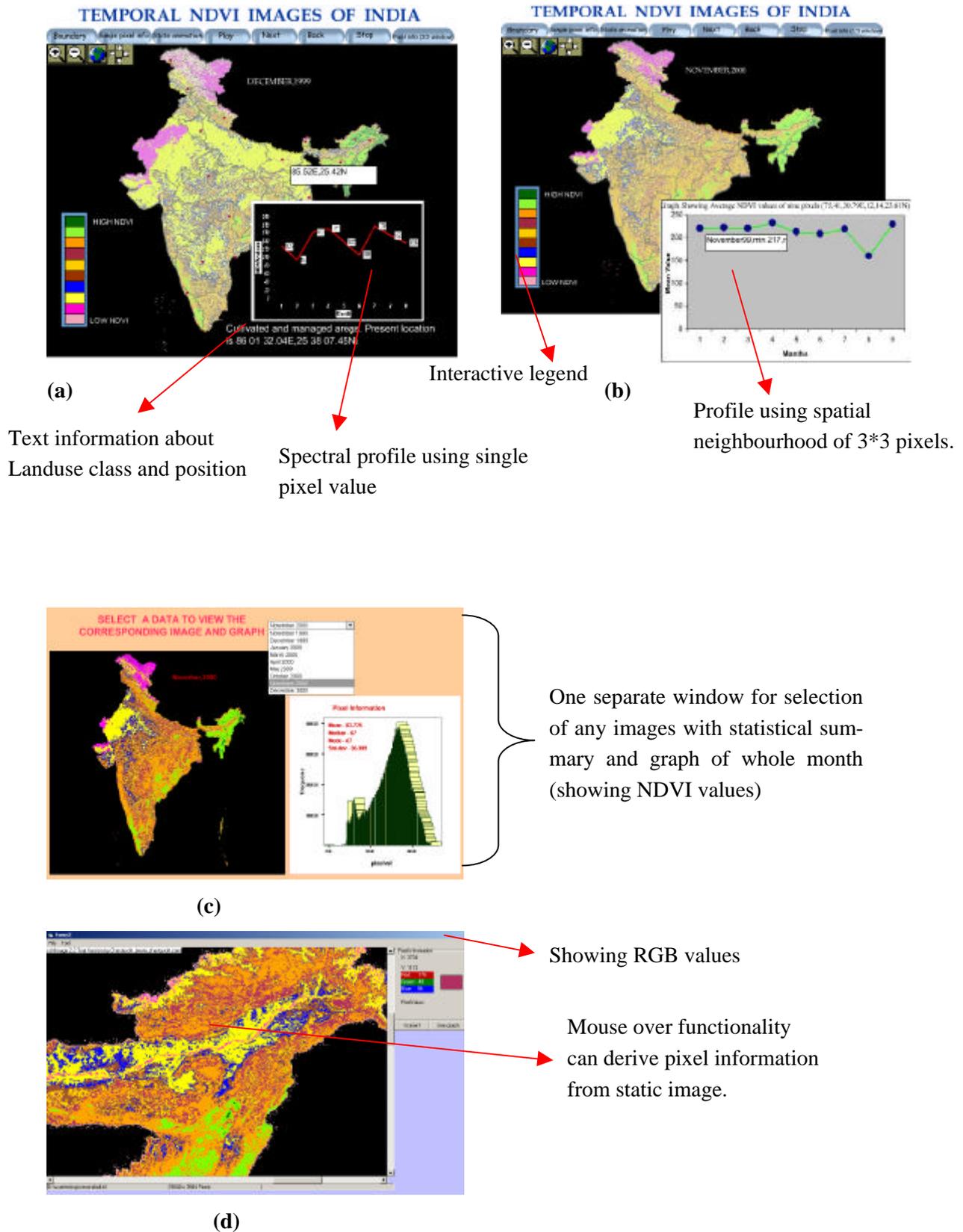


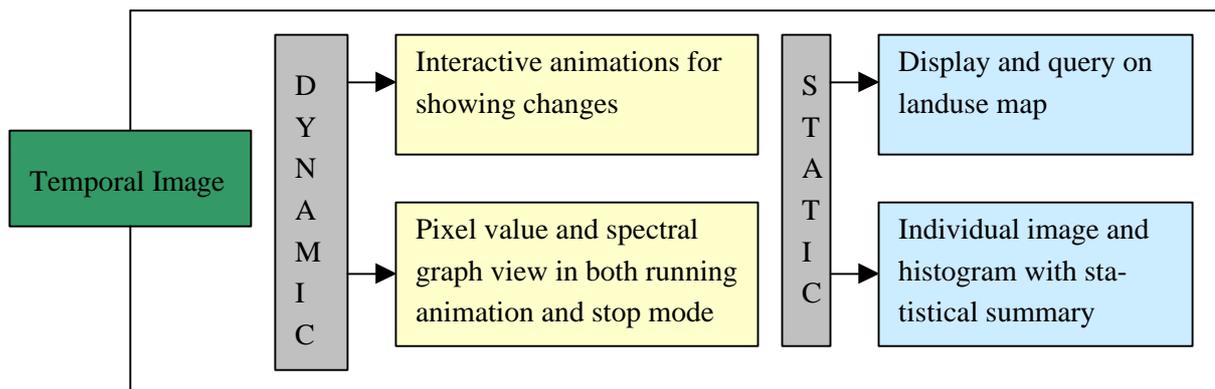
Figure 5.4: Functionality of TEMPVIZ

(a) is showing single pixel information of selected pixels, which are showing by a single point in red colour. These are sample points. **(b)** Multiple pixel information of a sample area covers by 9

pixels. (c) Static image with statistical summary and graph of a particular month. (d) Mouse over technique for getting pixel information.

Beside these four windows another window is also present which displays the landuse map of INDIA. This map can be used as a reference, which is a static map. The combination of static and dynamic maps can provide better data exploration. Thus multiple views and linked graphics approach is better for change detection, change identification and change measurement of complex phenomena.

