Exploratory visualization of temporal geospatial data using animation

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EXPLORATIEVE VISUALISATIE VAN TEMPORELE RUIMTELIJKE GEGEVENS MET BEHULP VAN ANIMATIES

(Met een samenvatting in het Nederlands)

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PATRICK JOB OGAO

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Prof.Dr. Ferjan J. Ormeling
Faculteit Ruimtelijke Wetenschappen Universiteit Utrecht

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Division of Geoinformatics, Cartography & Visualization, International Institute for Geo-information Science & Earth Observation, Enschede

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To my parents, Benjamin ogao okinda & Jennipher apondi oduma,

Who modeled in me the zeal for pursuit of knowledge

Learn from the mistakes of others--you can never live long enough to make them all yourself - John Luther

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INTRODUCTION

"Life is either a daring adventure or nothing. Security is mostly a superstition. It does not exist in nature" KELLER, HELEN

While the emphasis in early geographical information systems (GIS) has been predominantly oriented towards collecting more and more information, lately we are seeing more importance being placed on the need to extract useful geospatial information from the information already collected[1]. The magnitude and wealth of the geospatial data available demands that domain knowledge coupled with smart tools be used to acquire, process and disseminate information in a speedy and accurate manner. Scientific visualization has emerged as one of the most effective of today's analytical strategies through its ability to explore data and information graphically, thereby enriching the process of scientific discovery and understanding of raw data sets. Visualization then becomes a means to providing tools that help one interpret image data in the computer and also enable the generation of images from complex multi-dimensional data sets. The visualization environment at present can be described as one that is inclined towards applications in networked, virtual, ubiquitous, mobile computing. Together, the new scientific and societal demands have opened up new approaches to the representation and uses of visual products in a wide range of disciplines.

Lately, one of the interesting topics to have captured considerable attention for both research and discussions amongst cartographers is on the emergent map use practices of presentation versus that which emphasizes the exploration of raw data sets. Dynamism and interactivity became the identifying traits for exploratory cartographic tools and have characterized deliberations and concern within the field of cartographic visualization where geoscientists examine unknown and often

[1] A section within the GIS user community advocates for the formation of a working approach to the synthesis of geospatial data and information into real knowledge that can have an impact on the world in very meaningful ways (Coté, 2001).

raw data creatively in pursuit of knowledge construction, hypothesis generation or problem solving. This is a change from the previous one-way presentational maps to the ones that put emphasis on highly interactive maps to visually explore raw data interactively and generate hypothesis (MacEachren, 1994; Kraak and MacEachren, 1997). Recognition must be made of the fact that in an exploratory environment an "unknown" data set is relative and dependent on the user's identity. Data that is known to one user might be unknown to another, recalling that the user in this environment would most likely be a geoscientist, from whose perspective the meaning embedded within the complex data sets is unknown or unclear. The data sets that the geoscientist uses may have sources in different databases locally or widely distributed geographically. It is for this very reason that the geoscientist sets out to explore the data set using tools that will prompt thinking and facilitate knowledge construction and decision making within a particular problem context (MacEachren, 1995; Kraak, 1998). It is then possible to search geospatial patterns, steered by knowledge of the phenomena and processes being represented by the interface.

Cartographic animation has become one of the prominent tools in this environment (MacEachren & Kraak, 1997). Computer animation have apparently been a subject of great interest among the computer graphics and mainstream media enthusiasts. However, the necessary theory and functionality to apply it in exploratory environments in geoscience application was lacking or not yet fully developed. The techniques at our disposal in cartographic animation were still in their infancy in terms of the types of functionality use and adaptability to geospatial data sets. Initially most of the development in cartographic animation functionality came directly from the media, especially from video and film technology as can be seen in the earlier passive animation, in which viewers had to be content with the pre-assembled key-frame animation no matter how intriguing or irrelevant the contents were. Specific areas in cartographic animation research have been those that look at the parameters that control and determine the character of the animation, user tasks, interface and cognitive issues.

In view of these trends, researchers have focused on providing tools that will enhance investigation amongst geo-scientists in geospatial data exploration through emphasis on the purposeful exploration and search for patterns among a given data set. Currently, much research work is being done to develop tools to support exploration of geospatial data sets (MacEachren & Kraak, 1997; 1999 & 2001).

A key issue with all these developments is that visualization should not just be limited to enabling the process of seeing patterns and relationships in geospatial data, but rather to envisage manipulating geo-structures to search, filter, control level of detail, reorganize, change, and derive new useful information. The context of using visualization tools should extend to encompassing individual private exploration as well as collaborative exploration in distributed environments *(Figure 1.1)*.

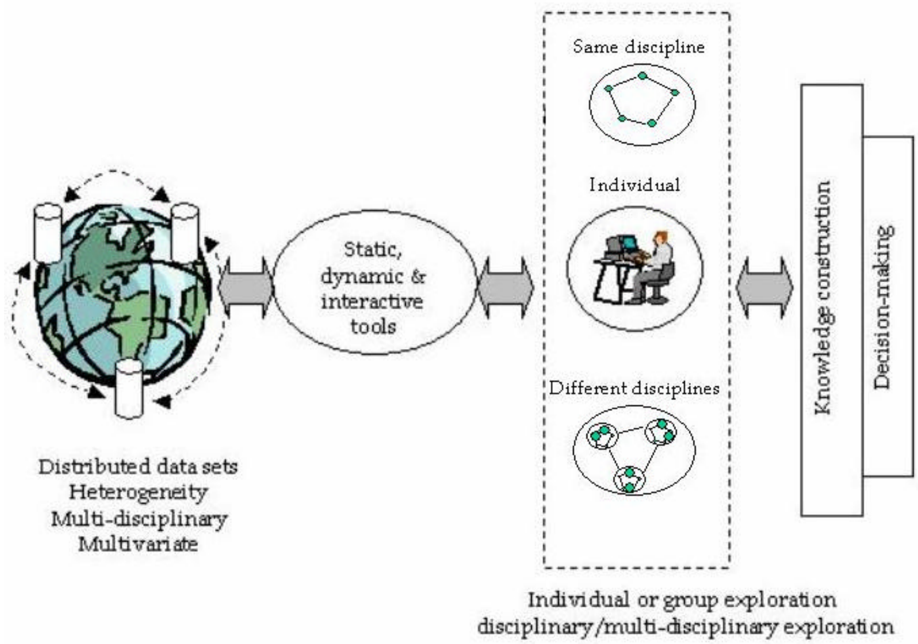

Figure 1.1. A general view of an exploratory cartographic environment utilizing static, interactive and dynamic tools for effective knowledge construction.

1.1 Research motivation

To a greater extent cartography seems to be experiencing a whole range of divergent methods and techniques for representing geospatial information. They are interactive, dynamic, multiple views, which can also be dynamically linked to each other. The question that arises then is, do these methods and techniques function to facilitate geospatial data exploration? This thesis seeks to address this question. One thing is for sure, unless one attempts to understand the underlying cognitive structures and processes that can unveil emergent temporal geospatial patterns and their relationships, it becomes very difficult to give a concrete answer to the effectiveness of these representations. An overriding opinion amongst general users of modern visualization techniques is that much can be gained from interacting with innovative and, or dynamic graphical representations such as animation, 3-dimensional maps or virtual worlds. Further, there is the notion that interactive animation are better than the non-interactive ones, and are even more suitable for use in exploratory tasks. So far, many of these opinions on the use of animation functionalities have not been experimentally proven.

The reason for the proliferation of visualization tools might be partly due to the lure by the realities of computer graphics usage as applied to media and entertainment industries. Making map-like products has become simplified due to the easy availability of user-friendly graphic software. Most resulting products rarely adhere to sound cartographic methods for map production. If so, the concern about the use of visualization techniques in geospatial applications will have to also address aspects of data integrity and the impacts and effectiveness of these modern visualization techniques on users.

The present status of cartographic animation shows both good and poorly designed products. Most designs camouflage products with a great deal of incongruent graphics at the expense of the information being conveyed. The cognitive influences of these products on learning, problem solving, and decision-making are yet to be fully investigated and ascertained. Most probably these products could trigger different cognitive processes and even overload a user's working memory thereby causing unfounded visual and conceptual judgements (Zhang & Norman, 1994).

At present, the use of cartographic animation in general is characterized by a nature that is passive and that which is based on predetermined linear playback paths of the animation frames. By this, the animation is pre-designed to run with little or no interference from the viewers and only along specific predetermined story lines. Partly, the reason for this passivity that also translates into low levels of interactivity (and which may significantly hamper its capability for performing geospatial data analysis) is due to the fact that during playback, each scene is viewed as a graphic image whose content therein cannot be disintegrated into the individual geospatial features that it encompasses.

Most cartographic animation is compiled using bitmap graphics[2]. A typical creation process will involve selecting, converting (from vector to raster) and

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[2] This is a one-layered raster-based image consisting of a matrix of dots – the pixels of which the popular formats include the Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPEG), Tag Image File Format (TIFF) and Windows Bitmap Format (BMP). The transition to using Object Oriented Graphics (vector-based) within the geospatial disciplines has been minimal. This is despite the advantages that vector graphics stand to offer. Vector graphics are mathematical definitions of objects and therefore enable each object to be separately manipulated and adjusted. Their use has been incorporated in CAD and 3-D computer graphics applications. Their use within the geospatial discipline is promising especially if they are to be incorporated within a GIS environment.

interpolating the needed thematic layer files. One may add a corresponding number of annotated, marginal information and background frames (*Figure 1.2*).

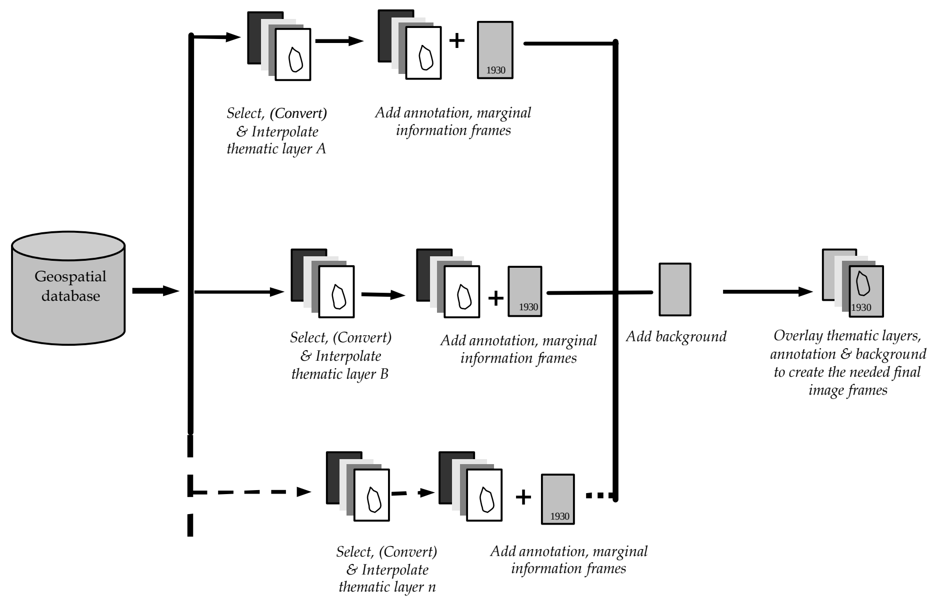


Figure 1.2. Animation compilation environments

The format that the resulting animation takes when using either raster or vector based images may portray geospatial attributes in either a single or separated multiple views (*Figure 1.3)*. A single frame view involves transparently overlaying the thematic layers to result in a single view display. Alternatively, the layers can be separately displayed and synchronized to each other resulting in multiple views. One could also have the views and their contents alternate temporally (Blok et al., 1998).

Cartography as a discipline that is rich in geospatial graphical representation methodology can play a unique role by enabling producers to have relevant knowledge of map production and uses. The need is for cartographers to come up with a more systematic approach that though theoretically driven would account for the cognitive processing of the way people interact and use cartographic animation. Without such a framework, it would still be a long time before the user community can have insight into these newer forms of maps incorporating animation and virtual environments.

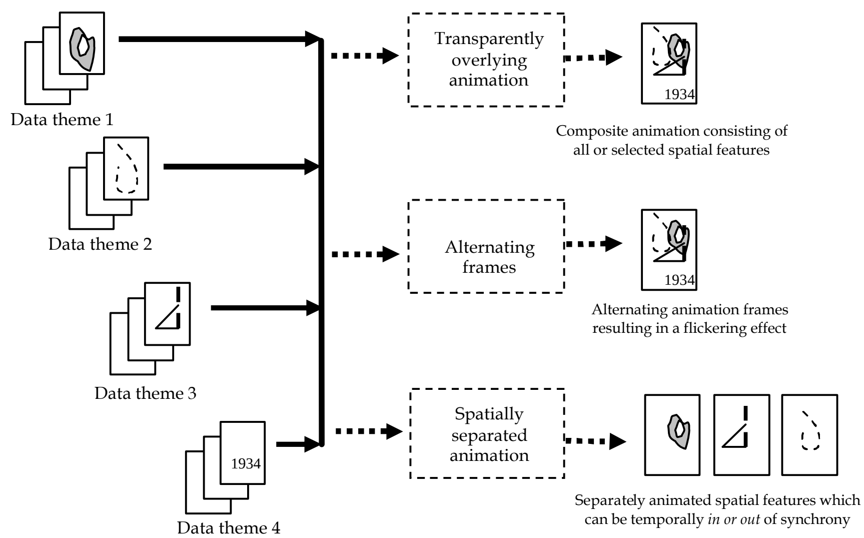


Figure 1.3. The many ways of viewing a cartographic animation

This thesis addresses one of the research questions raised by the International Cartographic Association's Commission on Visualization and Virtual Environment, whose key objective is to see the development of innovative approaches to and applications of dynamic cartographic visualization and the sharing of perspectives on visualization with the wider scientific community.

1.2 Research objectives

The specific objectives of this research work are;

a) To review the roles, and uses that both passive and interactive temporal cartographic animation play in facilitating geospatial data exploration.

b) To define the necessary functionalities needed to enable temporal cartographic animation for use in an exploratory environment. Achieving this objective will encompass:

   i. Studying typical explicit accounts of the cognitive processes and structures that contribute to visual thinking, insight and /or knowledge discovery.
   ii. Identifying the core geospatial structures and processes that stimulate insight into exploratory cartographic environments.
   iii. To demonstrate in a prototype that is based on the typical geo-application environment the incorporation of these functionalities.

c) To perform an evaluation of the exploratory success of the developed functionalities.

1.3 Scope of the research

Computer animation have been widely used in the media and entertainment industries for quite a while. Both 2 and 3-dimensional animation have found application in a diverse range of fields. Design methods have been adequately tailored to the type of data and audience that they are meant to serve. Generally the animation techniques employed for example in entertainment use quite sophisticated graphic algorithms and methods, partly because of the level of realism that they seek to attain in their products. In essence, these achievements (computer animation in the entertainment world) are quite commendable and reseachers in the geosciences can borrow, use and learn a lot from these products. Nevertheless, a breakthrough for effective cartographic animation will entail undertaking a collaborative effort from a diverse range of disciplines encompassing: domain knowledge in the field of experimental cognition and specific geoscientist domain knowledge, computer graphics, cartography, Human Computer Interaction (HCI), and the specific geoscience discipline that the product is to be used in. This thesis, will in a generic manner look at the various relevant contributions from these diverse backgrounds and integrate the useful functionalities that will define the new nature of cartographic animation. Our position will be to ascertain the usefulness of the functionalities from a cartographic perspective.

Some of the concepts in experimental cognition will be adopted and the reader will be referred to relevant backgrounds and literature where detailed studies have been undertaken. A specific case in point will be in delineating between tools that enhance knowledge discovery for the geoscientist and techniques for enhancing one's creative ability for knowledge discovery processes. Our focus in the research is on the former case.

Whereas the research focuses more on theoretical concepts that contribute to defining the nature of temporal cartographic animation in exploratory environments, the practical applications as given in the prototype narrow down to 2-dimensional representations, though the concepts in a generic sense will still find application in 3-dimensional animated representations.

The research does not study the specifics of individual contributing parameters related to animation construction, control and their uses. For example it does not address the details of the additional human memory processing demands that may be required when using animation, both in terms of memory overload and the possible strain on the human visual system that may arise when interacting with dynamic sequences of complex graphic images involving simultaneous variation of several parameters. Nor does it address the influences of dynamic variables in performing exploratory tasks with animation.

This research therefore focuses on the underlying theoretical concepts that contribute to defining an effective exploratory, temporal cartographic animation environment. It explores the different types of animation; from the key frame animation to alternative higher-level animation, as with cognitively modeled animation or those that are imbued with domain intelligence (Funge et al., 1999). The thesis outlines the vital visualization operations that enable users to read and extract geospatial information from cartographic animation. The research also studies the possible contributions that these types of animation provide in enabling users to explore geospatial data sets in the anticipation that new or unexpected patterns or structures will emerge leading to geoscientists enacting new hypotheses. To do this, the research reviews results from experimental cognition that are concerned with creative visualization processes (Finke et al., 1992).

1.4 Methodology

In line with the objectives, three levels of methodology are pursued. These are; conceptual, operational and implementation levels (*Figure 1.4).*

1.4.1 Conceptual Level

Initial phases of the research looks at the types of animated maps and their use for geo-science applications. A great deal of earlier cartographic animation took on a passive nature that encompassed a predetermined linear playback path which later had interactivity added on to them. The thesis explores these possibilities in relation to their effect on geo-scientists' interpretative and judgmental workload during exploratory tasks. It also looks at constrains that prohibit certain aspects of interactivity. The thesis ascertains the role interactivity plays when using visual products, such as with maps - by improving a user's functional performance during visual exploration processes. It also reviews the conventional frame based animation techniques and highlights how these inhibit the incorporation of more interactive functionality. It ascertains that interactivity increases, as the geospatial features represented within the frames become more autonomous. In this state the feature's individual characteristics can be steered and tracked and its relationship and effect on other features can be ascertained.

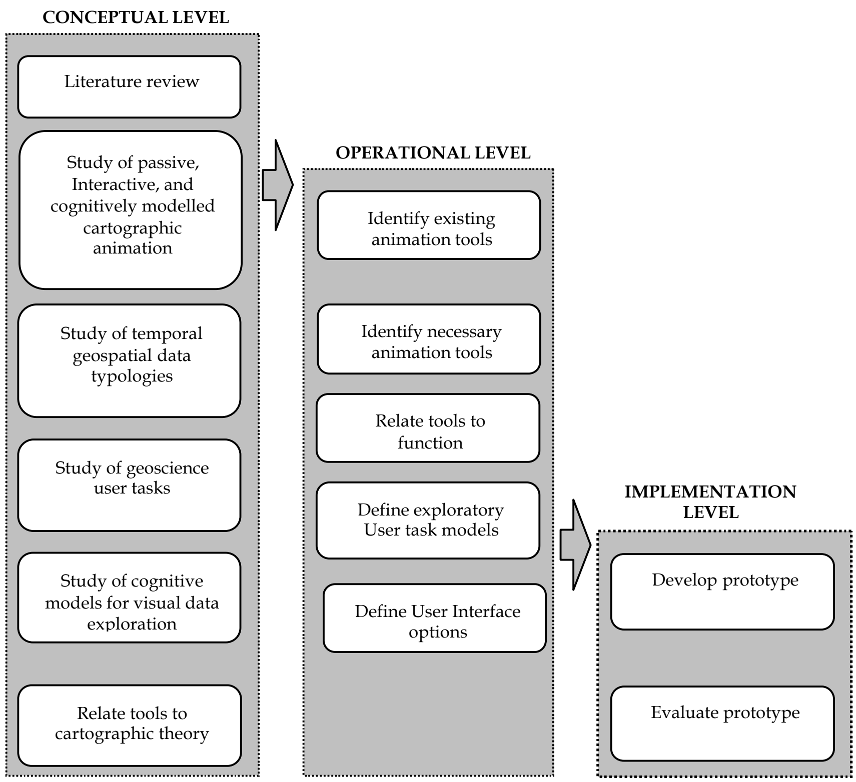


Figure 1.4 Main stages of the research methodology

To enhance interactivity, the thesis proposes that cartographic animation be embedded with an inference mechanism down to the geospatial features contained in the animation frame. Doing so ensures that the animation can autonomously make decisions and respond to the user and other geospatial object's actions during run-time.

In relation to geospatial data characteristics, the thesis outlines an approach that defines visualization operators within temporal cartographic animation. Visualization operators are those visual actions that implement user tasks. The thesis looks at processes that are typical of space-time data sets and draws from previous results and experiences in temporal geospatial typologies (Claramunt & Theriault, 1995) and formal aspects of temporal relations (Allen, 1981). Not only do these processes characterise the nature of the data, but they depict the range of queries about the data and processes that users will want to explore.

A distinct feature of the methodology is the incorporation of cognitive knowledge about processes and structures that lead to knowledge discovery or stimulate insight. The thesis makes use of a generic cognitive model developed by Finke et al., (1992) to define typical processes involved in knowledge discovery.

1.4.2 Operational level

The main interest here is to highlight the cartographic animation functionalities, both those previously identified by other researchers and those that are found to be useful from the studies undertaken at the conceptual level. They are then linked to specific exploratory tasks that they perform. Specific issues will address the animation compilation environment with regards to providing the user with tools for manipulating the frames, database, and other interface options.

The success of any functionality has to be subjected to a usability test to find whether it aids geoscientists during exploratory tasks. For this end the research uses regional demographic data sets of the Overijssel province in the Netherlands.

1.4.3 Implementation level

The third phase encompasses the creation of a prototype that demonstrates exploratory functionalities identified in the operational level. The prototype highlights four distinct types of cartographic animation, namely: passive, interactive interface, animation with dynamically linked views and lastly the intelligent animation, which have domain knowledge embedded within them. In each of these types, a functionality is implemented that enables users to perform the basic essential tasks namely: to be able to *identify*, *locate, compare* and *associate* geospatial features.

Based on this a cognitive test is performed to find out the suitability of the developed functionalities and animation environment and how they aid in hypothesis generation during exploration.

1.5 Structure of the thesis

The work presented in this thesis falls basically into four distinct parts. First, the Introductory notes and theoretical concepts of cartographic animation and exploratory cartography. Next is the development or derivation of essential concepts that ought to characterize animation when used within exploratory set-ups. The implementation, evaluation and conclusions of these concepts in a prototype as applied within a geo-science discipline concludes the last two parts of the thesis.

Chapter 1 gives an overview of the entire thesis structure, with highlights on the motivation, problem definition, methodology and how the thesis results seek to contribute to cartographic theory.

Chapter 2 outlines various definitions of terms and phrases as used in the thesis. It gives an overview of the types and functionalities in the commonly used cartographic animation and outlines a generic outline of the influencing factors in animation design and uses.

Chapter 3 explores the distinguishing aspects in the design of cartographic animation encompassing the geoscientist, user tasks, geospatial data characteristics and interactive interface options. It discusses each of these aspects and the way they can be influenced and improved in order to enrich geospatial data manipulation capabilities within an animation use environment. The chapter also introduces the need to imbue intelligence in animation as a means of enhancing feature-to-feature interaction.

Chapter 4 introduces a rounding up component and strategy for sound animation design for exploratory uses by geoscientists. It stands out from the earlier chapters in that whereas the previous concepts do apply to cartographic animation in general, here the focus narrows down to their uses in exploratory environments. It reiterates the fact that users in such set-ups are dealing with unknown data types and seeking unknown outcomes. The only way to help design functionality is by utilizing knowledge gained from studies in experimental cognition that define the specific cognitive structures and process that lead to knowledge construction, thereby giving insight into the data.

Chapter 5 gives the basis of the choice of a functional evaluation methodology that is used to evaluate the success of the functionalities as tools for exploration.

Chapter 6 outlines a prototype environment where the previously derived concepts in *chapters 4* and *5* are developed. An animation user test environment is defined based on typical geoscience applications in urban growth, demography and epidemiological studies. Results are analysed and discussed based on exploratory indicators of originality, sensibility and practicality.

Lastly, *Chapter 7* outlines the main contributions and conclusions of the research. Recommendations for improving the attained results and for pursuing further work in this and similar research fields are presented.

2

CARTOGRAPHIC ANIMATION

"Vision is the art of seeing the invisible." JONATHAN SWIFT

All along, cartography has been known to be a discipline that is concerned primarily with the graphical representations of geographical phenomena through a process that in essence translates geographical facts into graphical forms or language using cartographic techniques or methods. But lately there has been a sudden inclination to use maps not just to communicate geographical facts, but also as a means of exploring raw geospatial data in anticipation of the emergence of new knowledge structures from the process.

In this chapter, we give an overview of the research efforts that lead to this new emergent concept of exploratory cartography and the quest for tools that accompanies the process. One of the prominent tools and that which is the subject of the thesis, namely cartographic animation is introduced. We highlight the potential role that animation stands to play in both presentation and exploration processes. We look at present and potential future functionality (tool) status and its use within a range of geoscience application fields.

2.1 Exploratory visualization

The ACM SIGGARPH report on Visualization in Scientific Computing by McCormick, et al., (1987) is normally regarded as the basis for modern day understanding and insight into visual exploration of data and phenomena, aspects whose importance had captured little attention. Its outcome has enhanced interdisciplinary collaborations in domains that include computer graphics, image processing, computer vision, computer-aided design, human computer interaction, and signal processing. Scientific Visualization thus becomes a complementary technique to computational data analysis, both of which play crucial roles in unraveling meaning in the colossal multivariate and multi-dimensional data that is nowadays so readily available. To visualize then becomes a means by which computers and software are used to create and interpret internal and external visual representations of something that may or may not be visible to sight.

Lately, there has been a proliferation of visual approaches to data exploration. Terms such as *Exploratory Visual Analysis, Exploratory Data Visualization, Visual Database Exploration* and *Visual Data Mining* have been coined to distinguish these techniques and approaches in diverse user and application domains. *Tables 2.1, 2.2 and 2.3* give an overview of the range of goals pursued in visualization processes, the techniques that can be used to pursue these goals and specific characteristic pertaining to the techniques.