Table 5.2: Combined Approach of Static and Dynamic Display- a Conceptual Design Layout



- Multiple views are useful for visual comparison of different state of change. In animation mode user is able to detect the changes and on the other hand static view of same image can help him/ her to compare the changes visually.
- Animation within animation (state wise animation) has made to facilitate the view of local changes as per the user’s interest. It can be a debatable issue. But when an animation is showing changes of large area then to view the changes of small area this type of representation could be effective.

In case of animation the visual variable used to show these changes is colour. In ‘TEMPVIZ’ animation is not continuous and after a certain time it will stop automatically but it can be replayed. State wise animation is also made in the same fashion. The basic display functionalities (zoom, pan etc.) are applicable in static mode. An attempt has been made to design the prototype, which is based on the nature, characteristics and user’s requirements for the exploration of temporal NDVI data.

5.5. Problems Encountered During Design

The problems encountered during designing the prototype has been described as follows:

- As Flash does not support images in tiff format, hence jpeg images are used for creating animation due to which there is some data loss.
- Individual pixel information could not be read in FlashMX in dynamic mode hence sample points are generated by use of a vector map for displaying the pixel profile in order to illustrate the concept. A point corresponds one pixel of a particular landuse class. Finally point

map is overlaid over raster image as the concept is to show the pixel information in animation mode.

- Flash MX is unable to open two or three windows simultaneously. Hence VB interface is used.
- Pixel information has also tried to make in VB but there is no functionality in VB that can support to read the pixel value from tiff, jpeg, png or bitmap image.

5.6. Limitations of the 'TEMPVIZ'

Despite all the functionalities the prototype 'TEMPVIZ' has some limitations:

- Image quality is not good due to use of jpeg image.
- It lacks GIS functionality: queries at any spatial location cannot be carried out in a dynamic mode.
- No database is linked with this prototype.
- Only NDVI values have been considered here. Other parameters like rainfall, temperature, which are responsible for vegetation growth, have not been used.
- Pixel information is also available for some sample pixels not for the entire image.
- Some extra component is required for using this prototype. Like shockwave and image box component.
- No other temporal datasets can be used in this prototype.
- It is a conceptual design, which can be improved.

5.7. Summary

A conceptual prototype is designed to fulfil the objective as mentioned in chapter one. The overall design is based on data characteristics and user's requirement for the exploration of NDVI images. To make a simple design Macromedia FlashMX has been used for animation and to facilitate the concept of multiple views Visual Basics6.0 has been used. The concept about representation of spatio-temporal data was implemented by using temporal NDVI images. The prototype 'TEMPVIZ' supports interactive visualization techniques for representation of complex spatio-temporal phenomena, and it has limitations, which can be improvised using set of software tools.

6. Usability Evaluation of ‘TEMPVIZ’

6.1. Introduction

One of the objectives of this research is to evaluate the usefulness of the prototype. As a result a group of people comprising of researchers, data users and students evaluated the prototype. This chapter illustrates how significance of usability evaluation, different methods and the usability testing was carried out and finally analysis of user testing is made in terms of efficiency, effectiveness and satisfaction.

6.2. Concept of Usability

Usability is the key concept of human computer interface and it indicates the easiness and learnability of the product. Usability determines a product’s quality for use from the point of view of user’s requirement by providing appropriate analysis tools. This is to ensure the effective usage of the technology on user-friendly atmosphere (Tobon.C, 2002). According to usability engineering principles a project is not complete without usability testing of the product (Tsoene, 2004). In cartography user testing and user studies is also common like usability engineering. The ISO 9241-11 standard for ergonomic requirements for office work with visual display terminals defines usability as “the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use”(ISO DIS 9241-11,1994,URL 2).

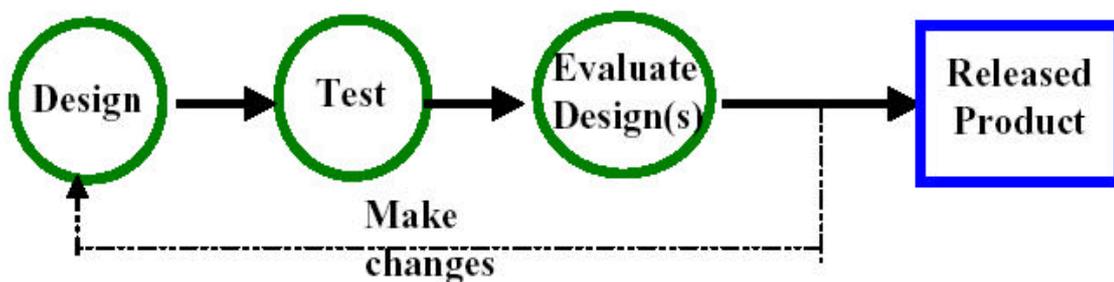


Figure 6.1: An Iterative User Centred Design Process (Source: URL 7)

From the figure 6.1 it is clear that usability is an iterative process, which continues until it fulfils the user’s need. Usability can also be defined as a measurable characteristic that describes how effectively a user can interact with a product. It can also determines how easy a product can be learnt and how easily it can be used. (URL 3)

According to Nielsen the attributes of usability are learnability, efficiency, memorability, minimal errors and satisfaction. (Nielsen, 1993 cited in Nivala, A. et al., 2003) Thus usability measurement includes the number of components to evaluate the product. The design starts by recognizing the potential users, their context of use and tasks and then design phase continues. In the next stage the de-

sign is illustrated to the user and based on their feedback product design is evaluated and modified. Thus the process continues until the product fulfils the user's task and requirements. The main component of usability has been illustrated as under:

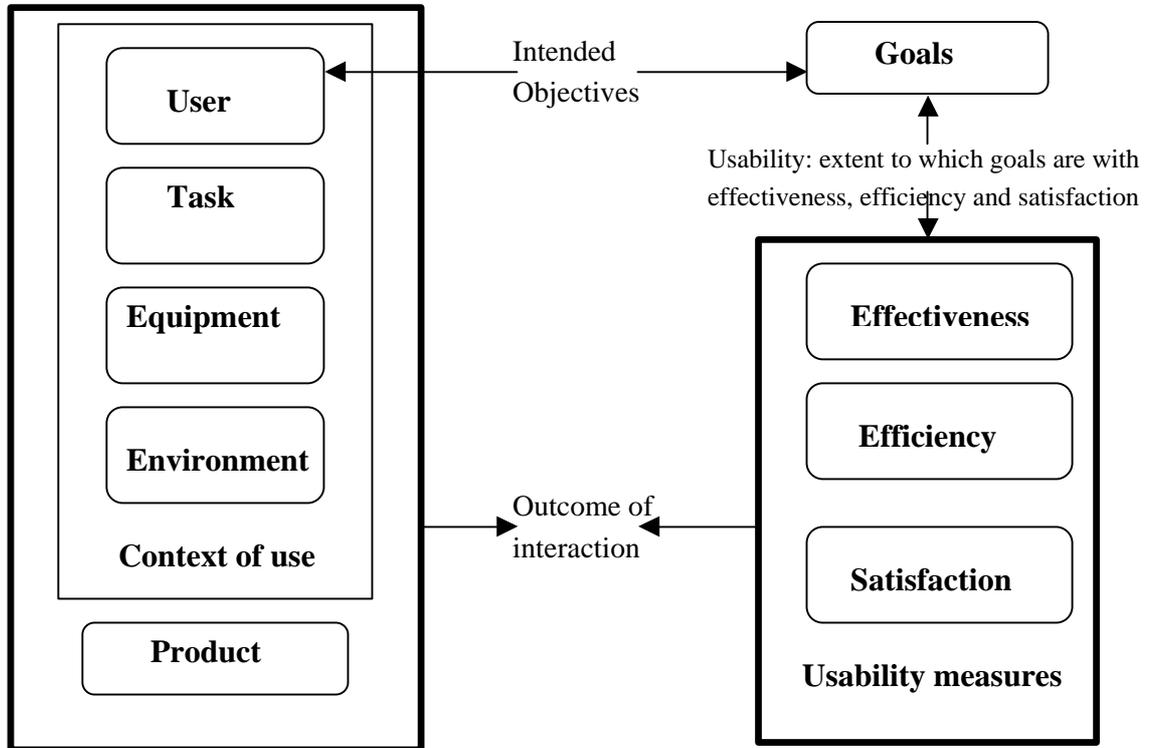


Figure 6.2: Usability Framework (source: URL 2)

All the components of usability are important for evaluation. The final feedback is measured in terms of effectiveness, efficiency and satisfaction. It indicates whether the product is achieving the goal of user's requirement or not. According to ISO DIS 9241-11 *effectiveness* implies accuracy and completeness with which user achieved goals, *efficiency* implies the resources spent in relation to the accuracy and completeness to achieve the users goals, *satisfaction* implies the comfort and acceptability of use (URL 2). The usability of a visualization prototype in the field of geovisualization is also same. Thus, research can be carried for developing an appropriate methodology for evaluating the effectiveness of different geovisualization methods.

In this research the prototype is designed for visualizing the temporal NDVI images. The designing phase considers three important aspects:

1. Understanding of nature and characteristics of datasets
2. Identifying potential users
3. User's requirement to explore the data

As prototype is designed based on these aspects, it is required to know from the user that

- Whether the prototype display tools are appealing.
- Whether prototype/system can be used for a given task.
- Whether the system is fulfilling their expectations or not.
- Whether the system is informative according to their needs or not

Hence, to get the feedback on these four questions a proper evaluation method is to be considered.

“Usability evaluation can be done by a number of methods. According to Jacob Nielsen (1993) and Reeves & Hedberg (2001), those methods are observation, think aloud, questionnaires, interviews, focus groups, logging actual use, user feedback, heuristic evaluation, pluralistic walkthrough, formal usability inspection, empirical methods, cognitive walkthroughs and formal design analysis”(URL 4). Some of these methods are explained in brief as below:

- Think aloud: Participants in testing express their thoughts about the product during task session. It gives very close inference to actual individual user’s perception. It is a very time consuming method.
- Focus group: In focus group larger number of participants can participate and the discussions from the sessions provide useful ideas which are variable in nature for making further improvements in the product.
- Questionnaires: It is a method for extraction, recording and collecting the information. Generally three types of questions can be framed, factual, opinion and attitude (URL 8). It is a highly reliable method because response of each participant’s is generally same for same questions. The major advantage is that it gives feedback from the point of view of user. Large number of people can participate in this questionnaire method (URL 6).
- Interviews: the users are interviewed about their experiences and expectations about the product. It gives detailed information about the usability of the product (Genise, 2002). However it is not suitable to measure the efficiency.
- Heuristic evaluation: In heuristic evaluation evaluators and/or representative users independently examine a product interface in order to determine how well it adheres to a list of heuristics (usability principals). It is inexpensive and results are quickly available (URL 4).
- Pluralistic walkthrough: This method systematically examines the usability of a product from a task-based user-centred point. This method works well with paper prototypes as well as fully functioning products (URL 4).

After exploring all the above techniques focus group and questionnaires has selected for the evaluation of this research prototype. Focus group is an effective and faster technique for getting first impressions about the prototype design. To quantitatively analyse the user’s reactions questionnaires method has incorporated to evaluate this research prototype.

In this study the usability evaluation of the prototype ‘TEMPVIZ’ is carried out in two phases combining focus group with posttest questionnaires. Due to time constraints focus group method has adopted. As focus group discussion data is difficult to analyse hence posttest questionnaires is combined for quantitatively analysing the user’s feedback. Through questionnaires users give feedback about their experience with the system. This method helps to clarify the user’s thought process and their suggestions for increasing the effectiveness, efficiency of the system. At first an unstructured focus group session combined with post test questionnaires was conducted and thereafter a structured focus group combined with questionnaire was arranged. The aim of this usability evaluation is to find which needs to be improving within the prototype and to identify the user requirements, which is not addressed in the prototype.