Table 2.1 Goals of visualization techniques (Keim, 1997)

	Start	Process	Results
Presentation	Known facts	Choose Visualization	Quality visualization of facts
Confirmation	Hypothesis about data	Goal-oriented examination of hypothesis	Visualization to confirm/reject hypothesis
Exploration	Data without hypothesis	Interactive, undirected search for structures & trends	Visualization that provides for hypothesis

Table 2.2 Some characteristics of geographical visualization process (Wachowicz, 2001)

Main stages	Visual representations	Interaction forms	How knowledge process can b constructed
Exploration	Parallel coordinate plot	Assignment	Prepositional form
Confirmation	3-D scatter plots	Brushing	Analogical form
Synthesis	Virtual reality views	Focussing	Procedural form
Presentation	Space-time cubes Multivariate glyphs	Perspective Manipulation Sequencing	

Table 2.3 Characteristics of exploratory visualization techniques (Gahegan, 2001)

Method	Driven by	Usual exploratory mode	Usual visual stimuli
Chart-based	User	Interactive	Clusters of points, single outliers
Projection-based	Algorithm	Static, animated tour	Clusters of points, single outliers
Iconographic	User	Static	Patterns in icons & symbols
Compositional	User	Static	Patterns in layers of shapes & symbols
Pixel-based	Algorithm	Static	Clusters in dense pixel arrays
Hierarchical	Metadata	Static	Patterns in nodes & links
Map-based	Map	Interactive	Patterns in geographic space

From a geospatial perspective, the visualization process is considered to be the translation or conversion of geospatial data from a database into graphics by applying appropriate cartographic methods and techniques – a kind of grammar that allows for the optimal design, production and use of maps, depending on the application (Kraak, 1998). The result of the process aids in the formulation of new hypotheses, in developing solutions to problems and in knowledge construction (MacEachren, 2000).

Earlier efforts by cartographic researchers to define the evolving concept of visualization can be seen in DiBiase (1990). He presented a model that draws attention to the role of maps and other visual displays in the process of science. The model covered both the communication and "thinking" functions of the map. Communication in other words refers to maps aimed at a wide public audience (public visual communication), whereas thinking is defined as an individual playing with the geospatial data trying to determine its significance (private visual thinking). MacEachren (1994) came up with a model of a "map use cube", which focused on three main aspects of changes in map use based on audience, data relations, and the need for interaction. Kraak (1998) builds on these models by projecting data presentation and exploration on to the visualization process. From the projection, it appears that presentation goes well with the traditional practice of cartography. Here the cartographer uses known data to create communication maps. Exploration is depicted as being an otherwise exclusively private realm, where the user (in this case a discipline expert) is dealing with unknown data. Maps in this environment are for a single purpose use – most probably bordering the expert's field. Working in such an environment will require that essential visualization tools including cartographic knowledge of map making are available to the expert.

Cartographic visualization is emerging as a visual technique that enables a direct depiction of movement and change, multiple views of the same data, user interaction with the image on display, realism and multimedia components (MacEachren & Monmonier, 1992). The key words that stand out in these developments are interaction and dynamics (Hearnshaw & Unwin, 1994; MacEachren & Taylor, 1994). Of course the interactivity has now been widely embedded in virtually every other cartographic technique in both presentational and exploratory realms of map uses, and as such one wonders whether it can be used as a distinguishing trait between the two realms.

2.1.1 Exploratory cartography

The basis of our use of the term *exploratory cartography* comes from the aforementioned research studies in cartographic visualization and specifically the map use cube model. Here the user, who happens to be an expert domain user, explores raw data sets in order to prompt thinking, knowledge discovery or stimulate insight into the data. The process is characterized by an interactive, undirected search for patterns and trends, and its sole purpose is to come up with hypotheses about the data. Exploration therefore contrasts significantly to presentational uses of maps, where facts are presented to the user. In between the two strategies is the confirmative use of maps where one engages in a goal - oriented examination of hypotheses to confirm or reject a given hypothesis.

Thus the term *exploratory cartographic environment* depicts the context under which visualizations are produced and used to facilitate knowledge discovery or stimulate insight into data sets. It basically is an environment that enables its users to mentally synthesize visual forms to come up with unexpected, novel discoveries. Using maps then becomes a starting point, (not the end product) and a means to generating questions that subsequently result in tentative explanations of certain geospatial behaviors, phenomena, or events that have occurred or will occur. These explanations are what we in this thesis term hypotheses[3]. They are

[3] The word *hypothesis* as used in this thesis connotes an unproved proposition about a specific geospatial phenomenon based on a geoscientist's current understanding of the situation, which is assumed to explain certain aspects of the phenomenon and offer the basis for further investigation (Christakos et al., 2002).

explanations with sound rationale and clear relationship that are testable (Indrayan & Kumar, 1996; Brewer, 1999; Gahegan et al., 2001). Thus, in this we use them as traits of success in geospatial data exploration.

2.1.2 Exploratory tool development

Although previously maps had served as visualization tools by presenting answers to user questions, the need today is also for visualization tools that would foster a search for questions and hypothesis formulation. In the Geo-disciplines, there is a need for tools that will enable users of Geographical Information Systems (GIS) to have a direct and interactive interface to their geographical and other (multimedia) data. Such tools should be based on cartographic expertise and directed at those without any cartographic training. This will allow them to search geospatial patterns, steered by their knowledge of the phenomena and processes being represented by the interface. The need for exploratory visualization tools is intensified as one moves from a data poor to a data rich environment and also as the link between GIS and application-based models is intensified. As a result, an increase in the demand for more advanced and sophisticated visualization tools or functionality is required.

The word *functionality* as used in this research refers to the mechanism by which a user's exploratory task is visually accomplished. This may be through abstracted forms of visualization techniques (Zhou & Feiner, 1998) and encompasses visualization operations (acting on the display or database), and display components or forms, which can be interactively manipulated together or in part to effect a desired change in the users' mental or display environment. Thus the whole essence of the functionality use within an exploratory cartographic environment is to facilitate a geo-scientist's quest for knowledge or insight into raw data. The functionality may involve the use of dynamic variables and interactive querying tools. It similarly should enable users to perceive relationships and manipulate temporal geospatial data sets using more efficient perceptual and motor operations and not obscuring or engaging one in redundant and demanding cognitive operations.

2.2 Computer animation

The mention of the words *computer animation* triggers thoughts of Hollywood or entertainment in most people's minds. It has become synonymous with big screen movies such as *Star Wars*, *Toy Story*, and *Titanic* (Parent & Parent, 2001). It is also associated with advertisements and special effects in films and its uses now encroach domains in multimedia, interactive games and virtual reality (Thalmann & Thalmann, 1996).

The word animation bears also the meanings of "motion" or "to give life to". In essence the animator specifies either directly or indirectly the parameters of this behavior. An object's position and orientation are obvious candidates for animation. An object's shape, shading parameters, texture coordinates, light source parameters, and the camera parameters can likewise be animated (Parent & Parent, 2001).

Traditional animation has been defined as "a technique in which the illusion of movement is created by photographing a series of individual drawings on successive frames of film" (Halas & Manwell, 1968). In relation to computer generated animation, it is a technique in which the illusion of movement is created by displaying on a screen, or recording on a recording device a series of single frames, as with film or video (Thalmann & Thalmann, 1996; Roncarelli 1988).

Parent & Parent (2001) categorize computer generated animation into two techniques: low and high level techniques. Low-level techniques enable animators to precisely specify motion, since they have a fairly good idea of where they want the next motion to be. The techniques consist of such methods as *in-betweening* or shape interpolation algorithms.

High-level techniques describe general motion behavior. They encompass the use of algorithms or models that are used to generate a motion under specific rules or constraints that have previously been set by the animator. A variety of modeling techniques can be used for generating animation. This can range from: geometric, kinematic, physical, behavioral and cognitive models as illustrated in *Figure 2.1* (Thalmann & Thalmann, 1996; Funge et al., 1999).

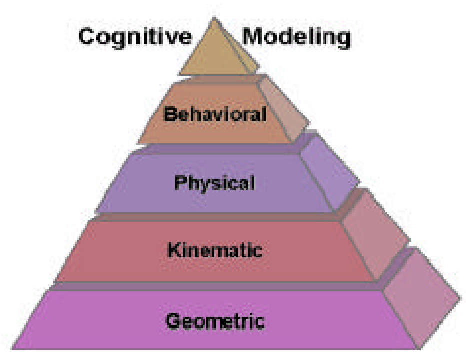


Figure 2.1 Hierarchy of modelling techniques for computer animation (Source: Funge et al., 1999).

Geometric models and inverse kinematics models do simplify the key-framing technique, while physical models find use in animating particles, rigid bodies, deformable solids, fluids, and gases by offering the means to generate copious quantities of realistic motion through dynamic simulation. Behavioral modeling aims to create self-animating characters that react appropriately to perceived environmental stimuli. Cognitive models enhance the behavioral models by directing the knowledge imbued in characters, how that knowledge is acquired, and how it can be used to plan actions. Here one encounters highly autonomous, quasi-intelligent characters found in production animation, interactive computer games, and playing subsidiary roles in controlling cinematography and lighting (Funge et al., 1999).

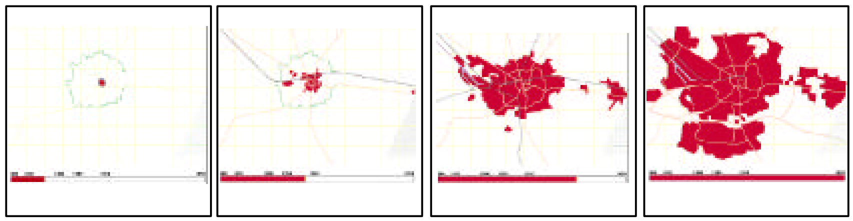
2.3 Cartographic animation

Cartographic animation is about change, change of geospatial data components of location, thematic attribute and time. Their real power lies in showing the interrelationship between these three components.

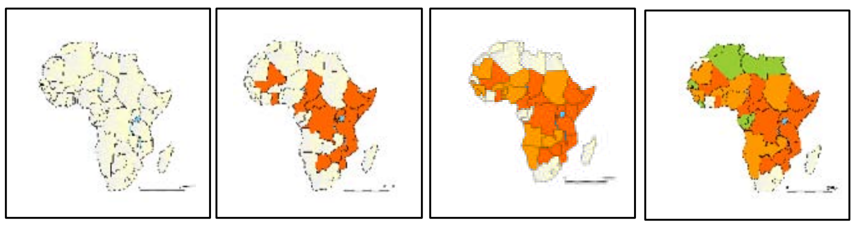
Descriptions of the potential and evolution from traditional animation to computer assisted creation of animation are detailed in Thrower (1961), Cornwell & Robinson (1966), Moellering (1972; 1973a; 1973b, 1980), Rase (1974), Tobler (1970), Campbell & Egbert (1990), Karl (1992), Peterson (1994; 1995) and Acevedo & Masuoka (1997). Earlier efforts to formulate a conceptual foundation for the design and use of animation in cartography can be seen in Monmonier (1990), DiBiase et al., (1992), Ormeling et al., (1995) and MacEachren (1995). Early animation formats were in: Apple's Quicktime, Moving Pictures Expert Groups (MPEG), Microsoft's Audio Video Interleave (AVI), Macromedia's Shockwave file (SWF) and Virtual Reality Modeling Language (VRML).

The changes in the components can be used to classify them into: temporal animation, animation with a successive build-up, and animation of changing representations (Kraak & Klomp, 1995). Temporal animation show changes of geospatial patterns in time (*Figure 2.2a*). In these animation, a direct relation between display time and world time exists i.e., world time is displayed in a temporal sequence and a transition between individual frames indicates change in the geospatial data's location and/or thematic attribute component. These animation offer geo-scientists the opportunity to deal with and monitor real world processes as a whole (DiBiase et al., 1992).

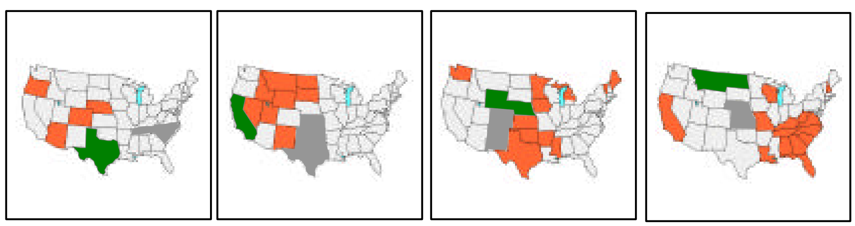
In the case of a successive build-up animation, the temporal geospatial data's component is fixed, while the thematic attribute and location components are varied during display time (*Figure 2.2b*). In animation of changing representations, all the three geospatial data's components are fixed. External influences, which may involve graphics or data manipulations, are then plotted against display time.



(a) Temporal animation



(b) Successive build-up animation



(c) Animation of changing representation

Figure 2.2. Classification of animation (a) temporal animation showing the location changes of the growth of a town, (b) successive build up animation showing incremental adding up of map layers, and (c) animation of changing representations by manipulating data through varying the classification methods used [Source : Ogao & Blok, 2001]

The types of animation mentioned above can be used in mapping dynamic environmental processes based on the user goals and nature of the data (Kraak & Klomp, (1995), Ormeling, (1995). 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. This arises from the need to deal with real world processes as a whole rather than in instances of time. The ability of temporal animation to mimic real environmental processes in world time makes them effective in conveying dynamic environment phenomena (Baek & Layne, (1988); Hays (1996); Rieber et al., (1990)).

The complexity of environmental processes can be expressively represented by successively building up individual features (map layers). An example of successive build-up animation involves displaying regions of intense air pollution, where alternating categories, from regions with high to low pollution values are shown. Blinking symbols or exposing alternating image frames of the same representation but at different geospatial resolutions could be used to highlight hotspots, reveal patterns or points of interest through their ability to attract the viewer's attention. Practical application could be in traffic flows to highlight accidents, in weather patterns to pinpoint emergence of tornadoes, or hurricane formation.

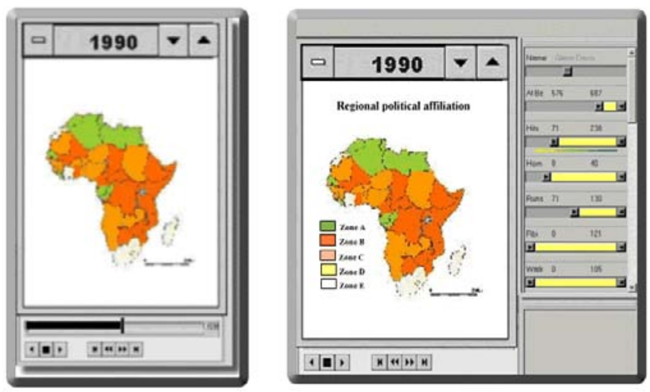
Animation can have a narrative character. They often tell a story (Monmonier, 1990). The flow of the story can be influenced by application of the dynamic variables (MacEachren, 1995). Most prominent of these variables are *duration* and *order*, which have a strong impact on the animation's narrative character. They define the time an individual frame is visible, as well as the order of the frames. In case of a temporal cartographic animation *order* presents the viewer the link to world time. For the user of a cartographic animation it is important to have tools available that allow for interaction while viewing the animation (Monmonier & Gluck, 1994).

2.3.1 An alternative classification

In practice animation have varying levels of interactivity, an aspect that goes a long way into determining how far users can get involved in compiling, controlling and interacting with the contents on display. We can distinguish between three types of animation based on their varying levels of interactivity. *View only* animation are the most common (*Figure 2.3*). They are passive in nature with minimum interactive ability. These animation are meant to function with little or no interference from the viewers, thereby leaving no room for viewers to modify the sequences of the images or frames making up the animation.

Interactive interface animation uses interface controls as seen in media player controls of *play, backward, forward* and *pause*, while the interactive contents animation employs an environment that supports a user definition of animation sequences and manipulation of their contents. This latter case can either be effectuated *directly* onto the features in the frames or *indirectly* using the interface tools.

The directly interactive animation go beyond just providing media player controls. Additional controls in the form of buttons, active legends, and switches for turning layers on and off during plays are provided. Indirect interactive animation deploy varying levels of interaction between the user and the animation. Their nature encompasses media player control tools to start, stop, pause, and fast forward/rewind the dynamic display using either command menus or buttons.



(a) (b)

Figure 2.3 Varying levels of interactive animation of successive build-up type

There is also an animation environment that is characterized by dynamically linked views, where the main view is supplemented by alternative synchronized views of either the thematic or geospatial attributes of the subject at hand (*Figure 2.4*). The views may consist of re-expressed graphic representation resulting from the transformation of the original data.

Playback animation are best suited for presentation purposes, while interactive animation could perform in both presentation and exploratory environments. The ability to engage users in interactive data selection, query and answer sessions are important data exploratory tools that an environmental scientist could find useful. This frees users from being confined to pre-determined animation paths and allows the facts to be represented, experimented with and analyzed with different combinations of data, map projections and graphic symbols.

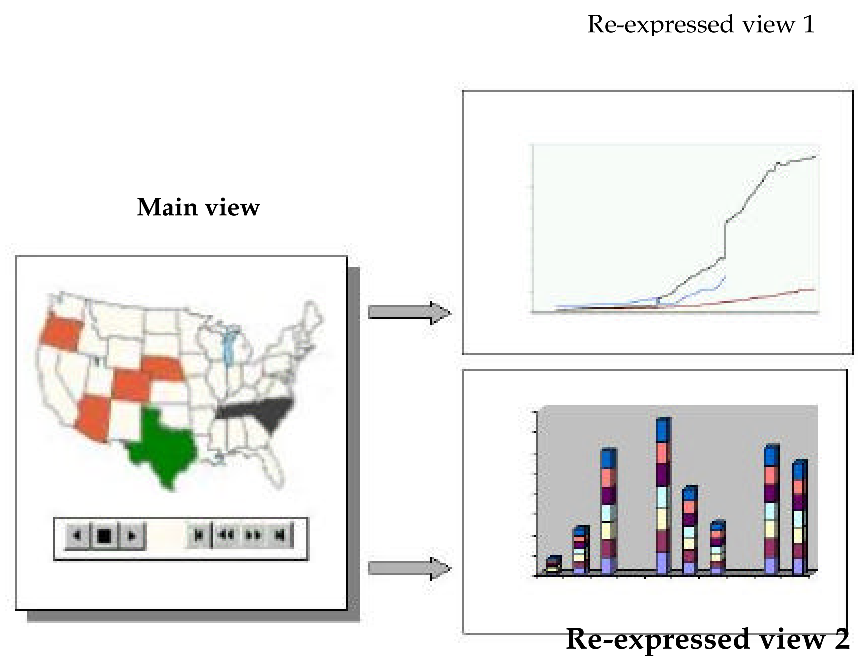


Figure 2.4. Animation with dynamically linked views

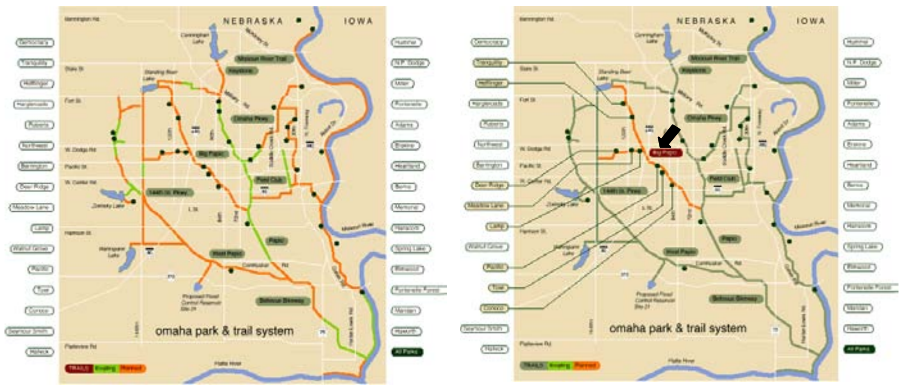
The potential of animation showing interrelationships between the temporal, location and thematic attributes of the geospatial phenomena has led to the implementation of yet another analytical component termed the *brushing* technique (Monmonier, 1990). Brushing is an interaction technique that is used for analyzing multivariate data. It was first applied in scatter-plot matrices (DiBiase et al., 1992). Using this technique, it is possible to link the displayed map to a slide scale in such a way that changes in a data set are viewed geographically, chronologically or in thematic attribute. As such, the user gets an overview of the relation between geographic objects based on location, thematic attributes and time. Applying the linked brushing concept into the temporal realm, allows users to recognize important periods during temporal cycles. A slide bar in which location in time is represented by a marker on a line that depicts the time span of the animation or through numbers that represent time in discrete units can be used to represent linear time (Kraak et al., 1997).

2.3.2 Overview of existing functionality

There are a wide range of commercial packages that are used for creating and displaying cartographic animation. Slocum et al., (1994) presents a list of software tools that are suitable for exploratory cartography. They include: Advanced Visualizer (AV), Interactive Data Language (IDL), SpyGlass (S), Data Explorer, (DX) and Khoros (K). Macromedia's Director and Flash software (*URL 2.1*), World Construction Set (WCS) by 3dNature *(URL 2.2)*, Curious software *(URL 2.3)* have reputable capabilities for animation production and posting on the Web. These packages are not explicitly animation software; rather they incorporate other visualization capabilities of which animation is but one for data display techniques. General animation functionality allows for generation of animation using key-frames, whose in-between frames can be generated depending on the behavior the phenomenon depicts. The maps can be zoomed in or out, panned or rotated, details can fade in and out, text written on, region colors faded etc. Feature layers could be added (put on/off). Possibilities for incorporating movies, video clips and text characterizes these packages. The animation apart from being generated as sequences of images can also be output in the form of video, or movie files.

Vis5D handles temporal geospatial data in a 5-D framework encompassing location, time and attribute. Time can be visualized as animation (Hibbard et al., 1994). Vis5D is commonly utilized within disciplines in atmospheric sciences. Another recent product is MapTime, a software package for exploring temporal geospatial data associated with point locations and which also has animation display capability (Slocum et al., 2001).

In earlier animated maps, the explanation of features rested entirely on the map author. Buziek (1999) proposes a variety of design considerations for animation. They include; focus of the user's attention to a selected object, explanation of an object by the text on the screen, additional explanation by spoken text, graphical insertion of a legend field and, visual guidance of user to the next map object. Others who have explored design aspects of legends in animated maps include Peterson (1999) and Kraak, et al., (1997). They acknowledge the dual task that legend in animated maps play for navigation purposes and providing the essential information about features appearing in individual frames. The concepts of *mouse over* and *click on* could well be used for both identification and locating geospatial features (*figure 2.5*).



(a) Before mouse over *(b)Mouse over area indicated by a black arrow*

Figure 2.5. Illustrating the *mouse over* technique. (Source: Peterson, 1999)

Harrower and MacEachren (1998) explore focusing and brushing as data analysis methods that when integrated with map animation produce a manipulable dynamic representation that facilitates conceptualization of time as both linear and cyclic. Temporal focusing reinforces the linear characteristic of time and is used here to adjust the start and end dates of the animation, while temporal brushing brings out the cyclic characteristic of time and here is used to select what times of day are to be included in the animation.

The use of an analogue clock in which location in time is represented by the orientation of a dial or hands is a suitable way of explaining cyclic time, such as the day or seasons. Whereas tools can clearly depict location within the temporal cycles, they fall short of portraying location in the full time span.

The use of sound to represent time can relieve users from the burden of divided visual attention. Use of narrative sound can be used to depict instances in time and the passing of time by sonic sign vehicles (Kraak, et al., 1997). Sound can also be used in animation to convey uncertainties surrounding geospatial information (Fisher, 1994). *Figure 2.6* illustrates the concept by which linear time can be depicted.

There have been efforts to use animation to depict uncertainties, fuzzy and complex objects and relationships (van der Wel et al., 1994; Blok, et al., 1999; Jiang, 1996; Peuquet, 1999).

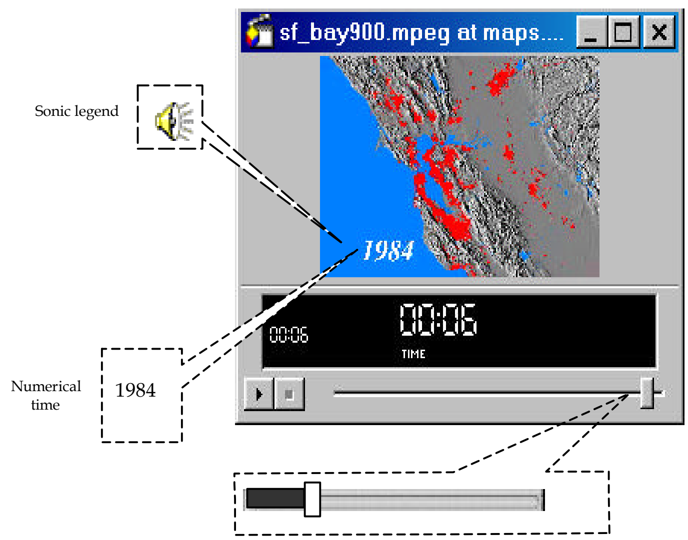


Figure 2.6. Illustrating the concept of using a slide bar, numeric and sonic legends to represent linear time in animated maps. In the case of the slide bar, past events are depicted by filling or darkening the area before the pointer or indicator. Adapted from Acevedo and Masuoka, 1997)

When viewing complex temporal geospatial changes in an animation, there is the tendency for users to fail to recall past patterns because recent sequences are obscured by the entire past history. Robbins and Robbins (1998) outline ways of overcoming this phenomena by employing animation that superimpose previous frames over the current one and also leave a fading track of the motion of an object.