6.3. Focus Group Evaluation Method

“Focus groups are a low-cost, efficient qualitative method for investigation and design improvement. It was developed as an alternative to traditional interview methods”(Monmonier & Gluck, 1994). This method gives qualitative feedback from the users. It is not a tool for hypothesis testing. The members in the group discuss the weak and strong points of the prototype after getting familiarized with the prototype. The group generally consists of five to ten members and a moderator arranges the session. According to Nielsen, group session needs a moderator who prepares a list of usability issues for discussion after evaluating the prototype (Nielsen, 1993 cited in Tsoene, 2004). The prototype or system designer serves the role of a moderator. The moderator prepares questions about different aspect of prototype on which he/she calls for more inputs from the users. The main purpose of focus group is to portray the users attitudes, feelings, beliefs, experiences and reactions about the testing product. In the group session user’s reactions vary from each other but due to interaction users are able to modify their attitudes and perceptions. The focus group test is more inclined towards obtaining reactions than on cognitive aspects.

6.4. Questionnaire Evaluation Method

A questionnaire is a list of written questions, which can be completed either by postal questionnaires or by structured interview. Questions are mainly close ended and open-ended. Close ended provide quantitative data and open ended provide qualitative data (URL 6). In this study questionnaire is framed by using the both types of questions. As it is easy to standardise hence this system is very reliable method for usability evaluation.

6.5. Usability Evaluation Plan

In this study the goal of the focus group is to evaluate whether the functionality provided by the prototype ‘TEMPVIZ’ served the purpose of analysing and exploring the spatio-temporal data. The aim is to identify the potential areas for improvement regarding informativeness and coherence in visual exploration of temporal data. The output is analysed in terms of effectiveness, efficiency and satisfaction level.

The overall evaluation was carried out in two sessions. Each session started with a demonstration of the prototype. After familiarization the participants started the discussion. It was a valuable discussion. Then performed some tasks. Finally they reflected their opinion by filling out the questionnaires. Two main issues were selected for discussion: one identifying areas for improvement and second on additional requirements to fulfilled the user tasks.

6.5.1. Participants and Place of Evaluation

The evaluation group consisted of ten and two members in session one and two. The session one members are mixed group of users. It is comprised of two scientists working in the field of remote sensing for more than 10 years, four research fellows carrying out research in the field of forestry for more than one and half years and four students doing their masters in geoinformatics. The second session comprised of two scientists, one of them had experience in the field of remote sensing and GIS is 11 years, one with 7 years. All the members were from different background. Research fellows had

masters in forestry, one student had computer science background, and another in the field of urban planning yet another was from agriculture background. Among the student participants one is a forester. Two faculties have physics background, one is computer engineer and another one is doctorate in forestry and ecology branch.

6.6. Evaluation Session

The evaluation session was carried out on 4th and 10th November at computer labs of IIRS. It was a first usability evaluation session at IIRS. However due to inadequate test room facility the test were carried out utilising limited resources. Still a systematic test session was organised in both the sessions.

Session one

The first session was arranged on 4th November. It was an unstructured focus group session combined with post test questionnaires. Although it started with the demonstration of prototype followed by tasks and questionnaire session but the entire session was not in an organised manner. However the members reflected their opinions about the concept and design of the prototype. The overall discussion was interactive but was not recorded. Participants wrote their ideas, problems and specified gap in the visualization prototype TEMPVIZ by filling out the questionnaire. They responded well and their feedback was very useful for improving the prototype.

Session two

The second session was arranged on 10th November after carrying out certain modifications in the prototype. The session was organised in a structured manner. The focus group protocol was divided into six parts:

- 1) Introductory speech to welcome the members
- 2) Demonstration of the prototype 'TEMPVIZ'. All functionalities, main interface and concept behind the design of this system were described.
- 3) It was an uninterrupted demonstration.
- 4) After demonstration the users tried to get familiarize themselves with the system to perform some tasks/exercise. (See Appendix A)
- 5) In the task session users tried to show their skills acquired from the exercise and expressed their views by filling out questionnaires. (See Appendix A)
- 6) Finally the session ended with discussion.
- 7) The duration of the session was one and a half hour

6.6.1. Problems Encountered during Evaluation Session

The process of usability evaluation through focus group approach requires that the entire session should be recorded either by video or audio devices. But due to technical problems this recording could not be carried out.

6.6.2. Participants Feedback

Though the first evaluation session was not structured, yet the participants addressed important issues regarding improvements and additional requirements. The first feedback was collected from the demonstration session. The feedback did not address the usability issues but the weakness of demonstration process. Finally participants expressed their views after carrying out exercise and task session by answering the questionnaire.

Feedback from session one

The participants were able to perform all the tasks using all the basic display techniques and buttons provided in the prototype. They identified the locational changes. They also detected the changes through use of linked graphs. Some users managed all the functions well but others faced problems. They mentioned that multiple views are not effective for visualization purpose. They also expressed that changes are not so visible due to use of low-resolution images. They appreciated the combination of animation with display of spectral information of pixels and textual information. As sample pixels were incorporated in the prototype to demonstrate the concept of animation with linked graphics some users were confused about the use and need of these points. All the users preferred the technique of extracting pixel information by both the ways (mouse clicking over points and dynamic mouse over technique). Some participants expressed that the colours of the images and the legend is not appealing and others said that speed of animation was not adequate to view the changes. The participants appreciated very much the combination of animation with statistical information. But they also claimed that the type of histogram and graph is not effective and some participants highlighted that text fonts are not properly visible. In the end, the participants/users recommended certain points for improvements:

- Original NDVI values in the legend instead of rescaled values.
- Presence of scale and north arrow with all the images in both static and animated mode.
- Average spectral profile for particular landuse.
- Latitude and longitude information for the sample points.
- Improvement on panning function.
- Bigger size display window.
- Proper placement of buttons.
- Bigger window for viewing the state wise animation

Keeping in mind all this recommendations a second phase of evaluation session was arranged after a little modification in the prototype. Certain functionalities as per the user's request was added like-

- Average spectral profile for a particular landuse
- Rearrangement of button placements
- Latitude-longitude information for those sample points has incorporated and panning functions are improved.