Application oriented research studies are numerous, covering a wide range of disciplines. DiBiase et al., (1991) looks at the experimentation of tools that allows analysts to see models and the consequences of their predictions in temporal geospatial sequences as applied to earth sciences. Mitas et al., (1997) reports on a simulated landscape process based on multivariate fields. Weber and Buttenfield, (1993) apply animation to the study of average yearly surface temperatures for regions over a period of time. Andreinko & Andrienko (1999) used a software

DESCARTES (formerly called IRIS) to facilitate exploration of spatially referenced statistical data by incorporating an automatic map generator supported with interactive tools for data analysis.

Animation use in environment studies involves both presentation and exploratory tasks. An example involving a presentation task may be to dynamically map aspects of global warming by visually depicting results of experimental numerical projections of the global climate based on observed historical data, or specific climate models. Exploratory tasks enable domain expert users to search for geospatial patterns, steered by their knowledge of the phenomena and processes being represented by the interface. Examples of specific animation uses can be found in DiBiase et al., (1992) who, based on an earlier study on climate changes in Mexico, used a chronological ordered animation and scenes of a re-ordered and paced sequence viewing to observe temperature and precipitation variations and discrepancies in cities. Their whole case study traverses both ranges of using animation for presenting information and those that are highly exploratory in revealing the unknown in data sets.

Acevedo & Masuoka (1997) used time series animation techniques to visualize urban growth. Using data of land-use changes for the Baltimore-Washington region from a TGIS, with various land-use themes, resulted in views encompassing both 2D and 3D animation.

Choosing animation for representing certain aspects of the environment may be based upon reasons ranging from: their ability to enhance learning, acclaimed preference or superiority to other graphical representations, ability to optimize search operations and reduce load on working memory. Studies in animation and static representations portray a glean intuitive-led basis of some of these choices. The basis of their use should not just be guided by the impressive graphic mix, interactivity and dynamic capabilities, since these parameters do affect novice and expert users differently and should also depend on whether they are used for presentation or exploration purposes (Scaife & Rogers, (1996), Jones, (1998)).

The general question being addressed above concerns how to delineate between the new, different and capturing influences of animation and their functional influences especially as regards geospatial data representations. Whereas Moellering (1980) gives some clue to a similar dilemma involving 3D animation, we nevertheless have few animation use studies undertaken especially to highlight the underlying influences of the various animation components on learning and exploration tasks.

Animated stereo images are commonly being seen in meteorological applications (Papathomas et al., (1988); Papathomas et al., (1990), McCaslin & McDonald, (1996) and oceanography Marshall et al., (1990)). Stora et al, (1999) provided a visual realism in both motion and rendering by animating Lava flow. Other animated maps are those of global seasonal vegetation productivity, simulation of global climatic effects of increased greenhouse gases, fire dynamics by use of the Moderate Resolution Imaging Spectroradiometer (MODIS) to detect, identify and characterize wild fires (Kaufman et al., 1998) and Hootsmans (1996) and Blok et al., (1999) on fuzzy representations and analysis of geospatial data.

Generally, the way animation are being applied in environmental disciplines seems to be taking an integrative approach, where the need is to harmoniously merge the acquisition technology, and the visualization system, in this case animation, to enormous data sets. For time sensitive applications, it is being geared towards real-time intelligent analysis.

2.4 Cartographic animation & WWW

Maps are increasingly being used as primary real-time visualization tools in an interactive and dynamic environment. Here they are being used to explore geospatial databases that are hyper-linked together through the World Wide Web (WWW or Web). The Web as an object-oriented environment supports access to a variety of dynamic, linked object forms that depict geo-referenced information (MacEachren, 1998). It similarly supports both interactive and dynamic tools that can give access to hyper-linked documents. Data sets that can possibly exploit the Web's abilities are ones that are posted, updated and accessed frequently from multiple physical locations. There is a need to address a number of issues related to the Web and geospatial data such as the visual, digital and cognitive aspect of representation.

Research studies in cartographic animation linked to the Web are seen in special issues of C*artographic perspectives (Vol.26, 1997), Computers and Geosciences, (May 1997)*, *Cartography and GIS* (*Vol.2, 1999),* MacEachren & Kraak (1997), Ogao & Kraak (2000) and Ogao (2001a). The Web enables the distribution and display of cartographic animation on virtually any computer, anywhere (Peterson, 1995). The Web also provides a conducive environment for implementing animation as it enables the design of manipulable animation with the user having control of the direction, pace and other animation design elements (MacEachren, 1998 and Peterson, 1999).

2.5 Influencing factors in animation design & use

A number of factors influence the nature of cartographic animation meant for exploratory environments. Among these factors are; interface options, data characteristics, users and their intents (in what will be described *Chapter 3* as *visualization operations*). The individual controlling factors termed *dynamic variables* (DiBiase et al., 1992; MacEachren, 1995; Ormeling et al., 1995; Blok, 1997) will only be addressed as seen and implemented through different forms of interface options. Some aspects of the influencing factors have already been introduced in the opening paragraphs of this chapter. The rest will make up a considerable component of chapters 3 and 4. As an overview we look at them concisely in the paragraph below.

The proliferation of hardware and software tools, coming out as a result of the advances in the computer industry means that we have faster computers, more complex graphic software, faster data acquisition, storage, processing and visualization techniques. With these combinations, users are experiencing an upsurge of visualization tools centred on the words interactivity and dynamics (MacEachren & Kraak, 1997). Interactive tools allow for increased and effective user interaction (interface options) with the contents of the displayed map and even access to the data behind the display. This significantly improves one's ability to understand data, perceive trends, and visualize real or imaginary objects in a faster and more effective way.

Different maps will incorporate different functionalities depending on their use, availability and nature of data, all under the domineering eye of the available technology. Ideally the user goals or needs dictate the type of data that will be used, while the realities of data acquisition techniques determine the availability and format of data. The composition and structure of the available data does influence the kind of manipulations that can be effected by the user.

Map users in both presentation and exploratory environments exhibit unique use and domain knowledge characteristics. Users may be novice or domain experts, their purpose may range from learning, or discussing information to exploring raw data in pursuit of some new knowledge or hypothesis (MacEachren & Kraak, 1997). Differences between expert and novice users of maps stem from the fact that experts have the ability to construct more extended and elaborate mental models of a given representation and rely more on their rich knowledge about the properties of the phenomena's behaviour within their domain disciplines.

For data presentation purposes, and that which encompasses use by novices, simpler animation are preferred as they are effective enough in conveying the intended message and are readily understood. General care should be taken to ensure that the animation is not overused to such a level that it distracts the users. Here, animation should capitalize on their ability in portraying motion and trajectories. For exploratory purposes, the need is for tools that allow the user to look at geospatial and other geo-referenced data in any combination, at any scale, or resolution with the aim of seeing or finding geospatial patterns.

The nature of the data at hand also influences the type of animation that can be used. For example, bitmaps as opposed to vector images may inhibit complex interactions between the user and animation. Using vector data may allow for the autonomous existence of features and behaviour, aspects that influence exploratory tasks. Thus animation in this latter case are flexible and have non-linear playback paths consisting of loops and branches and representing user defined explorative pursuits. Data resolution and map scales will probably influence the reconstruction of events and processes in animation, an aspect that may be crucial in steering understanding.

2.6 Summary

Cartographic visualization is not new to cartography. Much has been studied and produced within the presentation realm of map uses. Exploratory cartography nonetheless is increasingly being used on a larger scale than before. Many factors have contributed to this situation, including the easy availability and use of computer graphic software, availability of an enormous amount of raw geospatial data, and changing user needs. In order to enable a continuation of effective map design using cartographic methods and techniques, cartographers find themselves with the role of helping software developers make tools that will facilitate data exploration by scientists. Among these tools, are those that can be used to dynamically explore geospatial data such as animated maps. One of the challenges facing software developers is for them to design and incorporate useful functionalities in animated maps that will enable geoscientists to communicate as well as to explore geospatial data sets more effectively.

3

MANIPULATING TEMPORAL GEOSPATIAL STRUCTURES

"In every walk with nature, one receives far more than he seeks." ANONYMOUS

The preceding chapter has outlined the distinguishing characteristics that are exhibited by exploratory cartographic environments. Users in this environment are expert domain users, bringing with them specific disciplinary knowledge as they seek to uncover hidden structures or meaning in raw data sets. The basic tools needed here engage the users in an interactive, undirected search for patterns, trends and relationships. Issues crucial here are those that exploit the inherent structures in temporal geospatial data sets, and enable the user to perform exploratory tasks using interactive and dynamic tools implemented by using appropriate interface options.

The chapter highlights four main issues that form the basis for defining functionalities for interactively manipulating geospatial data sets within an animation environment. These are: data characteristics, user tasks projected in the form of visualization operations, interactive interface options that enable the user to control and manipulate the map and data sets therein and lastly imbuing animation features with intelligence to enhance feature to feature interactions.

The approach presented here differs from earlier research studies in that, previous works were mainly focussed on the passive, predetermined, goal-oriented animation, whose objective was to communicate *a priori* fixed facts to users and to enable them to confirm derived hypotheses about the data. Here the focus is on interactive animation and their use by domain experts to perform exploratory tasks of unravelling hidden meaning in the raw data. This is the initial step to outlining a theoretical basis to defining cartographic animation functionality which encompasses understanding the underlying temporal geospatial structures, user's visual intents that define the visual operations to be performed on the display and an animation nature that embeds an inference mechanism within its geospatial objects thereby enabling the animation to autonomously make decisions and respond to the user and other geospatial object's actions during run-time.

3.1 Manipulating space-time data structures

Claramunt & Theriault (1995) outlined a framework of temporal geospatial processes that characterise typical processes in geo-science disciplines. The framework outlines processes involving the evolution of features, functional relationships between features and those concerning the evolution of geospatial structures amongst features. Our intention here is to outline how temporal cartographic animation functionality can be defined based on typical patterns, trends and their relationship as highlighted in this and similar typologies (Blok, 1999; Yattaw,1999).

A change is observed when new features appear and, or disappear after being in existence for a while. Changes are also observed when features undergo changes in shape, size, orientation and, or location. An example of this is seen in satellite image interpretation for cloud cover identification. Here clouds, which in essence change location in time, can be identified from the attributes they exhibit. Their edges may be ragged or well defined in shape. These shapes and their sizes, together with the cloud's attributes of brightness, texture and organizational patterns are all significant when identifying specific types of clouds (Conway, 1997).

Whereas the example of cloud identification affected only a single feature, there are cases where changes occur as a result of two or more features exhibiting a relationship between their attributes in time. An example can be seen in the building up of the storm phenomena. The basic building up phenomena for a storm are; rain and wind. Of these, the phenomenon of rain arises when the weather attributes of temperature, humidity and pressure interact under certain conditions or constraints. As used here, animation are able to show changes between inter-dependent weather features and the results of their interaction and relationship in time. By this, they facilitate the process of enabling users to distinguish between the agent(s) invoking the change and those that are being modified by its action.

When dealing with single or multiple entities, the temporal structures that are of interest to users are those that allow for the representation of occurrences and events as defined by Allen (1981) and shown in *Figure 3.1.* An event a starts at time t_1, and ends at time t_2. An event a can occur before an event b appears, or can disappear at the moment when b appears ("a meets b"), or can be in existence at the same time as event b ("a overlaps b"). Event a and b can start and end at the same time ("a equals b"). An event a can trigger the start or end of an event b ("a starts b", "a ends b"). An event a can contain an event b ("a contains b").

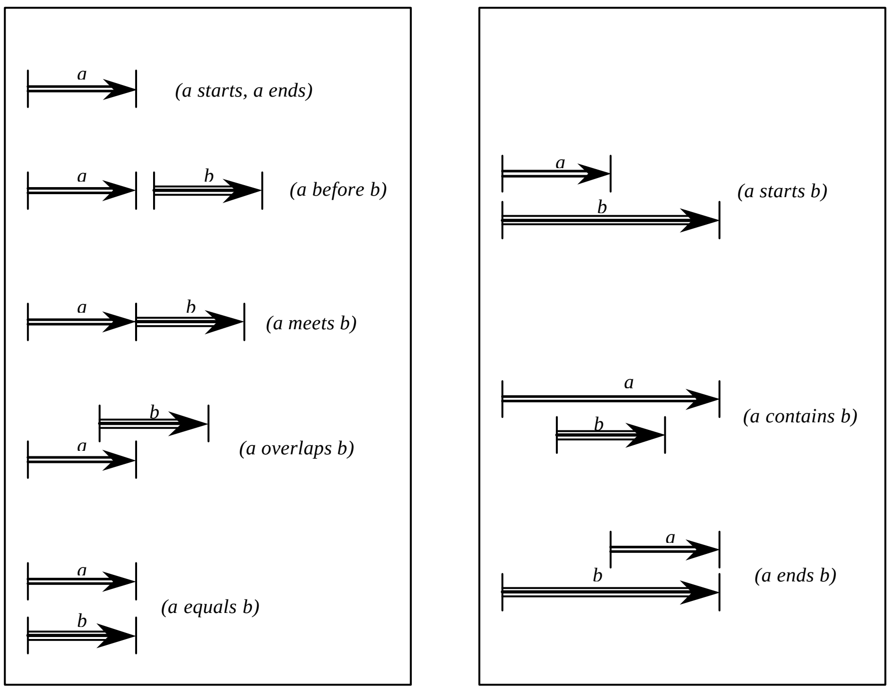


Figure 3.1. Temporal relationships between intervals (after Allen, 1981)

Apart from highlighting the typical temporal geospatial changes, we also acknowledge the queries that may be posed in relation to the changes under observation. Langran (1992), and Peuquet (1994) derive queries based on the what, where, and when of the geospatial data's component. Whereas previously animation had been used mostly in relation to historical or previously recorded data, we are seeing more and more use in simulation and modeling tasks. Here, the what if aspect of the geospatial data queries can be used to forecast a future scenario.

When viewing temporal cartographic animation, there are a number of ways in which changes can be further characterized. Social science, linguistic, and psychological approaches to these characterizations are the subjects of numerous research studies (Blok, 1999; Yattaw, 1999). Changes can be continuous as in motion or movement, cyclic or discrete, such as the change in shape of geospatial objects over time. Changes can be slow, fast, or abrupt. Changes can occur on individual features or an agglomeration of such features. Users can identify distinct objects, their regularity, anomaly, and areas of interest. The emphasis during observation is on the ability to display, at an appropriate scale and temporal resolution, features or patterns that are surprising or anomalous in some way.

From the aforementioned, we recognize the distinct temporal geospatial structures that characterize geo-phenomena and the way temporal cartographic animation can aid in unravelling them. These structures encompass having knowledge about when features come into view and when they go out of view, the temporal structures involved in interval relationships and the ability to track and control attribute and location relationships. Below we look at the way these temporal geospatial characteristics can be modeled into specific visualization operations, an aspect that is a pre-requisite for our definition of the design model in the implementation level of animation tool design.

3.2 Mapping user intents to visualization operations

The crucial role of users in present cartographic practice is depicted by what Morrison (1997) described as the "democratization of cartography", a trend within electronic technology where the map user is no longer dependent on what the cartographer puts on the map. In essence users have a wider choice to manoeuvre and explore geospatial data sets using functional tools at their disposal. This reflects a common trait in exploratory environments where the user's role is central and drives the whole interactive search for structures and trends to provide an hypothesis about a given data set.

In general, a user's needs during visualization may vary between presentation and exploration of geospatial data. The needs are made up of a series of tasks or a list of processes that are undertaken and invoked within the confines of the user's thought processes. *Figure 3.2* illustrates the central role that users and the tasks they undertake play in a visualization process (Knapp, 1995).

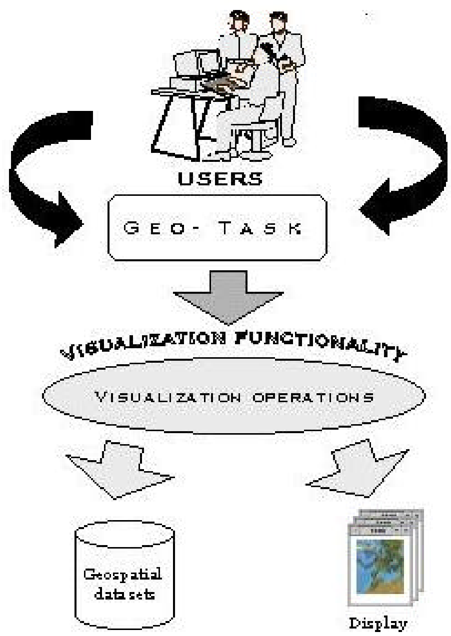


Figure 3.2. The role of user task in an exploratory visualization process

The task being undertaken has specific requirements in both data and map design strategy. The same data could be visualized using different techniques, with each technique supporting different tasks. Also, the availability of data will determine whether these needs are achieved or not. On the other hand an effective map design is greatly influenced by the tasks that the user intends to undertake.

In our approach visualization operations through their visual accomplishments, describe the mechanism by which user tasks are effectuated. A user task may require one or more visualization operation and a specific technique may support more than one user task. These visualization operations may be directed to the map on display or the data behind it with the result that they effectuate some changes in the user's mental state or display environment. The visualization operations that follow might be perceptually motivated, and, or backed by concepts already known to the user. In essence what is needed are prepositions that describe the user's probable tasks. In exploratory environments, the map serves as a starting tool to an iterative process of knowledge discovery.

To illustrate the concepts of user tasks, visual tasks and visualization operations, an example based on weather data visualization is used. Take a case where a user intends to explore the dynamic weather sequences using satellite images, surface measurements and weather maps for regions in the United States. Undertaking these tasks involves executing a list of processes or user tasks. One will have to ensure that the correct weather data is available, and if not, where and how they are to be collected. One can select weather variables, techniques and geographic views when compiling weather maps in readiness for the playback *(see Figure 3.3).*

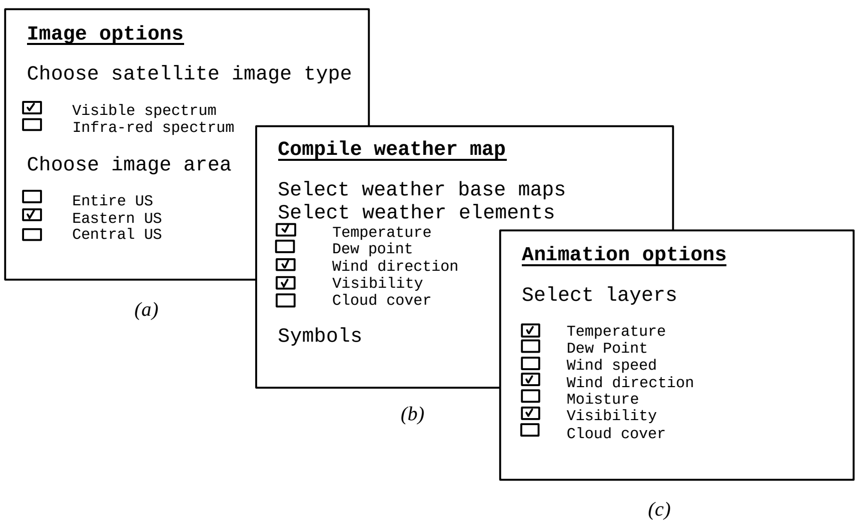


Figure3.3. Decomposing user needs into a series of tasks

Equipping the animation interface with playback and legend tools could enhance the process of identifying and locating specific variables at specific instances or intervals of time. These operations that are performed on the image on display are in an exploratory environment and arise from the features momentarily being displayed and from the user's wealth of domain knowledge. In the next section we focus on these visualization operations and the role they play in enabling users to manipulate the temporal geospatial structures discussed earlier.

A wide range of operations can be performed in such a set-up. One could select and animate single layers of weather variables, similar to the *six panel Image* that displays the six atmospheric variables mapped as colour (Fishman & D'Amico, 1994) or have different views of different weather variables on the same window for comparison purposes *(Figure 3.4*).

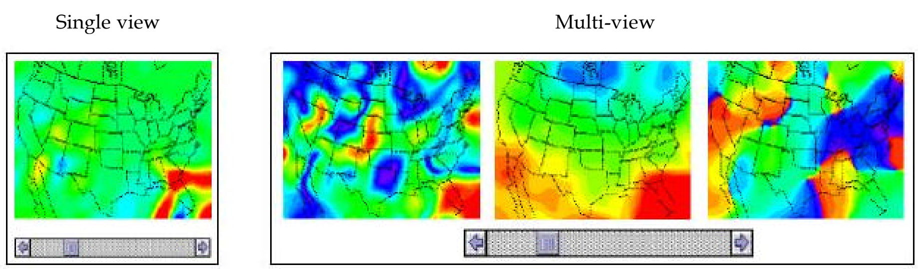


Figure 3.4. Single and Multi-views of animated weather variables (images source: Fishman & D'Amico, 1994))

3.3 Visualization operations

User centred task analysis methods have previously been used in system and user interface designs. The methods point to the importance of having explicit representation of user's needs in design processes. Wehrend & Lewis (1990) and Zhou & Feiner (1998) identified the following domain-independent classification of visualization operations; *locate, Identify, distinguish, categorize, cluster, distribute, rank, compare, associate, cluster, background, emphasize, generalize, rank, reveal, switch, encode, and correlate*. Knapp (1995) condensed these tasks into four; that is *Identify, locate, compare and associate*. Whereas these visualization operations can find application in various visualization techniques, our concern here is to apply only those that are relevant and functional in temporal cartographic animation (Ogao & Kraak, 2002).

Identify, locate, associate and **compare** form the basic visualization operations that are widely used and exhibit a more logical flow when analysing geospatial data. The task **identify** refers to describing an object which was previously unknown, whereas **locate** indicates a search for an object whose identity is already known. These two tasks enable the user to track down a particular process during run-time. Implementation of tools that effect these tasks can either be done before (through training programs) or during run-time. Similarly the ability to relate two different features in the displayed image, and which is effected by using **associate** and **compare** visualization operations, should be among the basic tools. An example of how relating visualization operations to the observed changes can be effected in tool design is depicted in *Table 3.1*. The **Identify** visual operator seeks to answer the, *what* aspect of the temporal geospatial generic query. The *what* question seeks to identify objects in the display - a task that can be fulfilled either by issuing an attribute name or giving the geometrical descriptions of the object. These tools have been implemented in interactive maps such as in *point and click* and, *mouse on/over* techniques commonly used with hypermedia environments.

Whereas some of the tasks in the table can be implemented on static interactive displays, their use in animation remains a challenge. Similarly some of the tasks in the table are better implemented using computational approaches for exploratory data analysis.

The definitive characteristics of the results column in *Table 3.1* relate the visualization operations to the expected visual result. Both qualitative and quantitative results are expected that incorporate time instants and intervals of time. The implementation will involve either varying the graphic, dynamic or data behind the display. Manipulating temporal cartographic animation entails locating specific frames and sequences of frames as well as events. Operations specifically ought to include examining relationships between features and events embedded within the temporal geospatial data.

Since temporal animation show changes or interrelationships amongst geospatial data components of location and attribute components with time, users will want to view the state of a process at a particular moment in time and between intervals of time. There will be a need also to compare different processes at a particular moment in time and to track their movement and behaviour over a given period of time. Based on the characteristics of the temporal geospatial processes, and the visualization operators reviewed in an earlier section, we list some essential visualization operations that geoscientists could benefit from when working with temporal cartographic animation.

i. **Identify** and, or **Locate** changes at a time, $t_{1,}$
ii. **Identify** and, or **Locate** changes between intervals t_1, and $t_{2,}$
iii. **Compare** or **Associate** changes at a time , $t_{1,}$
iv. **Compare** or **Associate** changes between times, t_1, and $t_{2,}$

Secondary visualization operations, such as **collocation,** extend the explorative capabilities of these four. As applied in an animation environment, collocation is the ability to locate specific animation frames from a set of many based on some user specified temporal, or geospatial characteristics.

Table 3.1. The four main generic visualization operators

VISUALIZATION OPERATOR	VISUALIZATION SUB-OPERATOR	EXAMPLE OF DEFINITIVE CHARACTERISTICS OF RESULTS
IDENTIFY	Geospatial Identification	Length, area, irregularity Minimum, maximum, range, distance, pattern of distribution
	Temporal Identification	Extent - longest, shortest Sequence - first, last Category - nominal, ordinal, interval/Ratio Movement - continous, cyclical, intermittent
	Thematic Identification	Name, symbols (legend)
LOCATE	Geospatial location	(x,y), grid locations (rows, colums) Near, within, between, above, below, neighbourhood of
	Temporal location	Event/Valid time t, Observed Interval (t_1-t_2) Before, after, together, next
ASSOCIATE/ COMPARE	Geospatial association / Geospatial comparison	Topological relations, geospatial collocation, covariance, correlation
	Temporal association / Temporal comparison	Temporal collocation, time between objects, orientation, (before, after), adjacency (just before, just after), causality (correlation)

Effecting a visualization operation like collocation involves sifting through vast amounts of animation frames, an aspect that can be taxing in terms of retrieval and structuring for animation play during run-time. Through a **query** operation, users can access the contents of the database from within the display interface and results can be attained instantaneously. A query operation can in essence be a sub-operation of the operations discussed above, just as collocation can encompass the **identify, locate, compare** or **associate** operations.

The most feasible way that we can incorporate these operations in animated maps is through interactive interface options. The following sections highlight the role that interactivity plays in animation, and the diverse ways in which it can be implemented.

3.4 Overcoming linearity in playback paths

One of the earliest and commonly used methods for creating cartographic animation was the *frame-based* animation technique. Here a series of individual maps or images are assembled and viewed sequentially and in quick succession. The maps are viewed in a predetermined linear sequence *(Figure 3.5).* Being predetermined also implies that their sequence of display is fixed and thus they normally are characterized as passive animation - in that they are pre-designed to run with little or no interference from the viewers (Ogao & Kraak, 2001a&b).

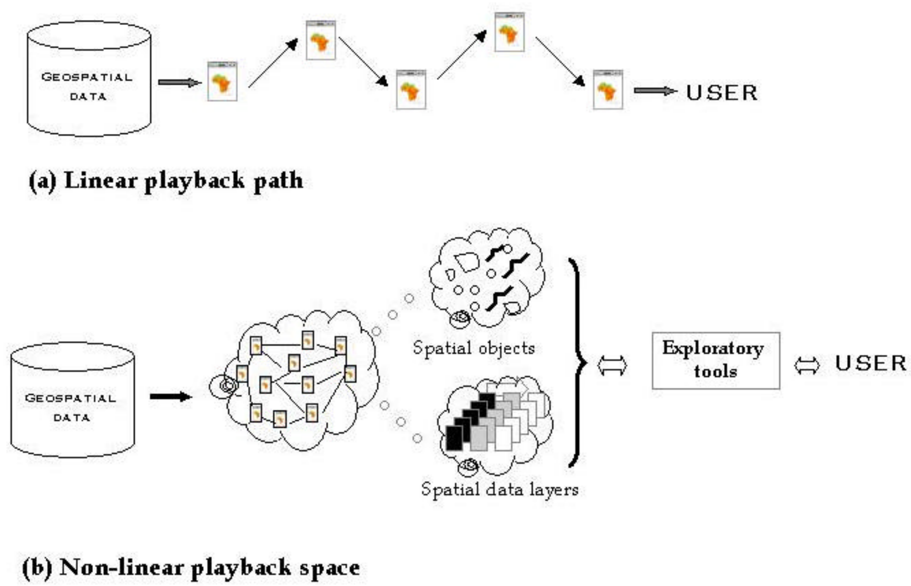


Figure 3.5. Linear and non-linear playback paths

Overcoming the fixed linear, predetermined animation paths that is prevalent in frame-based animation, can be achieved by giving the user tools that enable one to choose frames from amongst stored images and defining the path that the animation should follow. Alternatively images can be retrieved directly from the database computationally by having the user define the animation path and the system computes and fills in the appropriate images. This is a common technique when visualizing 3-D geospatial data using Virtual Reality Modeling Language (VRML). By using VRML browsers, viewers can walk-through or fly-by the virtual world wherever and whenever they opt to. In both these cases the computation and data transfer demands are quite high.

In exploratory environments, where enormous amounts of animation frames are involved, the need is for animation functionality that will enable users to choose frames from amongst stored images and define the specific paths for playback. Alternatively images can be retrieved directly from the database computationally by having the user define the animation path and the system computes and fills in the appropriate images.

More flexible non-linear descriptions of animation frames confine animation not just to a linear play path, but also to loops and branches. The ability to change which path an animation takes during run-time allows great scope for interactivity. By this an animator defines a lot of interpolating splines, and at run-time the system determines which one is used. However, this can be very time-consuming, since to make the animation responsive the animator will need to define a considerable number of different segments of animation. What we need are new motion synthesis tools that are responsive in that they allow an animator to describe a range of possible movements concisely. This requires the development of new motion synthesis tools that allow the animation to respond to the user.

Thus parallel to this, there ought to be development in interface options that allow for users to specify their queries and, the animation response parameters. This in essence will also determine the systems processing requirements. Real-time response is computationally engaging and thus requires computers with a high processing speed. Developers need to determine the optimal means by which changes within the animation are noticed whilst at the same time supporting interactivity, user goals and actions. Dynamic query abilities that specify queries and enable the visualization of their results by accessing the database and provide real-time feedback to the user's queries is crucial (Ahlberg & Shneiderman, 1994). Such query interfaces are faster, easier, more pleasant and less error prone than other query interfaces.

One reason for the low level of interaction when dealing with frame based animation is that in these animation, each frame is viewed as a graphic image in its entirety as opposed to individual features with each having more or less autonomous behaviour (Huizing & Barenbrug, 1997). This has the effect of limiting the level of user involvement in controlling the animation during run time. Perhaps, the use of animation where each graphic element is stored not as an image, but as a mathematical expression that describes its size, shape, position, and other attributes in relation to other objects and physical laws will suffice as a valid design approach. Such animation should find use in simulation and modeling tasks in temporal geospatial processes.

3.4.1 Model for visual interactivity in cartographic animation

Adding interactivity to visualization helps overcome some of the inherent hurdles common in static displays by allowing multiple and related visualization options to be available. In animation, this should significantly improve expert user's ability to understand data, perceive trends, and visualize real or imaginary objects (Foley et al, (1990), DiBiase et al., (1994)). Typical tools that interactivity offers include selection, transformation, query, navigation, orientation, multi-scale views, re-expression, linked views and animation (Kraak, (1998), Dix & Ellis (1998), Peterson, (1995), Shepherd (1994) and Cartwright (1996)). Interactive visualization tools can be used to steer processes, track changes and identify features that change as a result of variation in certain parameters in both real-time, modeled or simulated processes (MacEachren, 1995).

Interactivity is important in data visualization as a means for both exploring the information contained in the display and extending links to the data behind the display. This is because the current status of the animation environment inhibits query processes to the database from within the animation (Ogao, 1999). This link will enable an interactive visualization environment and visual data access that has a progressive real-time refinement of the displayed image. Interactive query processes and feedback capability will enable users to confirm, reject or steer evolving hypotheses. With interactive animation, the user has the power to control the views both spatially and temporally.

Visual problem solving tasks are iterative perceptual processes by which users formulate queries and use interactive tools to invoke actions and feedback (Tweedie, 1995). Problems can be reformulated in order to give rise to a different view of the same data. Users may also extract a new data set, or form a new specification of the problem, if either the initial one has been solved or its dimensions changed, and may require a new conscious plan altogether.

A typical scene in visual problem solving begins with the user extracting information from the visual product through an observation process that identifies the geospatial representations intended (e.g. …*an object of type B is present*, or *the river is to the left of the railway line)*. Beyond this, users engage in a visual reasoning process, where inferences are made from current information and background knowledge by explicit use of knowledge and inference rules. They are able to iteratively reason about the objects that they perceive and to add to or relate this reasoning to already existing knowledge. A simulation process might follow where a future state of the configuration and the corresponding perceptual observations are further represented. In *figure 3.6*, we highlight the view that image formation is not an end to the visualization process but rather a starting point to an iterative process of knowledge seeking. The user actions might be perceptually motivated, backed by concepts already known to the geo-scientist.

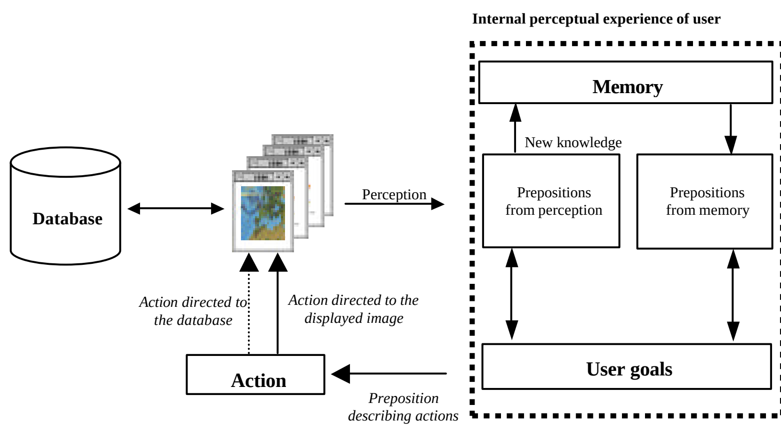


Figure 3.6. The basis of image interaction in cartographic visualization environments

The context under which this study is undertaken is signified by the user's need to engage the image on display in specific actions that may be directly addressed to the representation on display or the database. In essence what is needed are prepositions that describe the user's intended actions, an aspect that is important in tool design for interactive visualization.

3.4.2 Modes of interaction

The dynamic nature of cartographic animation makes it difficult to perform geospatial analysis tasks and to effect user control of the animation during playback. In general, there are two conventional ways of employing interactivity between the viewer and the display. These are by *direct* and *indirect* manipulations (Thomas & Demczuk, (1999), Beier, (1994)). A third form of interaction that can be used to counter the animation's fugitive nature involves having interaction between the represented autonomous graphic features (animation frames). We will provide the general concepts behind direct and indirect interactions and in the next section provide the detail on interactivity between autonomous geospatial objects which utilize an inference mechanisms embedded within the animation frames, thereby enabling them to make decisions during runtime.

Direct manipulations are characterized by: immediate feedback to actions, incremental changes, and reversible effects (Shneiderman, 1983). When applied appropriately they give the illusion that users are directly interacting with the geospatial features on display. Features can be selected, dragged to a new position, rotated, stretched to make them larger etc. The manipulation is simple to use and easy to understand since the user's focus and attention is directed towards the visual changes as they occur. Crucial to this type of interaction is the ability to give feedback in real-time which is much dependant on the rate at which computations are performed and images displayed. Whereas direct manipulations are instinctively preferred, they fail when it comes to actions that require a greater precision or when dealing with hidden features in the display. An example of such an action may involve a user transforming a displayed feature by a specified angle of rotation or moving a symbol to align it with another. These actions can be implemented by using commands either through use of buttons, toolbars or command scripts. Examples of such interactions are the *mouse over* and *click-on* (Peterson, 1999).

Indirect manipulations perform transformations of the displayed graphical objects through command menus and buttons. The most common tools by which users indirectly interact with the animation is through the media player controls; *play, pause, fast forward/rewind buttons* and to some extents through active legends and sliders. The functionality mainly addresses the interrelationships between the temporal, location and geospatial attributes of the phenomena.

3.4.3 Interactive geospatial features

So far cartographic animation in geospatial applications have focussed on visualizing historical data. Maps, images or data previously recorded have featured more frequently in these dynamic displays. Lately there has been an increased interest to "visualize the future". Manipulating data sets behind the map representation is one sure way of gaining understanding of the future. This is seen in environmental processes such as climate change, pollution, land degradation, desertification and deforestation, among others. These processes exhibit characteristics typical of temporal geospatial processes that are representative of the dynamic earth processes. Basic processes that depict the appearance and disappearance of entities and those processes involving movements and trajectories can easily be depicted in temporal cartographic animation. Interest here is in the individual patterns, trends and anomalies that characterize these processes. It is quite practical to animate individual layers, and even to overlay separate layers by synchronizing the animation's time line.

Showing relationships between different temporal geospatial entities can similarly be enhanced using temporal cartographic animation. But the nature of the animation has to take a different form, since some relationships or interactions between geospatial features or entities give rise to subsequent new entities, as seen with diffusion processes *(Figure 3.7)* where a transfer of characteristics between geospatial entities takes place (Claramunt, 1995). For example, a production process involves the creation of new geospatial entities from the actions of one or more entities of different natures. Where the parent entity is of the same nature as the newly created entities, then a reproduction process arises. At times, a transmitter entity modifies the characteristics of a receiver entity resulting in a transmission process. These processes are typical of temporal geospatial phenomena that characterize geo-spatial applications.

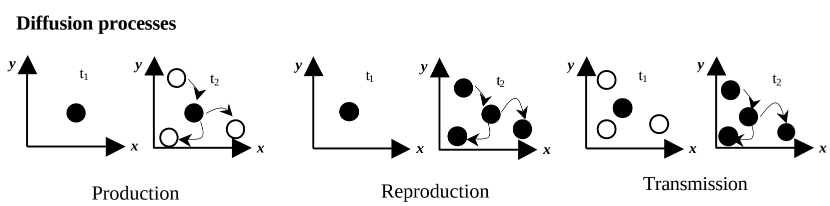


Figure 3.7. Functional relationship between entities (Source: Claramunt and Theriault, 1995)

One way of effecting this capability in cartographic animation is by embedding an inference mechanism in the animation frames to depict the autonomous and interactive behavior of a specific geospatial attribute or phenomena being represented. When animating these phenomena or similar ones, it is important to visually distinguish between the agent(s) provoking the change and those that are being modified as a result of their action. In normal cases with cartographic animation, unless records exist showing the result of say a production process, the task of interpreting the cause and effects are left to the domain expert. This can be a burden in terms of increasing the user's memory workload and at times may distract one's exploratory pursuits to less important tasks. With imbued domain knowledge in the geospatial features, appropriate frames that are in synchrony with the animation can be called upon or created to objectively depict the scenario at hand. One way of imbuing intelligence in animation is by utilizing a cognitive modeling approach as outlined below.

3.5 A cognitive modeling approach

Behavioural animation takes into account the relationship between features. The features are self-animating characters that react appropriately to perceived environmental stimuli. More elaborate animation that are based on cognitive modeling can govern what an animated object knows, how the knowledge is acquired, and how it can be used to plan actions (Funge et al., 1999). Such models may be beneficial in complex interdisciplinary tasks where variables may influence one another, as is the case of urban studies, and environmental monitoring (Ogao, 1999). These animation are intelligent as they can make decision during runtime and effect an immediate response. With intelligent animation, features within it are created on the fly and in synchrony with the other existing features. No longer are viewers confined to linear play paths, but loops and branches with new occurrences.

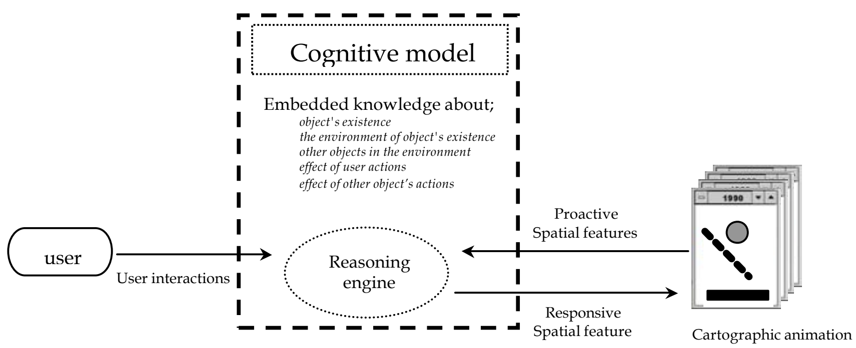


Figure 3.8. Cognitive modeling for imbued intelligence in cartographic animation

Figure 3.8 illustrates the concept of cognitive modeling for intelligent animation. The main thrust of the concept is to imbue geospatial features with knowledge about: their behaviour (existence state, movement, and trajectory), their behaviour in relation to that of other features within the environment (proactive), and knowledge about the way the features ought to behave and respond when acted upon by the user and by other features (responsive). Embedding this knowledge in cartographic animation increases direct user interaction and geospatial data analysis tasks.

3.6 Summary

The chapter ascertains the place and usefulness of interactivity in visual products, and, more specifically, shows how interactivity improves a user's functional performance during visual exploration of geospatial data using animation. The general impression suggests that more interactivity can be attained as the geospatial features represented within the frames become more autonomous. In this state the feature's individual characteristics can be steered and tracked and its relationship to and effects on other features can be ascertained. Embedding an inference mechanism within an animation plays a major role in modeling and simulation processes of the future states of temporal geospatial phenomena. Adding domain knowledge to animation relieves expert users of low-level tasks that can at times be distracting and constrained by the dynamic nature of the animation. This lessens the chance of overloading the users' working memory and leaves them to concentrate on higher-level issues in problem solving and decision-making. It similarly ensures that novice users understand and make better judgements of the patterns, trends and anomalies that they perceive, by depicting *cause* and *effect* scenes.

The chapter similarly outlines a visual typology of temporal geospatial changes in animated maps (which ranges from changes in an entity's status of existence to changes in processes and relationships) and it also presents a list of generic tasks that can be useful when visualizing and performing tasks on geospatial data using animation. Attaining logical results entails collaborating with specific geo-experts in defining and interpreting and executing specific geo-problems using temporal animation visualization operators. This collaboration will ensure that the user centred task model is meaningful, functional and effective since it is on the basis of the ability of the tools to solve specific geo-problems that the evaluation of the animation functionality will be based. Implementing the identified user-centred functionality entails giving access to the database from within the animation in order to cater for the wide range of user queries that may arise during the visualization process. In this case, user actions as prompted by the visual display could be attained either through a database operation or by manipulating the image on the display. This will in essence augur well for attempts at enabling a versatile, interactive and human-oriented means of linking a visualization system to a temporal GIS, providing the possibility of a progressive real-time refinement of the displayed image.

An area that is not addressed in the chapter is the additional processing demands that may be required when using animation in terms of memory overload and the possible strain on the human visual system that may arise when interacting with dynamic sequences of complex graphic images involving simultaneous variation on several parameters.

4

Exploratory cognition model

"I find that a great part of the information I have was acquired by looking up something and finding something else on the way." Franklin P. Adams

A shortcoming with most interactive display and data manipulation tools within the realms of cartography is that they favor a goal-oriented search for structures and patterns in geospatial data sets and as such only help to examine existing hypothesis about the data. Here, the specific questions about the data are known *a-priori* and as such the tasks involved is reduced to that of indexing and data retrieval (Gehagen, 1999). They therefore falls short of being a visual exploratory tool where users set out on an undirected search of unknown hidden information in data to come up with hypotheses about the data. Many of the already evolved approaches in the previous chapters fall within this level of tool development. They thus need an impetus to transform them into uses within the exploratory realms. This forms the subject of this chapter.

In this chapter, an approach that highlights the underlying exploratory cognitive processes and structures that give rise to the construction of new knowledge and insight is presented. It is derived from previous concepts in experimental methods of cognitive science and, is used to answer questions relating to the way emergent geospatial features are detected, synthesized and manipulated for the purpose of discovering new structures, relationships and meaning therein. The approach is based on the assumption that the possibility of generating hypotheses about a given raw geospatial data set is greater if the emergent and unprecedented visual structures therein are uncommon. The theme throughout the chapter stresses the fact that knowledge of the underlying cognitive model for exploratory cartography is a prerequisite for effective design and evaluation of exploratory visualization tools. Thus rather than base visual exploratory tool design on data characteristics and on anticipated tasks that users are prone to undertake, exploratory visualization tool design should be enacted from the acquired understanding of these cognitive pathways. The thesis thus builds more on the previously outlined basis of tool development as outlined in the preceding chapter.

4.1 Significance of cognition to cartography

Design of most cartographic products is in most cases done within the confines of conventions or accepted practices that ensure that they adhere to, and remain within the realms of the *usual* and *the expected* (Keates, 1996). This is evident in conventional practices in cartography where map design is overwhelmingly constrained by the need for functional maps that target specific predefined user needs by presenting geospatial facts or engaging users in goal-oriented validation of hypotheses. But when a user's map use objective is to engage in an undirected search for geospatial structures and trends, as is the case when seeking to develop probing questions and hypotheses about data, then a different design approach is needed. Today, most emergent visual techniques in exploratory cartographic environments focus on providing an enabling visual environment that can generate, manipulate and interact with geospatial structures embedded within the raw data. Whereas these techniques have elaborate interactive and dynamic data manipulation capabilities derived from presumed conceptual and perceptual user goals, they lack an explicit account of their use and effect in knowledge construction. Besides, since they have goals that are already anticipated, they in essence are determined and therefore cease to function as exploratory techniques.

Cognition according to Neisser (1967) is defined as being composed of,

> *"…all the processes by which the sensory input is transformed, reduced, elaborated, stored, recovered and used".*

The processes include mental activities such as perception, thought, reasoning, problem solving and mental imagery. The sensory input in cartography refers to the map and thus in cognitive cartography the processes defined above are in relation to locations and attributes of a phenomena in a spatial environment. Cartographic cognition research is therefore concerned with the active processing of the map, an aspect that is influenced by the cognitive structures and processes such as memory, thinking, imagery, motivation and attention (Medyckyj-Scott and Board, 1991).

Cartographic cognition is also important when one considers the multiple graphic elements that a map-reader interacts with. Understanding the mental processes of these interactions is essential in order to optimize the map reading process (Talasli,1990; MacEachren, 1992; Nelson, 1996). Maps also facilitate the acquisition of knowledge and communication between interested parties. The need to have these objectives fulfilled has been a primary motivation for the cartographer's involvement in studying cognitive processes in mapping. This is so, mainly because to design effective maps, cartographers need to understand both the perceptual limitations of the map-reader and the mental processes used to interpret and analyze the information on the map. This is even more relevant as we face an increasing proliferation of interactive, dynamic and multimedia map products. Researchers here should address design issues of innovative cartographic tools with the sole objective of guiding and evaluating the design of effective visualization tools (Keller & Wood, 1996).

Comparatively, and with regard to research studies in cartographic cognition, there has been considerable contribution made within the presentational realms of map uses than in exploration. In the exploration paradigm, map design is complicated by the non-availability of user information to the cartographers on their specific needs, wishes or intentions when performing exploratory tasks. In fact the challenge to the cartographers is the quest for knowledge on how geoscientists formulate their exploratory objectives, an aspect that needs input from psychology - perception, human vision mechanism and cognition.

4.1.1 Creative cognition & exploratory cartography

The role that visual images play in facilitating everyday thinking is evident in studies undertaken by Finke (1989); Finke & Shepard (1986), Cooper (1990), Pinker (1984), Shepard (1978), Peterson (1987), Larkin & Simon (1987), MacEachren & Ganter (1990), MacEachren et al., 1992, Beveridge & Parkins, 1987). The roles encompass those of spatial information referencing and creative thinking to those attributed to steering scientific discoveries. Their ability to facilitate image transformations by making abstract images explicit has drawn interest to scientific discovery research (MacEachren, 1985). Contemporary theories of image formation addressed concepts on how features are retrieved from long-term memory and assembled in a mental image to represent familiar objects and forms.

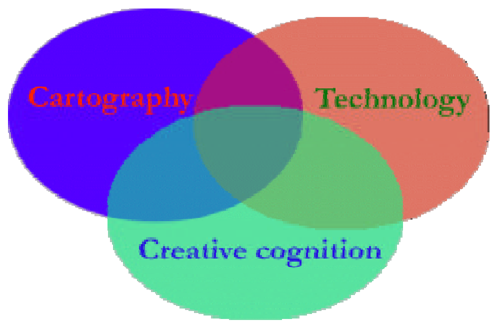
Previous research studies in fields of creativity have concentrated on cognitive processes in problem solving, and defining creativity in terms of products (Buttimer, 1983). In cartography, the design and production of a map falls short of creative practices in art, since map production is constrained by the needs and requirements of the organization and clients. The incorporation of creative practices within information technology domains will have profound effects on every institution. This, in cartography will no doubt be paralleled with the already occurring paradigm shift and emphasis on map use changes to meeting private users' needs within the exploratory precincts of cartography. In cartographic visualization, just like with other adjacent domains in database exploration such as visual data mining and knowledge discovery in databases (KDD), the core objective is that we are trying to understand, develop hypotheses, or make discoveries into an enormous amount of raw spatial data that comes our way in day to day tasks. Traditional monolithic approaches do not take us far and thus we see efforts to integrate core domains as in (MacEachren, et al., 1999 & Gahegan et al., 2001). To make the best of such complementary approaches to enacting new knowledge, the ability to visualize and imagine must consist of skills to generate images, discover structures and relationships between the images, transform the structures, and predict how the structures respond to internal dynamics or external forces (*Figure 4.1).*

So what role can creativity play in enhancing cartographic visualization tool development for exploratory environments? Creativity *per se* and as a human endeavour has a role to play in technology. As Shneiderman (1999) puts it,

> "….technology has always been part of the creative process…. Supportive technologies can become the potters wheel and mandolin of creativity - opening new media of expression and enabling compelling performances".

The important role that creativity can play in technology can also be found from what Finke et al., (1992) describe as the creative cognition approach. They describe how the cognitive structures and processes involved when undertaking a creative tasks have been used to satisfactorily describe how emergent features can be detected in mental images leading to unexpected visual discoveries (Finke et al., 1992). By this approach, one gets to understand the underlying mechanisms and phases involved as one undertakes in exploratory process of knowledge construction and to formulate hypothesis about specific phenomenon. When one is equipped with knowledge about how discoveries are made or hypotheses generated, and we incorporate this knowledge in designs and exploration strategies then one is apt to discover new aspects of a phenomenon by applying their domain knowledge, experiences or ideas in novel ways.

The creative cognition approach facilitates and highlights any emergent features from mental imagery. It involves a process where cognitive structures are generated and their creative implications explored. The result of the process is a product that is both novel and useful to accomplish a specific task. Just like with exploratory cartography, the process commences at a point of *unknown* data relations and progresses in an entirely unpredictable manner but within certain product constraints. By this we mean that certain properties must characterize the structures being explored and exploited to the point that they qualify to be creative products or results.



Notes:

a. Creative cognition - human capability of generating and evaluating new ideas
b. Cartographic visualization - the map use realm that emphasizes exploration of data to generate new hypotheses, knowledge construction and insight.
c. Technology - digital technology for enabling and encouraging creativity.

Figure 4.1. The merger of three distinct fields as a means to otpimizing the design, development and use of cartographic tools for geoscientists

4.1.2 A creative cognition model

The *geneplore* model (Finke et al., 1992) serves as a good framework for tracing both generative and exploratory cognitive processes that are vital for exploratory visualization. It also takes into consideration the diverse aspects of creative performance in terms of explicit cognitive processes and mechanisms that may come into play. The model has a generative and exploration/interpretation components (*Figure 4.2*). In the generative component, mental representations having distinct emergent properties are constructed and exploited for creative purposes in the exploratory phase. Then in the exploration and interpretation components, the emergent properties are exploited in which one tries to interpret the structures generated in the earlier phase in meaningful ways.

The model also distinguishes between the cognitive processes and the structures they act on. It also helps in identifying the key properties of the generated hypotheses or the constructed knowledge (*Table 4.1*). The validity or quality of these hypothesis or knowledge can further be evaluated based on how original (unique), sensible or practical they are to the specific domain under which the exploration is undertaken.