Feedback from session two

In this session the participants comprised of experienced persons in the field of remote sensing and GIS. Thus in this session the feedbacks were more subjective. In this session the users were able to detect and identify the changes through animation and linked graphs. They appreciated the concept of such visualization tool for the exploration of the NDVI datasets. They highlighted the most important technique in this prototype is that pixel wise information for viewing the changes from time to time

which can be effectively use for the exploration of temporal vegetation data. Thereafter they recommended additional requirements and some points for further improvement.

- The spatial location based query for all the images is most powerful requirement to detect, identify and measure the changes.
- Physiographic information, image or map is also useful if it can be displayed with animation.
- Ecological zones should be highlighted with animation.
- Some users need meteorological information for monitoring purposes.
- Region specific profile is also required.
- Users manipulation functionalities should be incorporated, so that users can also modify the view of images, legends and can able to generate the graph as per their needs and interest.

All their views were recorded in paper through the questionnaires.

6.7. Analysis and Conclusions from Questionnaire

User’s view about the usability of the prototype ‘TEMPVIZ’ is analysed quantitatively in terms of effectiveness, efficiency and satisfaction. The rank order chosen are low, moderate and high for all three terms. This ranking is based on positive and negative response of users. When their response is positive it comes under the high rank, when it is negative it becomes low and when it is in between then it becomes moderate.

In order to assess the prototype the users view is analysed in terms of effectiveness, efficiency and satisfaction. For analysis the questionnaires under each category has generalised and summarised as below:

Table 6.1: Percentage of Number of Participants View

Rank User’s View	Low			Moderate			High		
	E	EF	S	E	EF	S	E	EF	S
Response related to effectiveness									
a) Functions and design of tools	16.6			66.7			16.6		
b) Multiple views	50			16.6			33.3		
Response related to efficiency									
c) Techniques for visual change detection		8.3			66.7			25	
d) Techniques for measurement		50			16.6			33.3	
e) Techniques for identification		2.5			50			25	
Response related to satisfaction									
f) Combination of animation with linked graphics			8.3			50			41.67
g) Application of this technique for the exploration of linked graphics			8.3			41.67			50
h) TEMPVIZ is more appealing than other visualization system *			8.3*			33.3*			25*

* some participants mentioned that they have no idea

E = effectiveness, EF = efficiency, S = satisfaction

The user response about the effectivity of the prototype is related to functions and design and use of multiple views.

- a) **Functions and design of the prototype:** 66.7% of the participants expressed that the tool is moderately effective as they found some complexities while doing the exercises and tasks. 16.6% of the participants appreciated tool.
- b) **Use of multiple views:** 50% of the participants expressed that multiple views are less effective. The reason is that multiple views creates confusion among users and for displaying multiple views the size of the display window is reduced effecting the clarity of the image and hence the view is not user friendly.

The user response about efficiency is related with techniques (animation with linked graphics) for change detection, identification and measurement.

- c) **Techniques associated with change detection:** 66.7% of the participants addressed that techniques associated for change detection is not so easy to use hence it is moderately useful. Because some users found complexities to detect the changes by the given functionalities in the prototype. But 25% of the participants addressed that techniques associated for change detection is highly useful.
- d) **Techniques associated with change measurement:** 50% of the participants mentioned that change measurement techniques are not very clear to use. But 33.3% of participants highly appreciated the technique for measuring the changes. As the direct look up technique is not fully developed in the system, therefore maximum users response for this technique is very low.
- e) **Techniques associated with change identification:** is also moderate as per responses from 50% participants. Because the difference between detection technique and identification technique were creating confusion between the users.

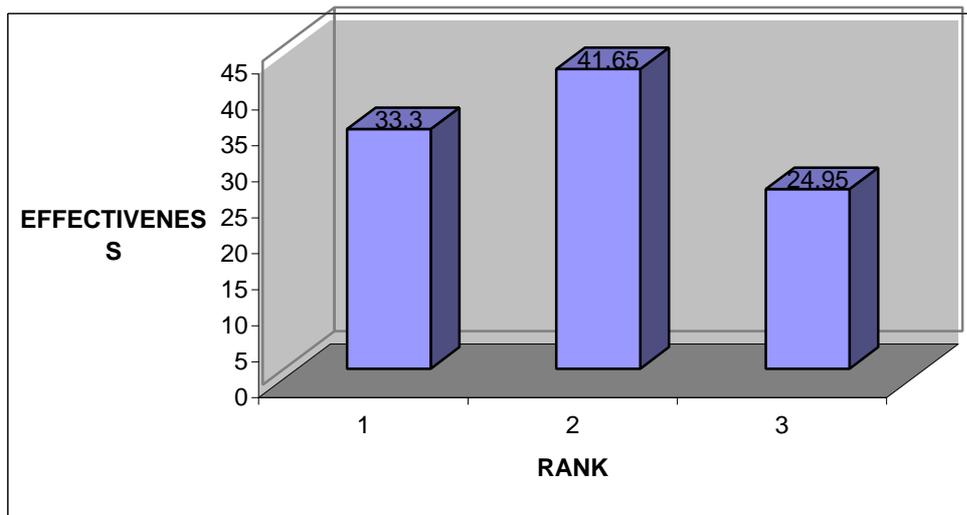
The user response on satisfaction of the prototype is related to combination of animation with linked graphics techniques, application of this technique for the exploration of NDVI data and comparison of TEMPVIZ with other visualization system.

- f) **Combination of animation with linked graphics:** Regarding this most of the participants (41.67%) agreed that animation with linked graphics techniques are very useful and can be applied to the exploration of any kind of spatio temporal data in a raster format but majority (50% of the participants) expressed that it is moderately useful.
- g) **Application of this technique for the exploration of NDVI data:** 50% of the participants expressed that application of this technique is highly useful. The users highly appreciated this technique and addressed that it is a powerful visualization tool for stimulating visual thinking.
- h) **Regarding comparison of TEMPVIZ with other system:** The major response is moderate (33.33%) and some participants expressed no idea about any other type of visualization system.

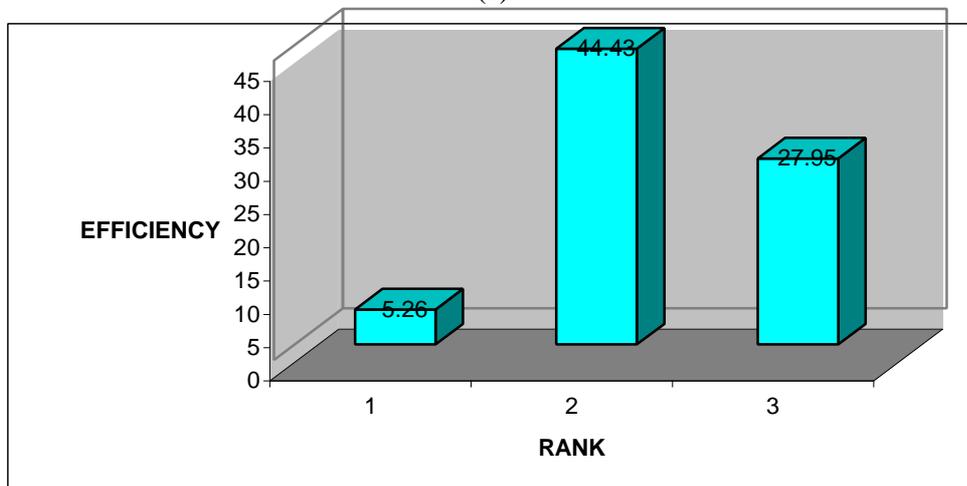
Table 6.2: Overall Participants View

Rank	Low	Moderate	High
Usability Measures			
Effectiveness	33.3	41.65	24.95
Efficiency	5.26	44.43	27.96
Satisfaction	12.45	75.5	58.34

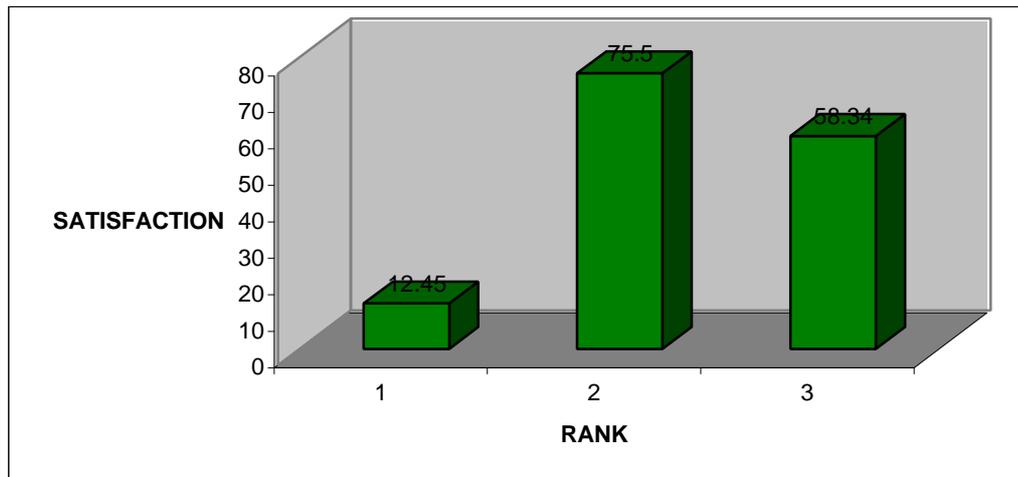
The overall response (Table 6.2) about effectiveness, efficiency and satisfaction are: 41.65% participants expressed that the prototype is moderately effective and 24.85% of participants stated that it is highly effective. While 44.43% of participant expressed that it is moderate in terms of efficiency and 27.95% of participants addressed that it is a highly useful tool. On the other hand 75.5% participants are moderately satisfied with the system and 58.35% of participants expressed that they are highly satisfied with system as it fulfils their requirement.



(a)



(b)



(c)

Figure 6.3: Number of User's View for the Questionnaire Expressed as Percentage

**(a) Response about effectiveness, (b) Response about efficiency and
(c) Response about satisfaction.**

Thus from this analysis it is clear that animation with linked graphics technique is moderately useful in terms of in formativeness and coherence. It is one of the effective ways for representing spatio-temporal data. Though some parts of the design need improvement but overall the users in terms of attractiveness and applicability in the particular discipline appreciated the prototype design. The positive response on the development of such type of visualization tool is a supporting point for carrying out further research and improvements for designing of such type of visualization tool.

6.8. Summary

The usability evaluation reflects the quality and applicability of TEMPVIZ for the exploration of spatio-temporal data. The usability evaluation session was carried out in two phases. The first phase was an unstructured session but feedback from that session has implemented for a primary improvement of the prototype. Second session was much effective and interactive as the participants expressed recommendations regarding improvement of the prototype. Focus group method though is a qualitative evaluation method but combining it with questionnaires proved to be successful in determining the participants view about the conceptual design of the prototype.

7. Conclusions and Recommendations

7.1. Conclusions

The study reviews the characteristics of spatio temporal data and existing techniques for visualizing them. All these existing techniques are important and useful for exploring the temporal data. However there are some possibilities to represent this type of data in a different way. Keeping this in mind the present problem was chosen based on which research objectives were identified. The main objective was to develop a prototype using animation with linked graphics and usability evaluation of the prototype. In order to design the present prototype in an effective manner the following conceptual questions were considered which were framed based on the objectives and research questions.

What are the uses of a particular temporal dataset?

Who are the users?

What are their requirements?

What is the nature of the data?

How to visualize those characteristics of data using animation with linked graphics?

What types of tools are needed to explore it in a simpler way?

All these theoretical questions helps to frame the research work and conceptual design of the prototype 'TEMPVIZ'.