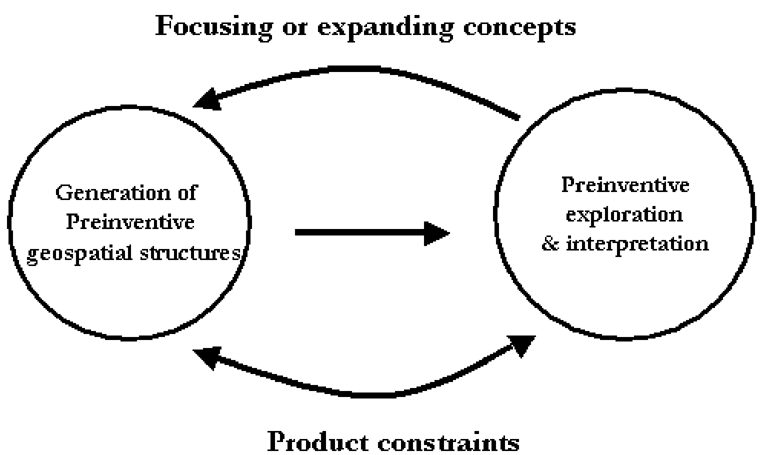


Figure 4.2. Cognition model for exploratory visualization (adapted from Finke et al, 1992, MIT press)

The model bears some equivalence to certain models in cartography, especially on the basis that both involve mental processes, each of which helps to set the stage for further processes in knowledge construction and hypotheses generation. From a Geographical Visualization perspective, MacEachren's (1995) extended feature identification model for map-based visualization integrates knowledge about human perception and cognition that contributes to the interpretation of visual information displays. Feature identification and comparison here are forms of a generative process, while feature interpretation emulates the exploratory processes especially on the inferential process of the "*reasoning why*" stage. Brewer, (1999) and Gahegan et al., (2001) attributes these inferential processes to abduction. Among the inferential processes abduction is the only one that starts a new idea or scientific explanation. What appears common to both models is the iterative nature between the *noticed* images (internal or external) and matching them to what is already known (MacEachren, 1995; Judson, 1987; Perkins, 1988).

Table 4.1. Examples of cognitive processes, structures, properties, and constraints in the geneplore model (Source: Finke et, al., 1992)

Generative processes	Pre-inventive structures	Pre-inventive properties	Exploratory processes	Product constraints
Retrieval	Visual patterns	Novelty	Attribute finding	Product type
Association	Object forms	Ambiguity	Conceptual interpretation	Category
Synthesis	Mental blends	Meaningfulness	Functional inference	Features
Transformation	Category exemplars	Emergence	Contextual shifting	Functions
Analogical transfer	Mental models	Incongruity	Hypothesis testing	Components
Categorical reduction	Verbal combinations	Divergence	Searching for limitations	Resources

4.2 Emergent exploratory visualization tools

One of the basic arguments forwarded for the use of cartographic animation in relation to single or a series of static maps is that using animation can help one see changes in spatial features or phenomena that could otherwise have gone unseen (Peterson, 1995). Temporal cartographic animation in particular has the ability to intuitively highlight dynamic phenomena as if they have occurred in reality. In a more general way, we could consider animation in this sense as a visualization technique that plays a crucial role in the generative components of the model. Keller & Keller (1992) outlines such techniques that combine the user's objective and the data type used. Different visualization techniques are effective when used under specific use conditions. Many of these techniques can be derived also from *Tables 2.2 and 2.3 in chapter 2*. Thus even passive animation could suffice as an impetus to further exploratory cartographic tasks. Where this is not so, then we need visual tools that are tailored to triggering generative processes, which sets a preparatory stage for exploratory tasks.

Within cartographic animation, techniques such as *re-expression or collocation* where original data sets are transformed and visually represented in a preferred thematic category or order could suffice as further generative techniques to help highlight emergent patterns. Generative animation functionality encompasses tools to enable one to make observations and descriptions of the data. Visual tools that employ low levels of interactivity could suffice when all one needs is to make initial observations and identify interesting features that will ignite the whole exploratory process. Generative animation tools are those that help a user make and describe data or spatial phenomena during run-time. Basic interactive tools, the media player controls, have previously played this role. Tools to allow one to observe the data sets under varying spatial scales or temporal resolutions or categories similarly find a role at this stage. Tools that support lower level inferential processes are dominant at this stage. Also the tools at this level enable lower inferential processes involving bottom-up encoding mechanisms (e.g. deductive and inductive).

An example of a generative processes using **collocation** is the ability to locate specific animation frames from a set of many based on some user specified temporal or spatial characteristics. The technique has previously been used in film and video editing domains. In presentational animation types, sequences of animation frames are pre-selected and played following a predefined linear loop. *Figure 4.3,* illustrates three main facets of collocation in cartographic animation; thematic, temporal and spatial collocations.

Thematic collocation *(Figure 4.3a and b)* maintains the theme of the display despite presenting alternating views of different map types without interrupting the message of the display. **Temporal collocation** is the ability for cartographic animation to be viewed under various temporal structures (linear, cycle) or various legend options (audio, graphical or numerical) as illustrated in *Figure 4.3c*. Lastly, **spatial collocation** is the ability to move between different spatial scales as in zoom in/out *(Figure 4.3d)* while maintaining the temporal and thematic flow-lines.

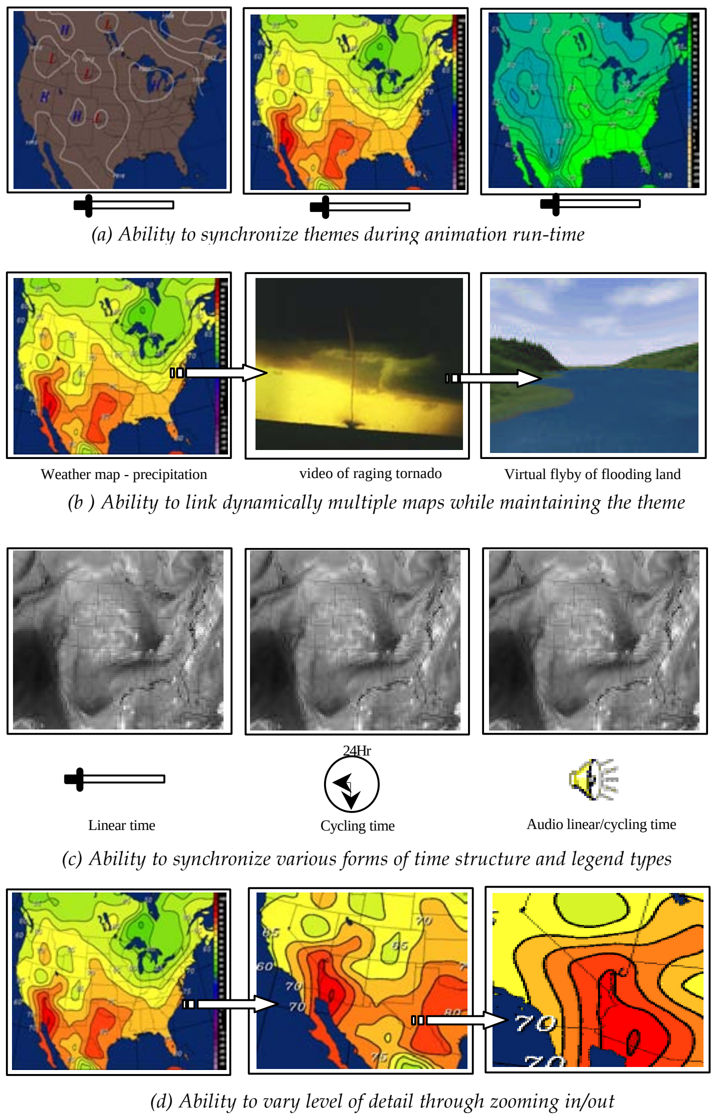


Figure 4.3 Illustrating some aspects of collocation in animation

At the explorative and interpretation stages of the model, specific emergent patterns, trends or anomalies that exhibit unique properties are explored and exploited. The tools needed here are those that help to describe the observed data or phenomena. This may entail attribute linking, where the temporal geospatial characteristics and temporal relations between intervals come into play (Claramunt & Theriault, 1995; Allen, 1981). Thus the tools have traditionally been incorporated for example, by using legends to identify thematic attributes and transparently overlaid maps for locating places. Lastly, we need tools that can enhance the inferential processes at the interpretation level. Abduction is one key inference logic that plays a role in knowledge construction. Examples of tools that may find use in this component of the model are those that: enable one to link the display to its attributes (*interactive filtering* – selection and *querying*, *linking and brushing*, *zooming*, *detail on demand*), confirm or reject specific hypothesis, those that provide a broad knowledge base to help in interpreting the emergent structures etc.

The entire exploratory process will thus involve generation, regeneration and modification of preinventive within the product constraints (most probably within the geoscientist's domain field).

There are certain traits that characterize the tools that are used to generate and explore geospatial structures. A relationship amongst these traits can be derived as seen in the *Figure 4.4*. First, is a prevalent component in many graphic tools – the *level of interactivity (*discussed in *chapter 3 section 3.4).* This describes how the level of involvement or interaction that the user has with the display contributes to the formulation of new hypotheses.

Second, is the type of reasoning that the users adopt when building up their knowledge of the specific phenomenon under consideration (*inference*). Inferences outline the mechanisms (arguments and premises) that lead to the formulation of the main claim (hypothesis). An argument is s series of persuasive statements made to convince someone of a specific claim. Premises are the building up blocks of the argument. They thus directly support the main claim being made. The inferences can be enacted from laws, rules etc or from previous observations or experiences. The inference logic considered are, *deduction, induction* and *abduction.*

Induction can be described as moving from the specific to the general. One begins an argument from what they know are true, put them together, and follow them to the conclusions to which they lead. Deduction begins with the general and ends with the specific; arguments based on experience or observation are best expressed inductively, while arguments based on laws, rules, or other widely accepted principles are best expressed deductively. Abduction is the only argument that starts a new idea or scientific explanation (Turrisi, 1990).

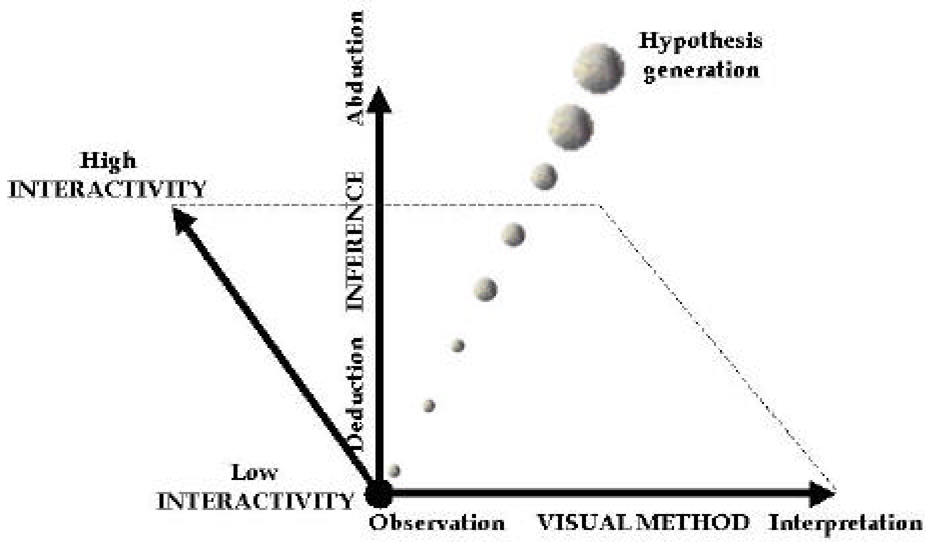


Figure 4.4. An exploratory cartographic visualization design model.

Examples from Pierce's (1878) syllogisms as[4] described in Brewer (1999)

Deduction
These beans are from this bag
All the beans in this bag are white
These beans are white

Must be true; specific result

Induction
These beans are from this bag
These beans are white
All the beans in this bag are white

[4] It is a form of deductive reasoning that consists of a *major* premise, a *minor* premise, and a conclusion. The major premise of a syllogism states that something, Y, is or is not true for all or part of some group, X; the minor premise affirms or denies that some group or individual, Z, is part of X; and the argument then concludes whether that thing Y (from the major premise) is true or not true for that group or individual Z (from the minor premise) (Mesher, 1999).

Probably true; general rule

Abduction
These beans are white
All the beans in this bag are white
These beans are from this bag

Possibly true; hypothesis

One of the main distinguishing differences between the between inductive and deductive arguments is in the way the arguments are expressed. Of course, an **inductive argument can still be expressed deductively, and any deductive argument can also be expressed inductively**. Each of these arguments requires different types of support. Inductive arguments are supported by previous observations, experiences, while deductive arguments are supported by his rules, laws etc.

Lastly, there is the type of *visual method* used in the process. Visual methods entail the visual cognition mechanisms that enable one to make visual encoding and description of a graphical representation, its subsequent interpretation and explanation of the phenomenon. The three components constitute part of the internal and external quantifiable components that can be used in visual tool design.

Thus *Figure 4.4* shows an animation design model that depicts the relationships between the contributing factors in an exploratory cartographic environment (Ogao, 2001b). The origin depicts the starting point of the process, where no hypothesis about the data is known. The process starts with the geo-scientist describing and making basic observations about the display, using low interactivity and making bottom-up inferences. The upper part of the diagonal depicts the point when a hypothesis has been formulated.

The model presumes that animation functionality should provide for the use of these components at distinct stages of the exploratory process if useful information has to be realized. Lower level inference logic such as induction and deduction seem to be useful with users when making observations of the representation. This stage is characterized by low levels of user-animation interaction. Abduction inference logic is commonly used at the explanation or interpretation stages of exploration process. The user's interaction with the display is much higher at this stage. The progression of the process is not a straightforward one, but rather involves tightly linked repetitive actions of the components.

The implication of the model to animation design is that knowledge of internal and external visual cognition mechanisms can help equip animation use environments with appropriate tools to aid in exploration. The remaining part of the thesis will discuss how the model can be used and validated by experimental tests.

4.3 Summary

Our objective in this chapter was to highlight an approach to defining exploratory tools that can be applied in exploratory environments. The environment entails working with raw data having no prior hypothesis. The challenge was then to trace underlying cognitive structures and processes that lead to users formulating a new hypothesis. The *geneplore* model is representative of a typical exploratory working model, and fits well not only with scientific methods of discovery, but also spatial feature identification, comparison and interpretation models in cartographic visualization.

A key to taming the proliferating tools camouflaged in the advancing technology is to formulate a general criterion for visualization tools to the uses that they can possibly be subjected to. The generative and exploratory tools we suggest can be subjected to experimental tests and their contributions to new knowledge formulation established as will be seen in the next chapter. It is our hope that with this general delineation of exploratory tools, cartographers will find a taxonomy that places the dynamic and interactive aspects of these tools in check in relation to their performances in knowledge construction.

5

Functional evaluation

"All things are subject to interpretation whichever interpretation prevails at a given time is a function of power and not truth." FRIEDRICH WILHELM NIETZSCHE

The discipline of cartography is not just about making maps. If anything, cartography strives for better quality maps; better in the sense that the maps are designed to adhere to certain quality indicators in both aspects of aesthetics, cognitive enhancements, communication demands, ability to meet technological demand and their aptitude to stimulate visual thinking (Gartner, 1999). Maps are not just evaluated on the basis of isolated symbols, but rather as a whole and in a wider context. No wonder the proposition "How do I say what to whom" has had the words "and is it effective?" added to it, because of the need to also test maps for their efficiency. The crucial question in the midst of all this is what exactly it takes to make better maps; an aspect that can otherwise be answered by having knowledge on how and why maps are used. Gaining this knowledge entails looking at a number of influencing factors, which include the nature of individual map users; of map user communities, of the environments in which the maps are used, and of the functions or tasks for which the maps are used. Evaluation of maps, then, becomes a vital component especially as we see an ever-increasing number of maps being produced and used for a diverse range of tasks in different types of environments (*Figure 5.1*). The map use environment seems to be highly dynamic as it is being bombarded daily by innovative technological tools.

Building up from the previous chapter, we would expect to get optimal results when using animation that provides the diverse exploratory design components highlighted in *section 4.2 of chapter 4.* So in this chapter, we seek to answer one major question: what method should we use when evaluating these optimal products resulting from the use animation that are designed based on this model. We begin by giving an overview of the many dimensions involved in evaluating innovative cartographic visualization products, their uses and use environments. Next, we outline a functional evaluation model that puts into perspective the geoscientist's map use objectives and relates it to the emergent exploratory product. Finally, the chapter highlights the concept of using exploratory indicators to evaluate these emergent exploratory products.

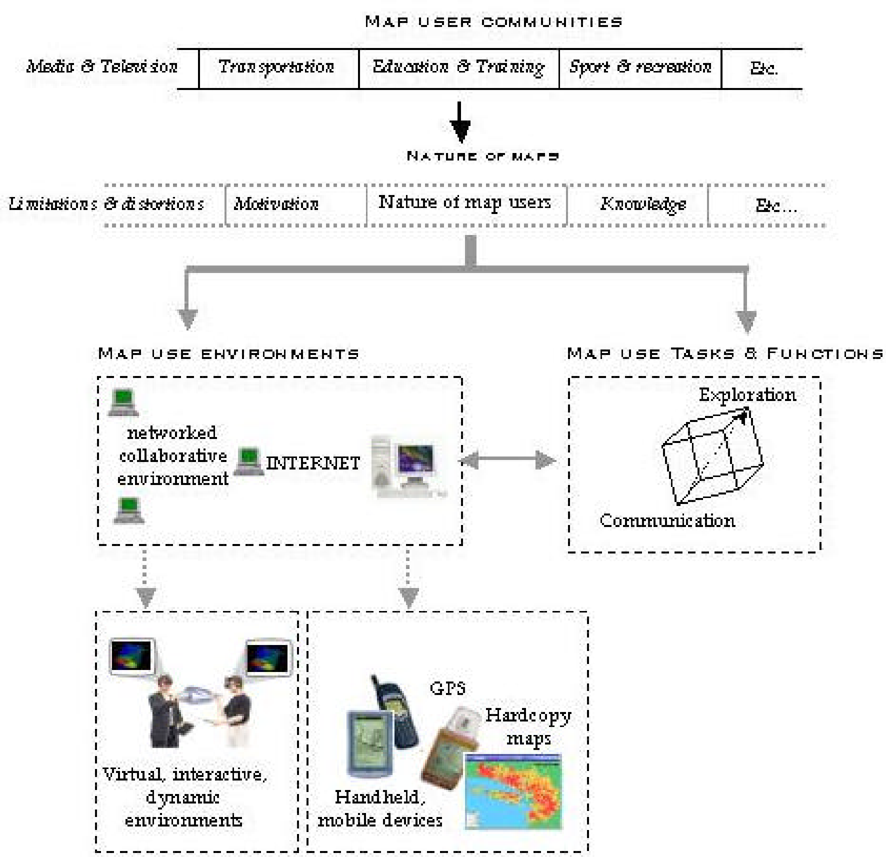


Figure 5.1. The many dimensions of innovative map use environments

5.1 The many dimensions of evaluation

The first uphill task for exploratory visualization tool designers is to come up with ways that will enable users to set out on an undirected search of the unknown hidden information in data in order to discover new knowledge or generate new hypotheses about the data. The question being addressed here is, how does one ever get to know the success or accomplishments of visualization tools if the users, in the first place, do not really know exactly what tasks they intend to perform or undertake? In addition, visualizations are components of many information interfaces and thus testing of these visual elements seem valid only when undertaken as a part of overall usability testing. To answer these questions, we look at the types of map evaluation that have been used in cartography in the past. We then highlight the recent components in the evaluation models that are worth looking into because of the recent innovations in cartographic discipline.

Starting with the cartographic communication model, map-making encompasses converting geospatial data into a graphical form through the use of symbols. Typically, the cartographer has prior knowledge of the kind of audience (map reader), and the environment in which the map will be exposed and used. In essence the map-making process utilizes cartographic techniques and methods (structured symbolization, selection, classification and simplification). Usually, a discrepancy occurs between the message the cartographer intended to communicate across and the one the map-reader receives. Thus, early research studies looked at the conception of the cartographic process as a means of communication. In Eastman's view, two broad areas can be delineated to typify these early research studies; a) analytical cartography that deals with the environment of map transformations and b) user research, that addresses ways in which the map-reader accesses and makes use of mapped information (Eastman, 1985).

In evaluating cartographic products and environments, previously both qualitative and quantitative methods have been used. Qualitative aspects encompass methods for obtaining verbal data (questionnaires, interviews, or think aloud protocols), direct observations and document data analysis of maps, images, or written material (Suchan and Brewer, 2000). Quantitative methods put emphasis on the statistical analysis of selected variables such as in hypothesis testing through which the experimenter seeks to confirm or challenge a previous theory. Uses of probability sampling, surveys and controlled experiments are components of such studies. Qualitative methods help to illuminate the factors that influence the results or observations. Despite their differences, the two approaches still form vital components and play complementary roles in evaluation research. Examples in both categories are seen in Brewer (1989); Monmonier & Johnson (1991); Crampton (1992); Kulhavy et al., (1992); Cole (1993); Wood (1993); Monmonier & Gluck (1994); Slocum (1995); Buttenfield (1997).

In the special issue of *Cartography and Geographical Information Science* on geovisualization in collaboration with the ICA Commission on Visualization and Virtual Environments, a number of issues on map evaluation are mentioned (Slocum et al., 2001). The authors agitate for a more concerted effort in theory-driven cognitive research in geoscience applications and evaluation of methods via usability engineering principles. From this perspective, we can outline some evaluation issues targeting cartographic visualization environments (*Figure 5.2).* These are:

i. effectiveness of visualization tools as used for enhancing visual thinking or knowledge discovery.
ii. cognitive control and performance of visualization tools.
iii. cognitive characteristics of users in this environment, cognitive models for knowledge discovery and hypothesis generation typical of geoscientists.
iv. effectiveness of map design elements encompassing symbolization, human computer interfaces etc.

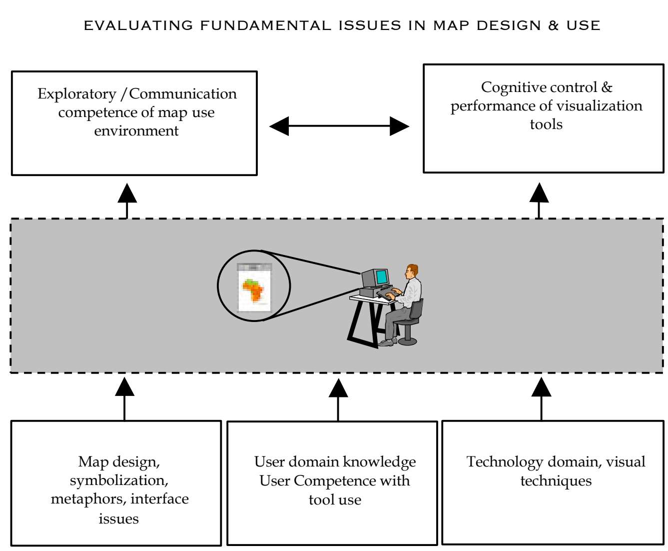


Figure 5.2 Some examples of inter-related components in evaluating cartographic visualization products

Maybe the many questions that are being posed in evaluation research are just a glimpse of the difficulties researchers have as they try to understand the role and influences of every cartographic tool involved in a visualization system. However, even with such questions, there remain wide loopholes hindering effective evaluation. Whether animated maps are less viable than static ones, assumes standard type(s) of animation, which in practice do not occur, since there could be passive, interactive or dynamically linked animation types. As such, studies like that by Morrison et al., (2000), which raise doubts about the usefulness of animation in learning ought to be considered within the specific *goal* based context, that is learning, since the "same" animation they use could have been useful for someone pursuing, say problem solving, operability or exploratory tasks with interactive or non-interactive animation.

5.2 Cognitive issues in evaluating cartographic animation

Not many strides have been made in accounting for the cognitive processes involved in how people view and interact with cartographic animation. This is even more crucial when the intended use of the animation involves that of exploring and unravelling hidden meaning. The goal, as we have seen earlier, is not distinctly addressed here. In addition, whereas a technologically enhanced animated map may be more appealing to the viewers and hold their interest longer, we need to differentiate their intended purpose or goal from the impact those enhancements might have on the efficiency of information processing. Let us look at a few of these interacting and contributing influences in cartographic animation.

The basic design units of a cartographic animation consist of visual variables (Bertin, 1983) and controlling elements known as dynamic variables (DiBiase et al., (1992); MacEachren, (1994)). The visual variables enable the viewer to discern the perceptual similarities or differences in the map. They also enable the viewer to group or disassociate graphic elements according to their spatial characteristics. On the other hand, dynamic variables enable a viewer to control the sequence of frames, pace and synchronization of the animation frames among other variables (MacEachren, 1995; Peterson, 1995). These design units together with the geoscientist's domain knowledge and tool competence influence the effectiveness of the animated map.

Exploratory tasks utilize highly interactive tools between viewer and the displayed map. This is presumed to enhance one's ability to understand data, perceive trends, and to visualize real or imaginary objects at a faster pace and in a more effective way. Nevertheless, the intensity and levels of interactions need to be regulated since they may influence the efficiency and effectiveness of information processing. This is exemplified in various studies, where claims have been made that animated maps may bring in additional processing demands due to the need to track components or make comparisons. As Monmonier (1992) puts it, the "rich and rapid sequences of graphics can overwhelm the eye-brain system". In addition, the dynamic nature of the images may make it more difficult for users to perform spatial analysis tasks especially where the visual field is complex and involves simultaneous variation in several parameters. Such influences are prone to create undesirable processing consequences (Lowe, 1996).

Cognitive issues on a) whether the use of the animation allows for the creation of a variety of mental models or inferences from the represented concepts and b) whether the use of animation portrays the salient features more clearly in time and/or space, are some of the additional influencing components in dealing with cartographic animation. Specifically the number, form and complexity of graphic symbols used have the potential to influence the computational processing abilities of the users.

Lastly, as has been partially unveiled, the user's goal goes a long way in determining the functionalities in an animation. Goals may include learning, reasoning, exploration, problem solving etc. Animation used in learning by novice users may benefit viewers by being able to saliently combine sequences of maps or information through their intuitive ability to capture the viewers' attention. There are cases where animation have been found to add complexity and confusion in problems being pursued (Jones, 1998). For problem solving with geoscientist, animation have been shown to enhance understanding when complex, multi-dimensional data are used.

In general, whereas there are documented studies that highlight the usefulness of animation in general, a conclusive stand has yet to be reached amongst researchers regarding these advantages over other modes of representations (Campbell & Egbert, (1990); Gurka & Citrin, (1996); Jones (1998)).

5.3 Outline of the evaluation model

It is our premise that defining the goal of any evaluation task should ideally help in determining the type of evaluation that is to be undertaken for cartographic visualization tools. Aspects such as the kind, style, mode and yardstick to be used for the evaluation should be outlined (Jones, 1997).

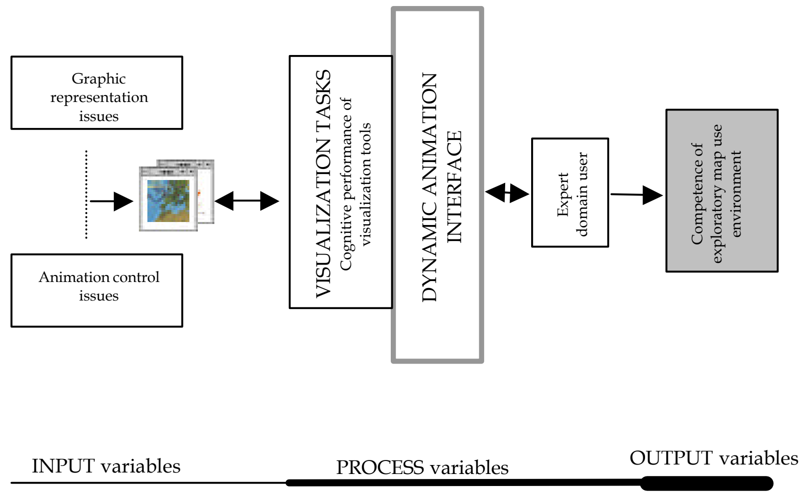


Figure 5.3. Evaluation components involved in an exploratory animation environment

Looking back to the introductory paragraph and specifically to *Figure 5.1*, one sees the many variables that are intrinsicly linked and which in their own indivdual ways and together, contribute to the effectiveness or success of map products. Accounting for the specific influences of these variables is what an ideal evaluation criterion in cartography ought to accomplish. On a similar line of reasoning, deciding which variable to use in an evaluation process is an uphill task. One of the common flaws in most evaluation methods is their failure to account for the diverse contributing variables that influence evaluation results (*Figure 5.3)*.

Functional evaluation is a method that considers only the system's input-output variables without regard for the specific mechanisms by which the output was obtained (Jones, 1997). It is synonymous with a product's quality, since it considers the external attributes of the product as perceived by a user. In relation to map use, the evaluation looks at whether the use satisfies the needs of the user *(Figure 5.4)*.

The functional evaluation model as applied in this research, presumes a level working ground for the evaluators in relation to the initial state of the animation environment. By this is meant that, data or information bias is minimal or non-existent. The evaluators work on the same type of data and initial information. The animation's graphic and dynamic variables are initially set to the same levels among all the evaluation groups. The animated map's quality is also made to a level that minimizes misinterpretation.

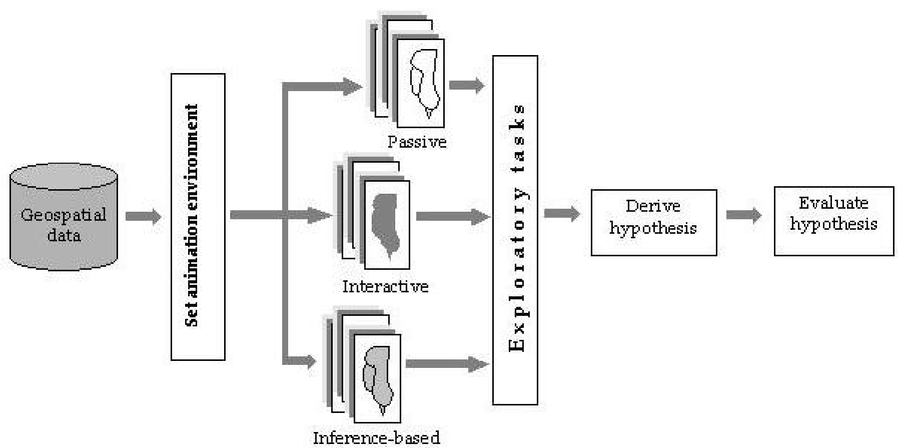


Figure 5.4. Functional evaluation model for exploratory cartographic animation

Therefore, in our definition of functional evaluation, we look at those external attributes that can be tested or measured without any need to access or evaluate the internal variables or processes of the temporal cartographic animation environment.

However, a few issues are to be considered if we have to apply such an evaluation to the animation environment. First, it must be possible to treat the animation environment as a "black box", meaning that we ought not to bother to understand the internal influences of the system. Secondly, we need to clarify beyond any reasonable doubt that the influences of the internal processes or variables do not in any way contribute significantly to the external evaluation results.

In the animation prototype, we largely try to account for any internal influence (the input and process variables in *Figure 5.3*) in a way that any variation in the external attributes (that the user aspires to derive from the product – in this case exploratory ability of the environment) can be quantified and linked to the output measure (*Figure 5.5*). The overall evaluation is determined by measuring the functional indicators (traits of exploratory environment).

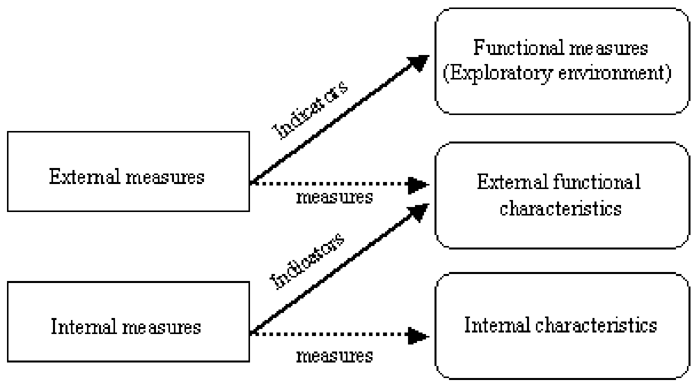


Figure 5.5. Relating the internal and external characteristics of an exploratory temporal animation environment.

Judging the success of the map use environment by the output or on the basis of whether it helps users achieve what they set out to pursue, be it learning, problem solving, knowledge discovery (as commonly done with pre- and post-test experimental studies) does not give a conclusive outcome. In this case, success or effectiveness is operationally defined in terms of the users' achievement i.e. by looking at or measuring the overall or individual performance of visualization tools as they are used for exploratory cartographic tasks. Descriptive methods of statistical analysis can supplement the method by quantifying the results.

5.3.1 Decomposition of the model

Going back to the exploratory visualization design model defined in *chapter 4*, on the basis of which we have defined the exploratory temporal cartographic animation environment, we delineate the three cognitive evaluation goals that will help verify the model. First, the evaluation seeks to analyse the relationship between the inference mechanisms and levels of interactivity in animation tool use. Secondly, it analyses the relationship between the types of inference mechanism at different levels of visual image understanding. The last goal looks at the output product and whether it qualifies to be termed an exploratory product.

Evaluation testing methods that are utilised include: the "*thinking aloud*" protocol , retrospective testing, accompanied by assessment methods in observation, questionnaires, getting actual log information of the test user and using expert domain judges (*Figure 5.6*).

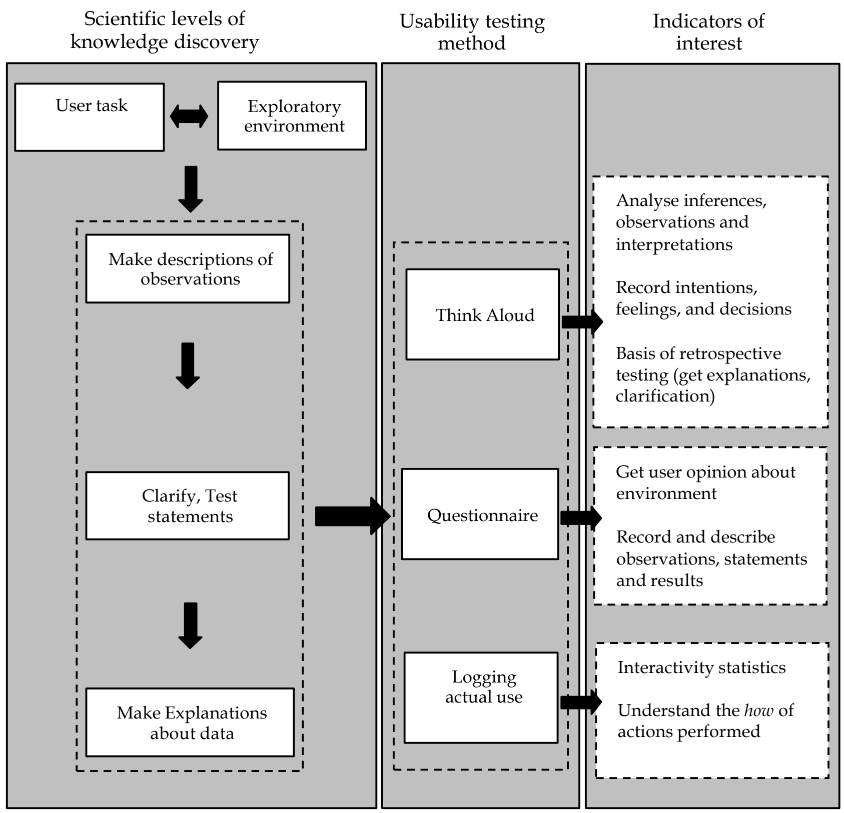


Figure 5.6. An overview of the geoscientist's involvement, usability methods and indicators needed to accomplish the evaluation process.

The evaluation method in general will utilize aspects of both descriptive and inferential statistics. The former is used to describe the basic features of the data in the study by providing simple summaries about the sample datasets and their measures. This helps one understand what is going on in the sample data set. They form the basis of most quantitative data analysis methods. Using inferential statistics helps one to reach conclusions that extend beyond the immediate data alone as in qualitative analysis.

5.3.2 Thought processes, interactivity & visual methods

Our initial postulation is that interactivity in animation tools becomes crucial at higher levels of reasoning inferences. By that we mean, during initial phases of exploration observation, low levels of interactivity are evoked, since more observatory visual techniques are used in decoding the features and meanings of the imagery on display. This corresponds more to the "*seeing that*" before engaging in the "*reasoning why*" phase.

The relationship between the types of inference invoked during exploration and the visual method of image understanding needs verification. The initial premise is that tools that enhance or facilitate one to derive plausible or reliable explanations from observations play crucial roles in knowledge discovery or in helping to generate hypotheses about the dataset in use. To do this the prototype uses the generic types of animation highlighted in *Figure 5.7.*

5.3.3 Analysing the output product

Does the output exhibit the traits of "new knowledge"? If so, what characterizes these traits? We will here derive the product traits based on definitions and pursuits within the realms of creative visualizations and key reasoning concepts in knowledge discovery.

A user might come up with a new idea that he or she had never thought of before. Similarly, no other person might ever have thought of the idea before. Thus, novel ideas can be subjective and confined to individual explorers, and at other times they may have global authenticity. From the earlier discussions on exploratory cartography in *chapter 2 subsection 2.1.1*, the geoscientist role emerges as being central to the entire exploratory process. They thus are better placed to determine the exploratory success of the output products. Nevertheless, we are of the opinion that exploratory products come up as a result of purposeful initiative by the geoscientist and involve skilful manipulations using exploratory tool rather than random or guess work manoeuvres. Based on this, it is appropriate to analyze the products by undertaking both consensual and conceptual evaluations. Consensual evaluation gives ratings to the output product, in this case the formulated hypothesis. Conceptual evaluation takes into account the *concepts* leading to the formulation of the hypothesis[5]. These evaluations can be likened to the use of the exploratory indicators that include: *originality*, *sensibility* and *practicality* aspects of the output products (*Figure 5.8*).

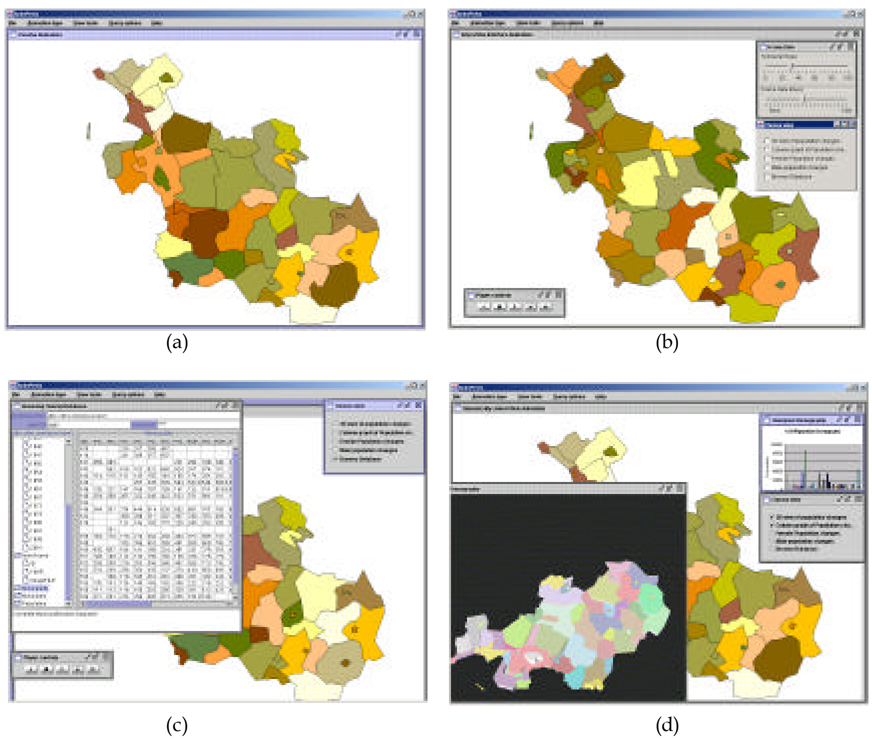


Figure 5.7. The generic types of cartographic animation adopted in the prototype; (a) passive, (b & c) interactive interface and (d) intelligent animation, whose views are triggered by embedded inference mechanism.

[5] Other evaluation criteria have distinguished between structural and utility-based criteria. Structural criteria uses the structural or syntactic attributes of the causal chain (length of chain, or number of abductive assumptions). Utility-based criteria also termed goal based puts the subject's motivation for deriving the hypothesis into context.

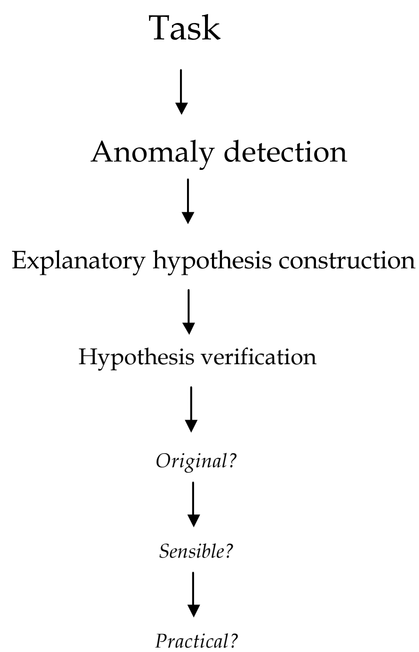


Figure 5.8 Validating the formulated hypothesis

A consensual and conceptual evaluation re-establishes and qualifies the output products in terms of its value and competence within the precincts of the application domain. These products must be inclusive – i.e. incorporate much of the input variables' characteristics. These are the known input and process variables, which play a role in structuring the new knowledge. Exploratory products are also characterized by their ability to highlight any associated or different knowledge domains. This trait is useful for making linkages or opening ways or relations for further knowledge discovery processes. Thus using these evaluations, exploratory products are not evaluated at an instant (an aspect that helps avoid problems associated with different senses or levels in which people might regard a product as being exploratory), but are rather subjected to evaluation from an objective functional perspective.

Originality refers to the ability of the geoscientist to achieve uncommon or unexpected results or output products. Whereas these products show marks of uniqueness, they could have been arbitrarily achieved, such as when a one combines geospatial structures and properties in random and unstructured way. Thus, for product to qualify as exploratory, then it has to pass the test of value and competence, an aspect that is achieved by evoking the use of the next indicators.

Sensibility refers to how relevant the output product is to the observations and interpretations made earlier on by the geoscientist. Does the product address the knowledge goals by the geoscientists (pursuits of information needs to better understand the subject)? This puts to check the range by which original products can be let to wander.

Practicality refers to the applicability of the output product to the geoscientists knowledge domain. The ultimate goal of undertaking an exploratory task is to offer support for making temporal geospatial decisions (Malczewski, 1999). Thus, the product (without any modifications) has to be useful in enabling the geoscientist undertake day to day domain tasks.

Other criteria that may be useful when evaluating hypotheses incorporates indicators are: applicability, relevance, verification, specificity, usefulness, plausibility and believability (Ram & Leake, 1991).

5.4 Summary

What we have addressed in this chapter sets the pace for an actual evaluation of a temporal cartographic animation environment when used within an exploratory map use realm. This is highlighted in the next chapter. Undertaking the exercise must take into account the diverse cognitive influences that the different types of animation have on the user. One unbiased evaluation criteria may be to evaluate the tools wholesomely and on the basis of the output product attained. Nevertheless there is a need to address the influences of the individual contributing factors involved in such an environment. The chapter also recognizes the fact that the continuous innovations in map products need continuously adaptive evaluation methods, and that no single or generic logical structure can assure a unique 'correct' evaluation. This is even trickier with exploratory environments, where the evaluation results may be subjective depending on who the user is, and who has the final word on determining the products quality.

6

Animation user research

"A common mistake that people make when trying to design something completely foolproof is to underestimate the ingenuity of complete fools." Douglas Adams

The nature of temporal cartographic animation emerging from *chapters 3* and *4* encompasses giving consideration to temporal geospatial data characteristics, type of domain users, map use goals, and specific issues on interactivity. An unlimited emergence of a diverse range in types and uses of interactivity in temporal cartographic animation can be foreseen. Containing this to manageable interactive categories could well suffice as a basis by which these animation can be adopted for different uses in both presentational and exploratory cartographic environments.

In this regard, three generic types of cartographic animation are adopted for use in the user research. These are: *passive, interactive* and *inference-based* animation. These animation differ mainly on the level of interactivity and complementary knowledge that each offers to the user. Passive animation maintains the *view only* status. The user has no control over its contents and dynamic variables. Interactive animation provides users with the basic media player controls, navigation and orientation tools. Inference-based animation incorporates these interactive capabilities (as in interactive animation) together with a complementary automated intelligent view that alerts users to interesting patterns, trends or anomalies that may be inherent in the data sets.

With these types of animation, a map user research is undertaken to achieve the following objectives. *First*, to observe test subjects as they perform exploratory tasks on test data using a specific type of the generic animation mentioned above. A record of their thoughts, feelings and opinions is made. *Second*, to trace the underlying cognitive structures and processes of these test subjects during the entire exploratory task and *lastly*, to relate the test subject's exploratory performance to the types of animation used.

To fulfill these objectives, evaluation tests were carried out using both thinking-aloud protocol and retrospective testing techniques using test data sets taken from the realms of demography, epidemiological and urban studies (*Figure 6.1*).

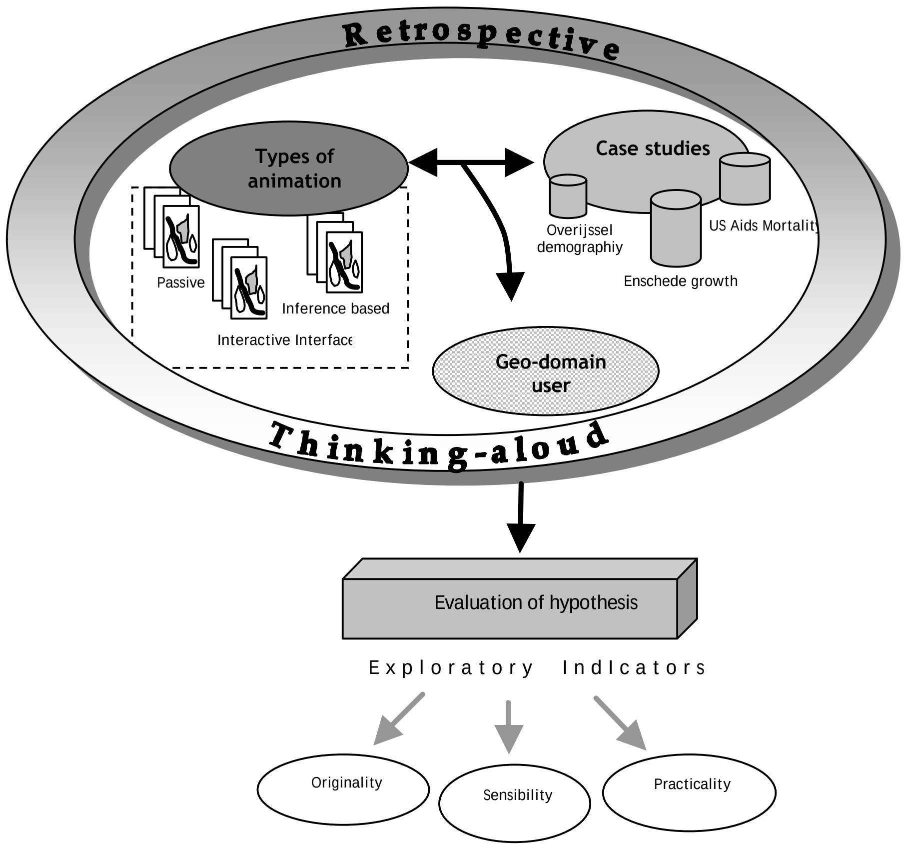


Figure 6.1. The constituents and test methods used in the animation user research

The output product from these test is then subjected to evaluation and ranked using exploratory indicators of *originality*, *sensibility* and *practicality* (see *chapter 5,* subsection 5.3.3).

This chapter gives details of the above undertakings. It describes the test environment, animation and data sets characteristics, test procedures and the test subjects used. Lastly, the results are analyzed and followed by a discussion that revisits and relates the achieved results to the earlier formulated test objectives.

6.1 Test environment

A cartographic laboratory room was dedicated for the evaluation exercise. The need was to have an isolated, quiet and yet spacious room to take all the needed equipment. A plan and the corresponding pictures of its constituents are shown in *Figure 6.2.*

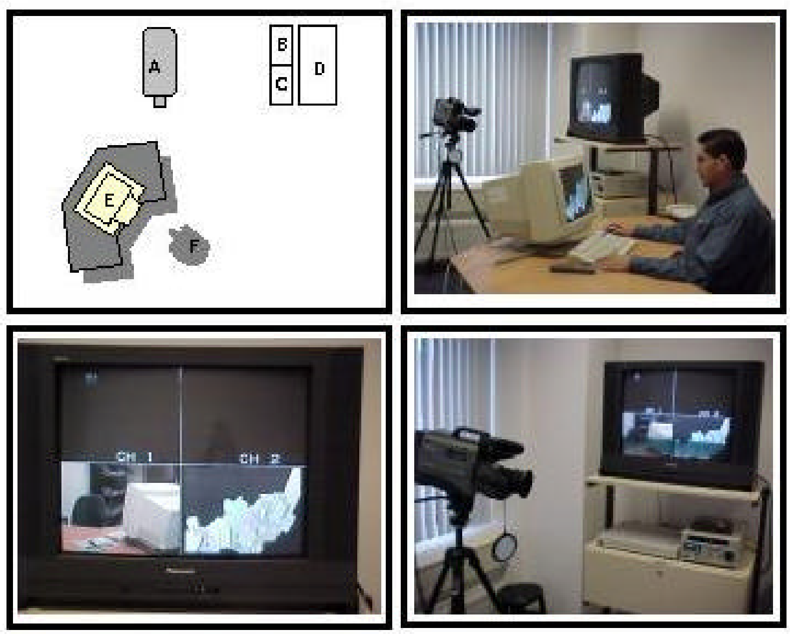


Figure 6.2. A set-up of the evaluation laboratory. *Top* the pictures show the plan and pictorial view of the laboratory equipment A – video camera, B – digital quad unit, C- VCR, D- TV monitor, E – the Computer and 17' monitor, and F – the test subject. *Bottom left is the TV monitor with a 4-part split view. Bottom right* shows the video camera, the digital quad unit right and the VCR.

The digital quad unit simultaneously takes in signals from the video camera, wireless microphone attached to the test subject, and the computer. The signals are temporally synchronized and appear in a 4-part split view in the TV monitor. The

TV image consists of a perspective view of the test subject. With this one sees the facial expressions and a considerable amount of the body movements. Also on view are all the activities (mouse pointer, application scenes) on the computer monitor. The image as seen on the TV monitor is recorded on to a videotape in the video camera recorder (VCR). Other systems specifications are highlighted below (*see also* Elzakker, (1999)):

i. Pentium III ® processor
ii. Microsoft Windows 2000
iii. 64 Mb RAM, 6Gb hard disk space
iv. Mouse, 17' Monitor, CD-ROM player
v. Backup capability via network or removable disk
vi. Graphics card (32 Mb), TV Card
vii. ScreenCam/ Capture software
viii. Studio Action

6.2 Test animation characteristics

Three case studies that involve data sets with varying levels of complexities were selected (*Figure 6.3*). Overijssel demographic changes between the years 1811 – 2001, US Aids Mortality for the period 1981 –1992, and the growth of Enschede town between the years 800 to 1998.