Thus the main findings of the research can be summarized as follows: -

- In geovisualization environment number of techniques exists for representing spatio-temporal data. The techniques can be chosen according to the nature and characteristics of the datasets. Spatio-temporal data deals with information, which is dynamic in nature, and such changes are mainly locational, attributinal and geometrical in nature. These are the main aspects of spatio-temporal data, which can be best represented through the use of different graphics.
- Simple animation techniques are not that effective to visualize the locational changes. Locational changes include existential changes (e.g. appearing, disappearing of object) of object and spatial property changes of object. Thus interactive animation is an optional visualization technique to represent all such changes. Sometimes locational changes needs to be addressed along with attributes and geometrical properties for better perception and analysis, in such cases animation can be combined with linked graphics. The attributinal changes can be viewed through the representation of statistical information in the form of histogram, scatterplot or any other graphs along with animation. On the other hand geometrical changes can be represented by use of different geometrical shape and use of visual variable size can be combined with animation.

- To visualize the complex geophenomena interactive tools are required. These tools comprise of basic display tools (zoom-in, zoom-out, pan) toggling, multiple views, brushing, linking between map and graph, highlighting and querying can support exploration of the linked graphics. Thus an attempt is made to use these interactive tools for designing of animation with linked graphics in a common interface. The characteristics and users requirements of data are considered while designing and emphasis is mainly given on linking the temporal images with the graphs.
- Numbers of softwares are available for designing the animation with linked graphics. It can be built in any programming language such as java, visual basic, c++. In this study the conceptual design of the prototype 'TEMPVIZ' is built using Visual Basics 6.0 along with shockwave component. The animation and linked graphics is built using Macromedia FlashMX and then it displayed in VB through shockwave component. Other views are created using VB and Flash. The overall design is created for the exploring of temporal NDVI data. It is frame-based animation. For designing in a very simple manner FlashMX has been used. Linked graphs are used to show the changing pixel values from time to time.
- The prototype is designed in such a way so as to provide maximum user interactivity. Direct look up technique has tried to built for change measurement. Simple query operation is provided using sample points. The main concept being that as per the users need, one can query at any point on the image by simply clicking the mouse and he is provided with the statistical information in form of tables and graphs. Since raster datasets are used they have some limitations to generate query-building operations. Hence interactivity is added by introducing an additional vector layer. To visually explore the datasets querying, multiple views and direct look up techniques are also added to the interface.
- Finally the prototype is evaluated through appropriate evaluation method. The evaluation is done using focus group in combination with questionnaire method. Without the fully development of direct look up technique the prototype is not useful. The users expressed that it is a very useful visualization tool, which can be used for exploration of temporal NDVI data. From the evaluation session it is observed that combination of both focus group and questionnaires is very effective for evaluating the usability of the prototype. The overall, the prototype developed, was moderate with respect to effectiveness, efficiency and satisfaction.
- Currently there is no proper theoretical and methodological background for the development of such type of visualization tools. The entire technique is based on user's need and characteristics of datasets. Hence an attempt was made to conceptually design a visualization tool for exploring and analysing the temporal NDVI datasets which has utility in various application like vegetation monitoring, crop monitoring etc.

7.2. Recommendations

Suggestions for further improvement and research in this area are:

- Animation with linked graphics can be made more user friendly and effective if other type of interactivity is added like sound, video, photographs etc. for this type of datasets.
- If dynamic variables are added with this technique then it will increase more usability and interactiveness for the exploration of temporal datasets.
- If database is also combined to it then it will be more useful to enhance the utility of the visualization tool and increase the applicability of the prototype. Like for extensive analysis and using the NDVI datasets other parameters like rainfall, temperatures, which are responsible for vegetation growth, should be incorporated.
- It is well known fact that different exploratory techniques are required for different types of spatio-temporal data therefore to develop a useful dynamic visualization technique this animation with linked graphics techniques should be experimented by using different types of temporal data.
- Since this prototype had certain limitations encountered due to which the above mentioned functionalities could not be incorporated, hence it can be explored to develop such visualization tool using alternative platforms like java, visual c++ etc.

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APPENDIX A: User Testing

Users Name:

Qualification:

Professional Status:

Experience:

1.Demonstration Of Prototype “TEMPVIZ”

2.Getting familiar with the interface and function of the tool:

- Open the interface
- Open the file
-  Icon of the movie files.
- Try to familiarize yourself with all the tools and button operations in main window. You can zoom; pan the moviefiles by right clicking over the animated image.
- Try to familiarize yourself with all other window operation



3.Do this small task:

- (a) Click on state animation button and select ASSAM and display NDVI.Are you able to appreciate the visual display of animation.
- (b) Try to display the histogram and statistical summary from staticgraph movie file.
- (c) Click on point map and try to display any spectral profile.
- (d) Open point map over the animated image and click on any point and try to find out the NDVI values of that particular point for all nine images.
- (e) Click on button pixel value and select any tiff file from folder and try to read the pixel value.

Questionnaire:

(Questions related to informativeness)

1. What information you are getting while you are doing task ‘a’ and ‘b’?

.....
.....
.....
.....

2. Are you able to identify the locational changes? (Related to task 'a')

- (i) If yes, then rank it
- (ii) If no, specify it

Rank	1	2	3
Effective			
Efficiency			
Satisfaction			

.....

.....

.....

.....

3. What type of changes do you observe from animated images? If you are able to observe then tick out the exact change and rank it. If no, specify the reason.(Related to task 'd' and 'e')

- i) Changes in color
- ii) Changes in pixel value
- iii) Nothing
- iv) Both

Rank	1	2	3
Effective			
Efficiency			
Satisfaction			

4. Which of the techniques is much better for extracting pixel information, mouse over or mouse clicking? (Related to task 'b')

- i) Mouse Over (If yes, then rank it and explain why)
- ii) Mouse Click (If yes, then rank it and explain why)

Rank	1	2	3
Effective			
Efficiency			
Satisfaction			

.....

.....

.....

.....

5. Is it possible to identify the land use? (Related to task 'c')

- (i) If yes, then rank it
- (ii) If no, specify it

Rank	1	2	3
Effective			
Efficiency			
Satisfaction			

.....

.....

.....

.....

(Question related to coherence)

1. What do you think about the functions and design of tools?

.....
.....
.....
.....

2. Is there any other tool required? If yes, then specify the type.

.....
.....
.....
.....