The character of test maps (the type and complexity) is one factor that influences map user test. Therefore, the design of the animation was given special attention. The animation are designed to ensure that they adhere to cartographic principles of design. This is to minimize misrepresentations by various users. The initial animation have undergone changes after numerous reviews by cartographers and geo-domain users. This ensured they were of optimal design and within the range of the intended uses.

The geospatial data available to all the animation environments are maintained at the same level of information density and complexity. This means that the symbols were easily distinguishable and any relationships between them could be found. The complexity also varied from simple 2- to 3-dimensional geospatial data sets. Also, since the test was concerned with evaluating the performance of different types of animation despite each type being used by different data sets, the information conveyed in each animation was maintained at the same level. This eliminates the bias related to offering varying levels of data and information details to users. Test subjects have to undertake the same exploratory task within the prescribed time. The animation constants or the dynamic variables are initially set to the same levels. For example, on playback the frame rate, orientation and perspectives of each of the types of animation are the same. Of course depending on the type of animation, users may when performing tasks, change any of these variables as they may deem fit. The structure of patterns exhibited in each case study is unique – e.g. clusterly and overly distributed, random and centric (showing patterns increasing outwardly from a central location. They help avoid bias due to obstruction, confined attention or concentration resulting from a restricted area of activity.

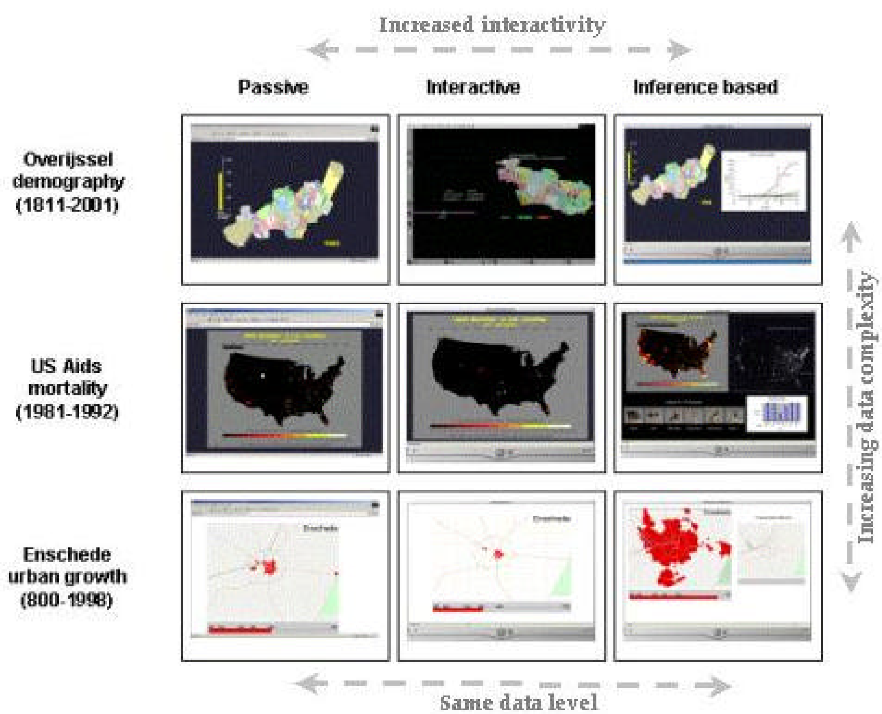


Figure 6.3. The case studies data sets and the type of animation produced for the evaluation test.

6.2.1 Overijssel demography

Overijssel is one of the provinces in the Netherlands. Within the provinces, there are municipalities, whose number has varied over the years. In general, the animation depict two major variables: the changing municipal boundaries, and the population variation of these municipalities over the years since 1811.

A total of 190 key frames, each representing a specific year in the period of study was used. Key changes in the demography patterns however were depicted on only 22 of the key frames. The use of all the frames enabled a smooth transition between consecutive frames. Some of the key changes are shown in *Figure 6.4*. The animation was created using Macromedia's Director 8 software.

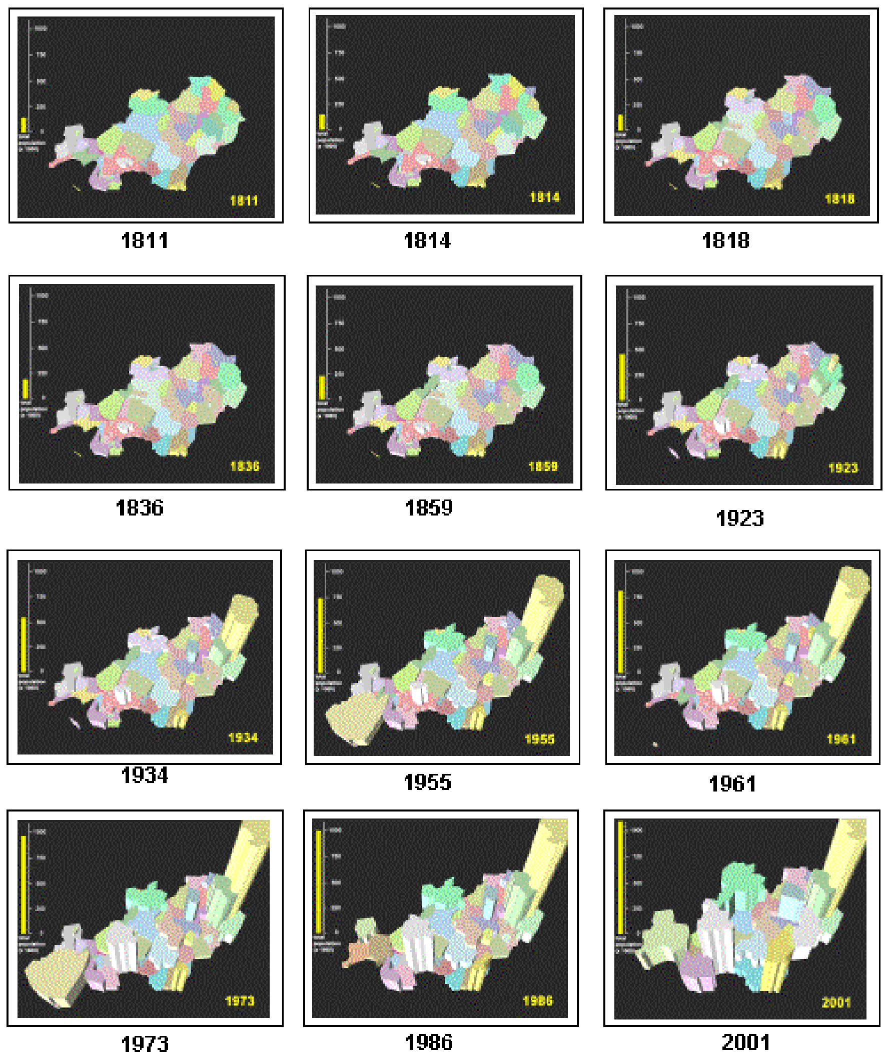


Figure 6.4. Representative key frames used to create the Overijssel demography animation

Screen captures of the passive, interactive and inference-based animation are shown in *Figure 6.5.* The passive animation is evoked as a Macromedia's Shockwave file. The animation content has a vertical scale depicting total population in the entire province at a specific period in time (depicted as a numeric), and the main view comprising the projections from the surface boundaries (municipality) showing the relative changes in the population of that specific municipality. The animation is made in a way that it repeats runs without any user intervention.

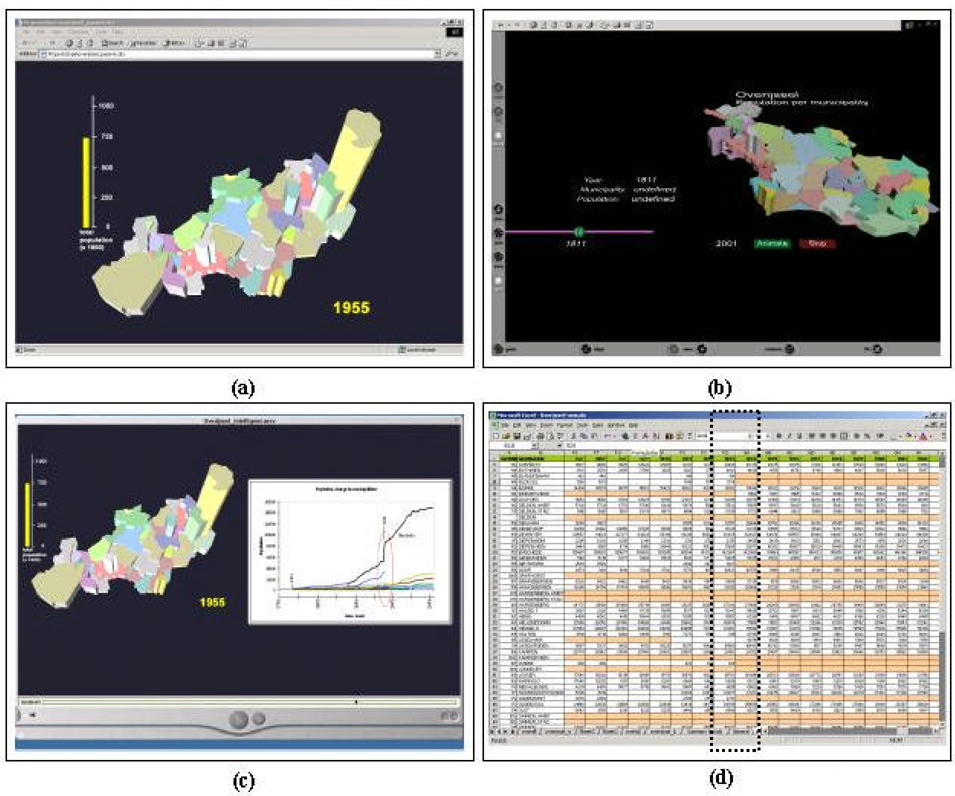


Figure 6.5. The passive *(a),* interactive *(b)* and inference-based *(c)* animation of Overijssel demography. The underlying threshold or periods where possible patterns of interest have been detected (*in dotted region*) and used as part of the inference-based animation is shown in *(d).*

The interactive VRML animation is viewed in a Parallel Graphic's Cortona 3.1 client browser. Users can start, stop the animation and also move to specific frames in time. A mouse over capability highlights names and population values for a specific municipality. The inference-based animation is evoked using a QuickTime player. It has a synchronized view that gives clues of instances when interesting patterns or trends have been detected. The view is created from Overijssel data sets stored in Microsoft's Excel.

The patterns that were exhibited by the animation included; basic changes in boundaries of single entities i.e. new municipalities appearing, municipalities disappearing, and those where no changes occurred over a period of time. There were detectable changes in relationships between the municipalities: *annexations* and *mergers* with neighbouring municipalities within and outside the province. Examples of extreme anomalies were detectable in the mergers of Enschede and Lonneker and the incorporation of Noordoostpolder into Overijssel (see the upper right part of key frame 1923, and the lower left part of 1955 and 1973 in *Figure 6.4*).

6.2.2 AIDS Mortality in US counties[6]

The data sets taken from *URL 6.2* illustrate the AIDS disease trends for the years 1981 to 1993 using Mortality data from the National Center for Health Statistics. The US-non-aggregate data are composed for each week in the 13-year period and uses 7 key frames *(Figure 6.6*). The animation give a general perspective on how AIDS Mortality has advanced in the decade.

The passive animation was created and evoked as a Macromedia's Shockwave file, while the QuickTime player (*from Apple computers Inc*) was used for the interactive and inference-based animation (*Figure 6.7*).

The inference-based animation incorporated similar traits to the interactive animation (*Figure 6.8*). In addition, it contained a complementary view of an averaged population distribution map of the US, whose contents were kept static. This view is incorporated in order to enable a novice user relate the Mortality patterns to population distribution of the US. Any hypothesis based on this relation could also be generated without the view, as seen in the passive and interactive animation. The animation also contained indexes of Aids Mortality in six regions of the US.

The animation exhibited basic changes in the county status, i.e. counties with specific Aids Mortality status appearing, disappearing or remaining unchanged. The Mortality rate in urban epicentres seems to be getting higher and recent increases in Southern counties are also aspects worth noting. Confidentiality

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[6] The data sets as used in this case study were geared towards the purpose of the evaluation and any meaning derived from them should not be presumed to be a true depiction of the Mortality trend within the stipulated period. Readers are referred to URL 6.2 for a full description of the situation within the periods highlighted.

agreements required that Mortality rates falling below three were not to be reported. Since the counts had a higher number of such rates, the data sets may underestimate the progression of AIDS Mortality in some areas.

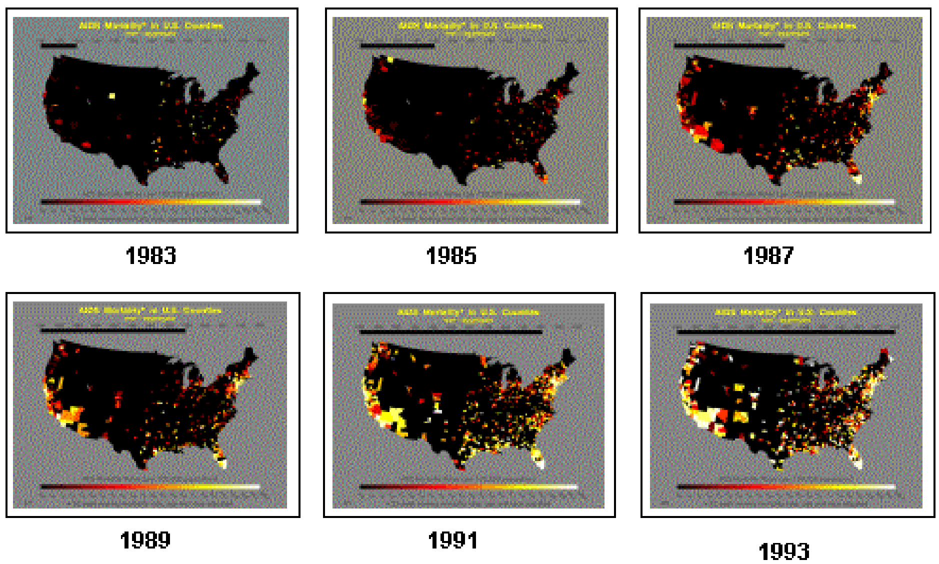

Figure 6.6 Animation frames used for the US Aids Mortality evaluation

(a) (b)

Figure 6.7 The Passive and Interactive animation depicting Aids Mortality in the US.

Figure 6.8. An Inference-based animation of Aids Mortality in the US.

6.2.3 Urban growth of Enschede town

Enschede is at present a city of 150,000 inhabitants and lies 110 miles east of Amsterdam, near the hub of principal routes to all parts of Europe. Since A.D. 800 it has served as a market center for the surrounding area. The data sets depict the growth in the town since 800 AD to 1998. Enschede was granted city status in 1325, but only in the 19th century did it gain any importance. It was once the center of the textile industry after the 1830s, and especially after Belgium's independence, when the Netherlands lost its southern textile industry. The area was chosen because of its traditional cottage industry. In 1862, a huge fire destroyed most of the town, thus hardly any old buildings remain. It has also been home to major rubber and machinery manufacturing companies. Enschede is at present an electronics-manufacturing center and is the home of Twente University of Technology and the International Institute for Geo-Information Science and Earth Observations (ITC), both of which are important Dutch scientific institutions.

Figure 6.9 Animation frames that have been used in the Enschede urban growth case study

The key thematic attributes that are highlighted include the transport network and the town's boundaries. 24 animation frames have been generated from the data set (*Figure 6.9*). Typically the temporal changes occurring within these frames are recognizable in 6 periods of time.

The passive animation is evoked as a Macromedia's Shockwave file and runs repeatedly. The interactive animation is evoked in a QuickTime player and users can only stop, pause and drag the animation to specific points in time using the basic QuickTime player tools (*Figure 6.10*). A similar number of frames as in the passive and interactive animation have been extracted from the data set to make the transportation network frames used in the inference-based animation (*Figure 6.11*).

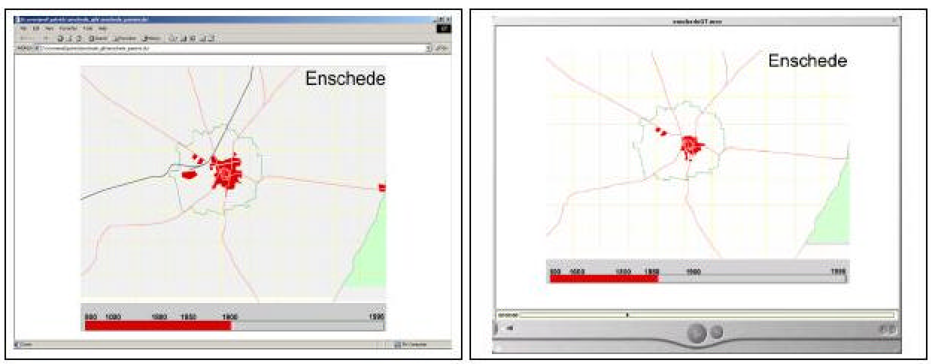

Figure 6.10 Passive and Interactive animation of Enschede town.

The animation depicts a combined extent of town's growth and the extent of the transport network in the main animation view. Users of this animation are not given the option to select a layer of their interest. The basic question here is whether offering an animation environment that has an alternative and complementary view (different perspective of the same information) and at the same time dynamically linked to the main view can enhance exploratory experiences.

The patterns exhibited in the Enschede growth animation include aspects of basic changes in appearance and disappearance of urban growth indicators, change in the type, and size of urban indicators.

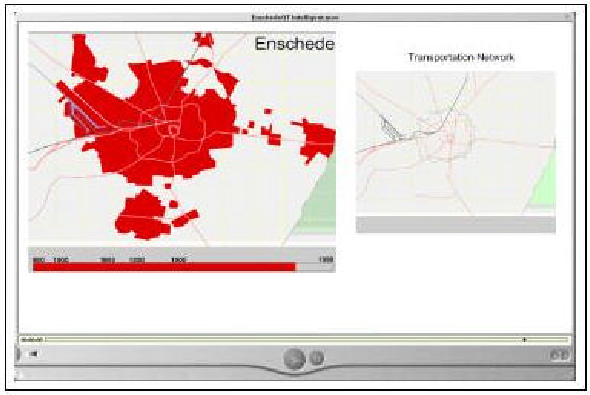

Figure 6.11 Inference-based animation depicting the urban growth of Enschede town.

6.3 Test subjects

The test subjects were volunteers drawn from the realms of Geoinformatics students pursuing a Masters of Science degree course in this writer's institute. A total of 35 students made up this number. The test subjects have a reasonable domain background in a geo-science discipline. Being postgraduate students, they have spent an average of 5 years in professional work in their relevant geo-disciplines. Their professional designation ranges from urban/land planners and evaluators, managers, researchers and programmers in census bureaus, geologists, geodesists and cartographers.

They similarly have a basic background in map reading (which also currently comprises a core aspect of their postgraduate study). They thus have produced or used a diverse range of map products to present their respective domain information to the public or aid domain experts and specific participatory groups in decision-making. All the test subjects indicated that they were familiar with animation, though none of them had used them practically in their professional work[7]. The test subjects are therefore regarded as being homogeneous based on their backgrounds (geo-expertise), present career interests or study status, their expressed interest in the use of maps and visual products in general.

[7] An earlier exercise assess the familiarity of geoscientists with the use animation in their professional tasks is described in the appendix.

6.4 Test procedure

The test procedure was to prepare and enable the test subject to undertake a free and unconstrained visual exploration in any of the case studies discussed earlier. This was done in three stages: a trial session, the actual test that utilized the thinking-aloud protocol and lastly a retrospective test.

6.4.1 Trial session

This is an introductory test that lets the test subject get accustomed to the test environment. The subjects have a few of their professional details taken. This includes their professional designations, years of work experience, experience with maps and animation among other details in a typical informal chart. Next, they are exposed to the laboratory room and equipment. They are introduced to an animation previously compiled using some test data (not related to the data used in the main test). They get the opportunity to play with the animation controls of the QuickTime player, and the Cortona 3.1 VRML client (*Figure 6.12*).

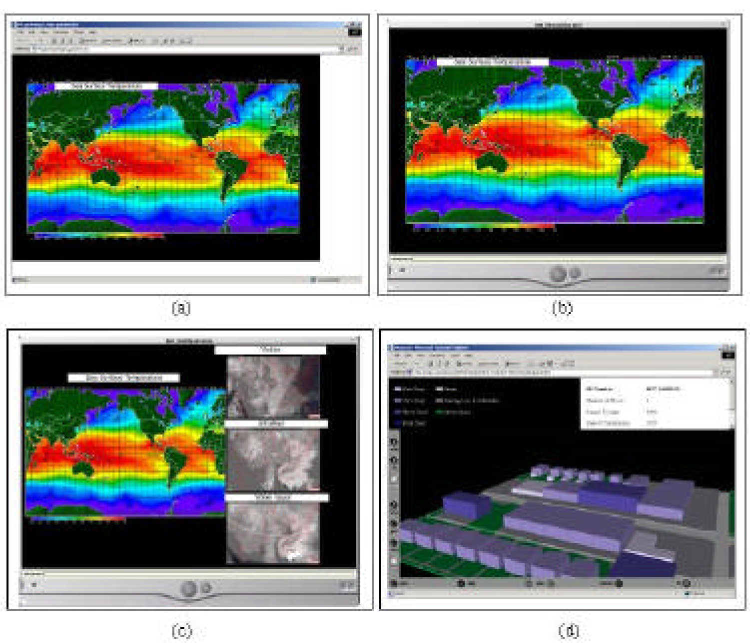

Figure 6.12 Test animation used in the trial session. (a) Passive, (b) and (d) Interactive and (c) Inference-based

The practice session is crucial since it prepares and places the test subjects on a level starting position as regards familiarization with animation and its associated tools. They also get sufficient time to get acquainted with the test environment.

Using the mentioned test animation, subjects are lead through a trial session. They are trained to think aloud along a specific line of thoughts. For the sake of the reader, the line of thoughts they are exposed to is synonymous to answering the questions that address the subject's initial observations, interpretations and animation functionality. We will highlight this aspect of training in the form of a list of questions[8].

Initial observations

These questions are employed as thinking lines to help the users report on key aspects of the representations that will aid in the evaluation process. They enable the users to make all observations that they can. They pinpoint their initial thoughts, i.e. what they think about the representation and pinpoint specific questions and /or themes that they seek to pursue. During exploration, users typically come with an open mind i.e. the test subject tackles or pursues questions that arise after viewing the representations. The questions or their pursuits are not defined *a priori*. Thus observations that they make at this stage shows the deviations, if any, in their thinking lines.

1. What are your initial observations on the information conveyed by the animation?

2. What are your expectations about the kind of information that you may find from the animation?

3. Based on your observations and, or impressions in (1) above, outline any major theme(s) (or generalized statements) that you intend to pursue.

4. Why do you want to pursue the theme(s) you have listed?

5. Can you formulate **one** major theme in the form of a question or statement?

Interpretation

The questions below help to filter out views in the test subject's thinking line in relation to what they make of their initial observations and how they connect or join up these observations to make concrete interpretations of the representation depicted. It also brings them to a point where they have to state or give the best explanation about the representation.

[8] The reader should be aware that these questions were only meant for training purposes. No written prints or otherwise were available for the subjects to fill in.

1. From your observations, is there anything that struck you most (something that you never anticipated to find or discover about the data)?

2. From your observations, is there any conclusion or explanation that you arrived at and which you had earlier on anticipated?

3. What is the most plausible conclusion that you have derived from the animation?

Functionality

Visual operations are those that enable you to read and understand a map. You use them to answer the questions about ***what***, ***where***, and ***when***. The following questions help filter out whether users used the visualization operators.

1. Did you in any way make use of the following visual operations (identify, locate, compare, associate) in outlining your statements?

2. Which other visual operations did you make use of?

3. Was the information and data provided self explanatory and sufficient for you to come to your conclusion?

4. Any other observations, comments about the animation environment, task that you wish to express about the evaluation.

6.4.2 Thinking-aloud protocol

This is a popular method for gathering information about actual use of a system (Nielsen, 1993, Elzakker, 1999). Test the subjects are observed as they interact with the system. By verbalizing their thoughts, feelings, and opinions while interacting with the system, the method is capable of capturing a wide range of cognitive activities.

In this session the test subject undertakes exploratory tasks for a maximum period of 10 minutes. In a session, the test subject uses one single case study using one of the generic types of animation. The assignment of case study and type of animation that a test subject uses is done randomly and prior to the trial session.

Two main groups of test subjects emerge out of this. *Group A* are those who use each type of animation with the same data sets *(the rows in Figure 6.3*). For example, a test subject may use each type of animation to explore the Overijssel data set. Beginning with say a passive animation with Overijssel data, then an interactive and subsequently an inference-based animation with the same data set. Similarly in this group, test subjects will use each type of the animation to explore either the US Aids Mortality or the Enschede urban growth data set. Test subjects will typically want to compare the performance of the animation with the data set – a typical heuristic comparison, an aspect that will later prove crucial when analyzing the results. This group of test subjects after their first session will typically transfer their already learnt skills and information about the case study to the next session. A total of 22 test subjects made up this group.

Group B test subjects are those who use each type of the animation to explore different data sets. In one task, test subjects used a passive animation to undertake an exploration task using the Overijssel demography data set, then an interactive animation to explore the US Aids Mortality data set and finally an inference-based animation to explore the Enschede urban growth data set. In the second task, the test subjects in this group used a passive animation to explore the Overijssel demography data set, then an interactive animation to explore the Enschede urban growth data set, and finally an inference-based animation to explore the US Aids Mortality data set. Since the test subjects in this group use different data sets, they tend to focus more on the tasks than making comparisons between the animation. Results from this group are crucial in determining a typical exploratory environment and test subject's performance using tools of varying interactivity and inference aids. A total of 13 test subjects made up this group.