3. Are the text fonts and graphs are visible/legible?

.....
.....

4. Is it effective to use both static and animated image simultaneously?

.....
.....
.....
.....

5. Legend is ok? (If no, draw your idea)

.....
.....

(Rough sketch)

6. Are you able to manage all the windows? (If no, mention the reason)

.....
.....
.....
.....

7. Is it effective to use all multiple views simultaneously?

.....
.....
.....
.....

(Questions related to improvement)

1. What are the main technical drawbacks present in the 'TEMPVIZ' prototype?

- A).....
- B).....
- C).....
- D).....

2. Is it useful for your application? (If yes, then rank it and write down the reason and if no, then specify it)

Rank	1	2	3
Effective			
Efficiency			
Satisfaction			

.....

3.What is your opinion about the concept behind this ‘TEMPVIZ’ prototype?

.....

4.How can you rate the visualization of spatio-temporal data in terms of effectiveness, efficiency and satisfaction?

.....

5.How would you rate this prototype in comparison to other existing visualization techniques in terms of effectiveness, efficiency and satisfaction?

.....

6.What are your expectations from this kind of animated representation?

.....

7.Which one of the technique is most attractive and important for the exploration of spatio-temporal data?

.....

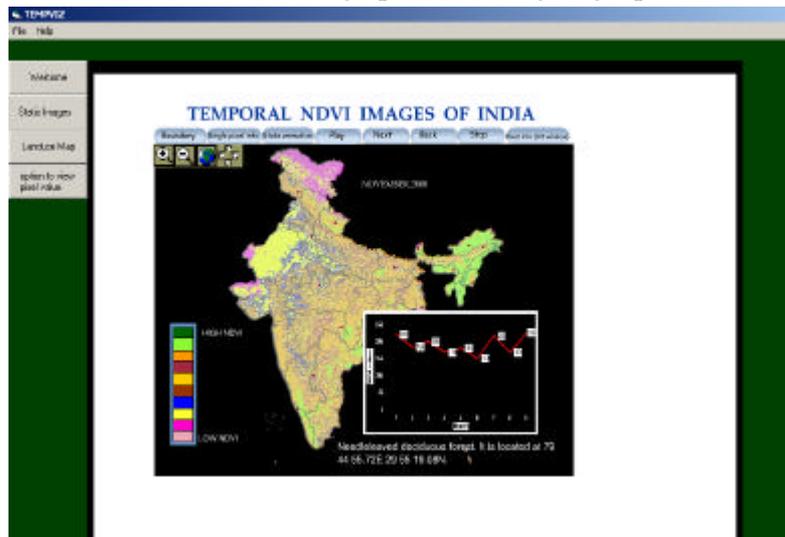
Signature:

Date:

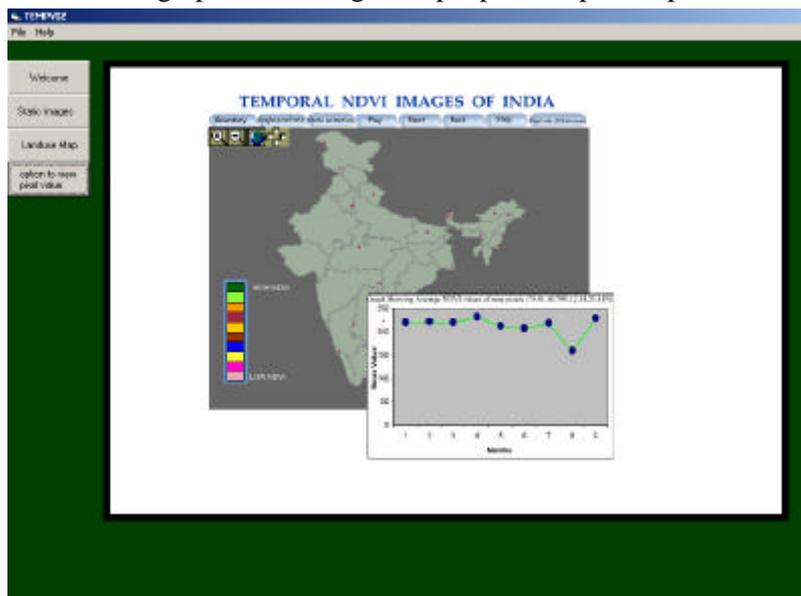
THANK YOU VERY MUCH FOR YOUR PARTICIPATION

APPENDIX B

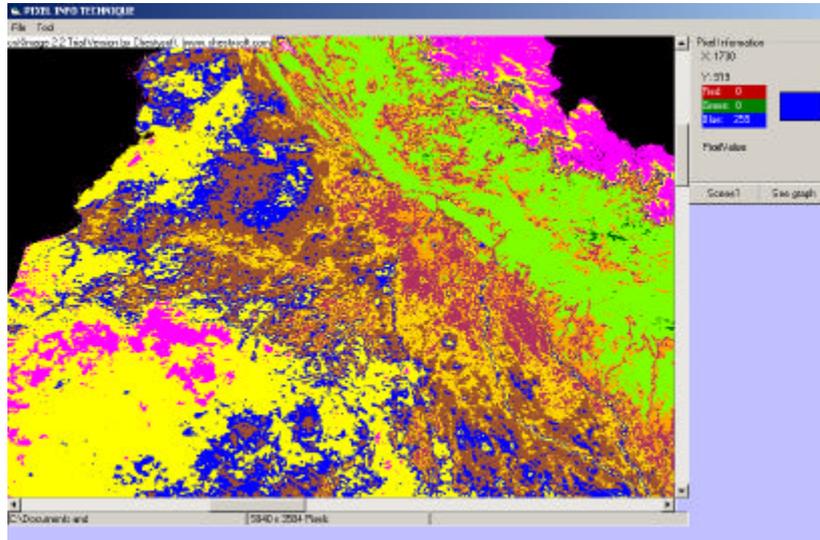
B1: Animation with linked graphics showing single pixel information



B2: Linked graphics showing multiple pixel's spectral profile



B3: Pixel information by direct look up technique



B4: State wise animation also with linked graphics