6.4.3 Retrospective testing

Since the test sessions using the thinking-aloud method were recorded on videotape, more information could be gathered by reviewing the tapes together with the test subjects. Test-subjects were asked to expound on specific questions regarding their behaviour during the exercise. Not all the test subjects participated in the retrospective testing, but rather, we selected specific cases where test subjects were scanty with information (or lost track) or where their comments were unclear or not audible enough.

6.5 Test results

For every evaluation, there is the need to ensure that the results attained are reliable and valid. Any form of bias needs to be removed and misinterpretations minimized. By reliability is meant the integrity of the evaluation procedure and results such that if the experiment were to be repeated, similar results could be achieved (Nielsen, 1993). To be valid, the results must reflect the objectives of the evaluation. The main objective is to test the overall exploratory suitability of the defined animation environments as depicted in the three types of animation. The users' cognitive structures and processes also go a long way to verifying the exploratory design model highlighted in *chapter 4*. The variation in the type of animation used is expected to result in a difference in the outcome of the exploratory process by giving varying measurements on the indicators of exploratory environments.

In the following sections, we present an overview of the process that was used to extract the vital information from the test session's video recordings. We also describe the results in relation to the test-subject's experiences with the interface aspects of the types of animation used, and a description of the attained results that focus more on giving credence to the exploratory design model (discussed in *chapter 4)* and the exploratory performance by the test subjects[9].

6.5.1 Extracting session's information

Each test subject was expected to formulate the best claim or conclusion about the phenomenon depicted by the animation. This was done by locating indicators consisting of such words as, *therefore, thus, so, as a result, consequently and my conclusions is that.* The best claim made by the test subjects was analyzed on the basis of the exploratory indicators earlier on introduced in *chapter 5, section 5.3.3.* Based on the realized conclusion, it was then more sensible to analyze the arguments. This involved looking for premises that directly support the conclusion. The premises consisted of, supporting arguments, evidence, assumptions, authority and explanations. They could be traced from use of such words as, *since, for, supposing that, given that, because and assuming that.* In essence what the foregoing translates to is the tracing of the three inferences of *deduction*, *induction* and *abduction*, from the test subjects accounts during the thinking aloud protocol.

On the visual method adopted during the exploration task, *observation* entail extracting test subjects visual descriptors (involving a conceptual representation of the display), interpretation (identifying meaningful patterns, trend or anomalies), and explanation (hypothesizing the causes of the phenomenon in the interpretation stage). We will give a few examples of the sample forms for analysis, and the subsequent information extracts (*Figures 6.13 and 6.14*).

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[9] The recording of the test session can be viewed on the accompanying CDROM. In analysing the results in this chapter, we will use a few extracts as examples from the recordings.

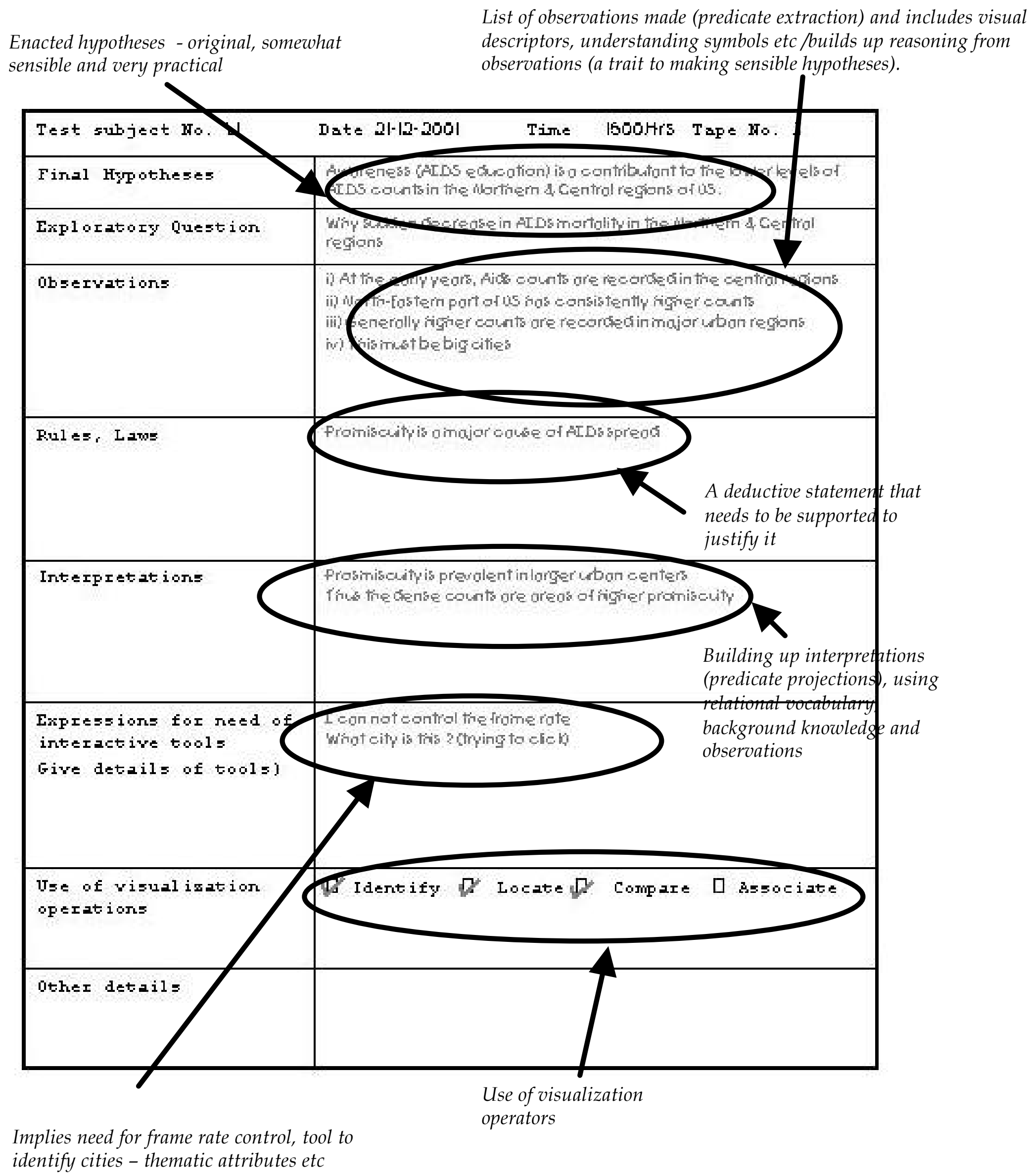


Figure 6.13. Extracting key information from the video recordings

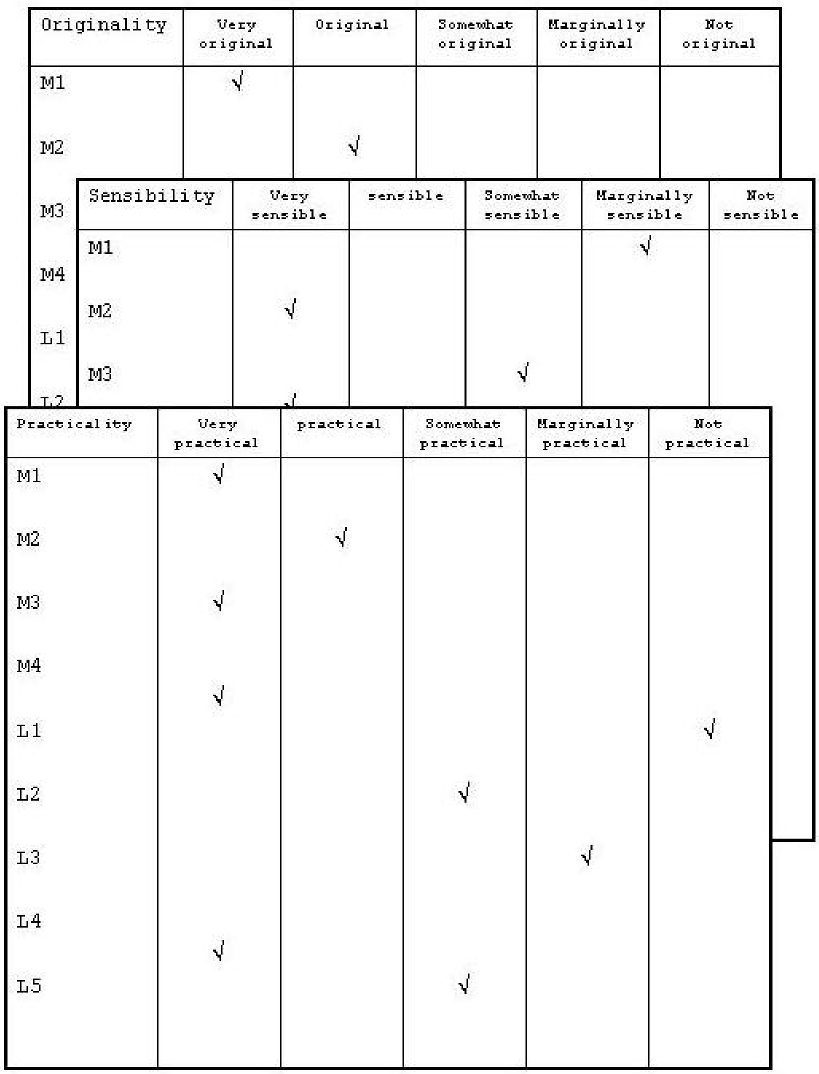


Figure 6.14. Evaluator's form for rating the formulated hypotheses

An example

The following were extracted from a test session of a subject using passive animation of the AIDS mortality in US counties. The analysis is shown as footnotes below[10].

```
a. this is a map of the US
b. it is a map showing the US AIDS disease trends for the years 1981 to 1993
   (reading from the map's title)
c. this is the scale bar…. Lighter colours signify higher AIDS mortality
   rate ….darker colours signify low mortality rates
d. this is funny… normally the darker the colour, the higher the mortality
   rate
e. ..oh maybe its because of the colour used for map's background
f. the animation is too fast…….
g. what is the name of this region (city)….(trying to click on the area)


h. Earlier higher rates are at the central regions of US.. later the rate is
   higher along the coastal towns
i. The major cities are located in those areas with high AIDS counts
j. Big cities are known to be regions of high promiscuity


k. The AIDS counts are highest in urban regions due to the high promiscuous
   activities that take place
l. The AIDS trends is higher in the big cities due to their high population
   densities
m. The AIDS trends will always be high in cities that are susceptible to
   immigrants due to their closeness to neighboring countries
```

6.5.2 Session experiences with interface

Tests undertaken by *Group A* test subjects reveal the need for tools for the user to interact with the animation during display. A count was made on the use of any verbal comments made and the actions performed by the test subjects to confirm

[10] The extracted information shows distinct phases of the reasoning process.

i. *a-g* describe the initial observations made by the test subject.
ii. *h-j* describe the interpretation phases that combines the initial observations, relationships amongst them and the use of the test subject's background knowledge.
iii. *k-m* are three probable hypothesis that can be enacted from the observations and interpretations.

In the ranking of the hypothesis formulated,

i. Hypotheses *k and l* will score high in the originality scale
ii. All the hypotheses have a flaw in their construct meaning that they will get a lower ranking in the sensibility indicator. Probably *k* will score higher, followed by *l* and *m*.
iii. All the hypotheses are quite practical and within the domain of the experts concern. For example the reasons indicated by each hypothesis for the AIDS trends are practical and of concern to epidemiologists. But within the limits of the available data, *l* might stand out as the best explanation that can be derived from the animation.

this need. *One* single count was given per task to the use of one or more of such expressions by a test subject. All the test subjects in this group unanimously expressed the desire to interact with the animation at one point or other. Results also show that out of the 35 test subjects of the two main evaluation groups (*Groups A & B*), a total of 30 expressed the need to interact with the animated map. This is quite significant given the fact that the instructions as described in *section 6.2* emphasized the test subject's role of exploring the given data sets as opposed to evaluating the interface of the prototypes. So the comments made for the need of interactive tools were uttered as a secondary item as they pursued the exploratory tasks.

Common phrases used when performing test with the passive animation were in relation to the need to control the frame rate, play, pause or stop the animation.

> Oh no.. this animation is too fast…. How do I slow it down…
>
> What is this? (*Moving the mouse over and clicking an area in the Overijssel passive map. This is a show of the intuitive reflexes to interacting with animation*).
>
> Which municipality is this?… (*Need for thematic attribute*)
>
> What is the population at this time? (*Need for temporal attribute*)

When the video recording of a session was analyzed in retrospect, test subjects expressed their frustrations at being unable to get information relating to the attributes of the representations. For example;

> **Question**; why did you click at that specific point on the map?
>
> **Test subject:** *I wanted to know which municipality that area represented… It makes it easier for me to compare and..*
>
> **Question:** Do you have to know the name before you compare?
> **Test subject**; *Yes!*
>
> **Question;** How do you think that can be improved or implemented?
>
> **Test subject;** *using normal click or mouse over and it is highlighted somehow.... or using legends*

Another perspective of the need for interactivity is expressed when test subjects in *Group A,* and who had earlier on used passive animation, moved over to using interactive animation. A common spontaneous word used here was *"better"*. Typical phrases were;

> *This is so much better!!* (*meaning better than passive animation*)
>
> *At least I can control the animation…*

Comparisons made in *Group A*, between the interactive and inference-based animation highlighted details of the interactivity desired to improve the interface. A finer temporal interval or ability to choose the temporal resolution between the animation frames, frame rate control, basic media play, stop controls, data access capabilities, orientation and navigation capabilities were among the necessary and commonly listed tools. Another point regards the use of inset maps to relate the complementary view to the main view.

Of the 35 test subjects (*Groups A & B*) using the inference-based animation, 22 used the complementary inference view to enhance their understanding of the case study. Test subjects were quick to pursue the hints provided by these views. The views seem to place test subjects straight away into an active exploratory status compared to when they use the other types of animation. 30 test subjects from both Groups *A and B* used or showed the need for the generic operators of: *identify, locate, compare or associate*.

6.5.3 Exploratory performance

Below, we describe results that relate to the exploratory performance of test subjects in the two main evaluation groups. In the first instance, a description of results is presented detailing how test subjects performed on the three case studies. This is followed by the presentation of a hypothesis index[11] ranking for each group's performances during the sessions.

Group A test subjects formulated a total of 9 hypotheses (*Figure 6.15 & 6.16.* There were *3* hypotheses using interactive, and 6 for inference-based animation). These results also tell something about the data sets used. They confirm the varying level of complexity amongst the three case studies. No hypothesis counts were recorded for test subjects using passive animation. *Group B* test subjects formulated a total of 12 hypotheses as shown in *Figure 6.16* (3 for passive, 3 for interactive and 6 for inference-based animation).

The quality of the formulated hypotheses was specified with respect to the exploratory indicators of: *originality, sensibility and practicality*. *Figure 6.17* and *6.18* presents the quality of the formulated hypotheses in *Groups A & B* respectively.

[11] A hypothesis index is the ratio of the number of hypothesis formulated (Actual hypotheses count) to the total number of test subjects participating in the test.

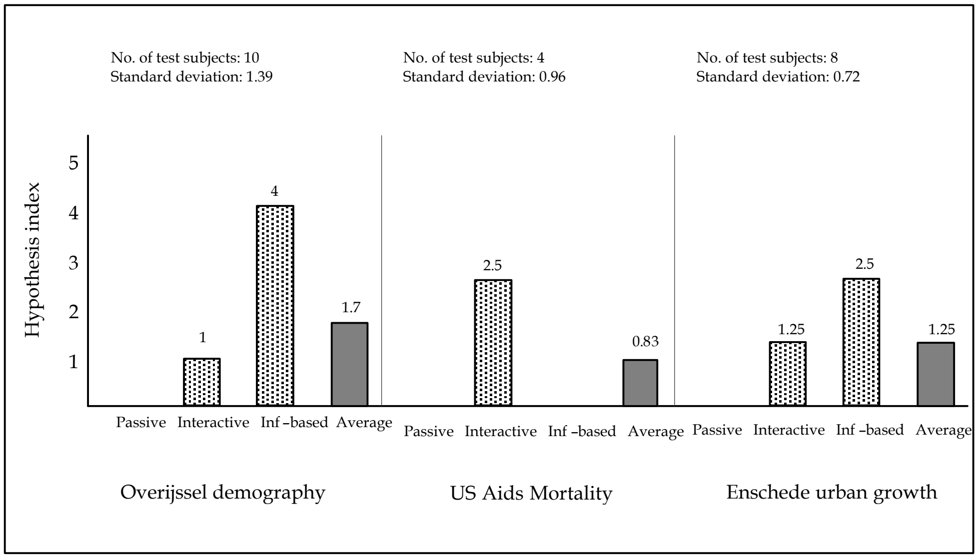


Figure 6.15. Contribution of each type of animation to hypothesis formulation (*Group A*).

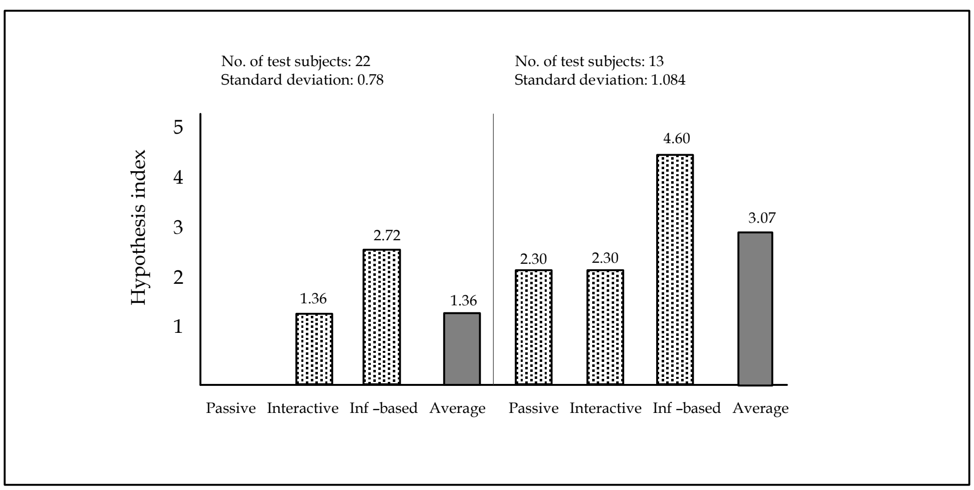


Figure 6.16. Contribution of each type of animation to hypothesis formulation in *Groups A & B*.

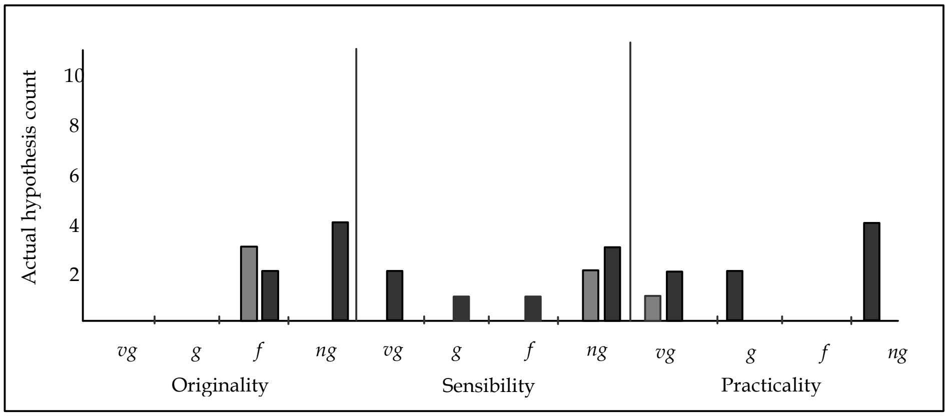


Figure 6.17. Ranking for the evaluation of *Group A* utilizing each type of animation to same data sets[12].

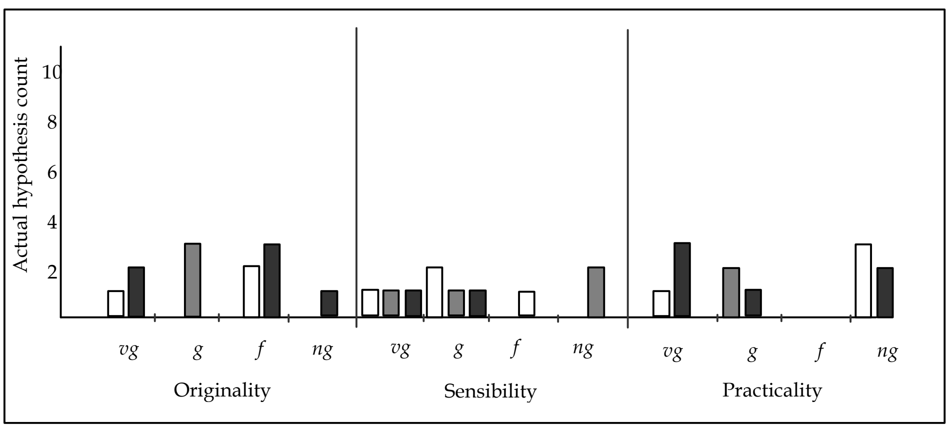


Figure 6.18 Ranking for the evaluation of *Group B* utilizing each type of animation to different data sets[12]

12

Key

vg-very good *g-good* *f-fair* *ng-not good*

■ Inference-based animation ▢ Passive animation □ Interactive animation

6.5.4 Relationship between visual methods & thought processes

The visual methods stages that were considered were: *observation*, *interpretation* and *explanation*. This in essence translates into the "seeing that – reasoning why" phases in visualization (MacEachren, 1995). Observation as used in the evaluation only gives the visual description of the representation in the specific animation. Visual description is characterized here by the test subject's use of the sensory input that translates into a description that utilizes perceptual schemata. Observations thus would focus on the typical graphic marks that are represented as in the observed case below;

> `..this is a scale bar…. The graduations range from shades of black to white….`
>
> `..there are numerous shaded areas on the map…`

Interpretation builds further on the visual description and results in a representation schema that identifies the features as in the examples below.

> `..the colours are used to distinguish between the different municipalities in Overijssel...`
>
> `..this particular line represents the roads …`

Finally in explanation and which we also term the *hypothesis formulation phase*, test subjects are able to hypothesize when they encounter meaningful patterns exhibited in the animation. This they do by utilizing their knowledge about the domain or case study involved and hypothesizing about the cause of the patterns observed.

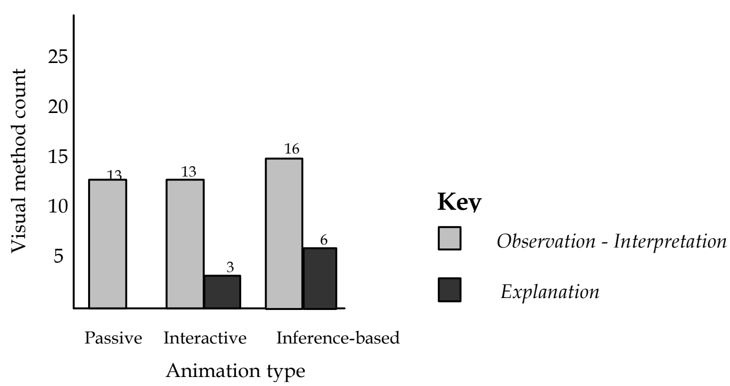


Figure 6.19. Comparing counts between stages in the visual method

Figure 6.19 shows a graph comparing the counts obtained from a combined count of observations and interpretations to that of explanations. These are plotted for the three types of animation used. Combining the observation and interpretation counts was necessitated because of the difficulties encountered in making distinctions between the two stages.

6.6 Discussion

The above results describe an evaluation study that was undertaken to give an understanding of how users perform exploratory tasks using the three types of animation namely; passive, interactive and inference-based animation. This in essence attempts to shed light on the exploratory design model highlighted earlier on in *chapter 4*. The distinctions made about these types of animation are simplistic and generic. Simplicity was to enable test subjects to focus more on the domain exploratory tasks rather than to get bogged down by the triviality of a complex interface and tasks. For instance, passive animation are *view only:* users here cannot change any parameters. Interactive animation engage only the basic media control tools of play, stop, navigation orientation tools, and a timeline that test subjects could drag to see specific instances of the representation. There are an infinite number of interactive possibilities, but the work restricted itself to the lower end of this range. Inference-based animation are in essence interactive animation but they have a complementary view that is dynamically linked to the main view. It is hoped that the complementary view in a way highlights a moderate knowledge of interesting patterns incorporated in the data set. All these types of animation had to be evaluated during the design and trial test phases and thus depict an acceptable interface for the specific test intended.

The results have met these goals. They have helped to confirm three main hypotheses about the explorative capabilities of temporal cartographic animation. We will use the hypotheses to further explain the results.

Hypothesis 1

Interactive animation is an intuitively preferred option to passive animation.

Animation parameters that include the frame rate speed, frame sequence, and viewing perspective affect users differently. Users want to be in control of the dynamic display. They want to play, stop and pause the animation at their own pace and rate. Inability to interact results in frustration as was evident in the tests. Test subjects were prompted (or desired) to vary the animation speed depending on where their attention was focused. Using the Overijssel animation for example, test subjects found the frame rate appropriate when they had their attention focused on the 3-D municipality boundary-population map. The moment that they expressed interest in knowing *when* (time) observed changes occurred they found the frame rate too fast. This pinpoints the need to optimize on animation production. Designers of passive animation ought to consider carefully how all represented features can be viewed effectively without causing undue strain to the user.

Employing interactivity in animation is also a convenient and intuitive way that visualization operators *(identify, locate, compare & associate)* can be implemented in the animation environment. Observing users move the *mouse over* features and *click* the mouse expecting to get some feedback on what they are seeing reinforces the need for tools to enable visualization operations. Related to this is the expression of the need to access further data. Users want to confirm their initial thoughts and explanations with the observed patterns and trends. To do this they expressed the need for tools to give them access to the original or related data sets. Tools here should facilitate selection of a specified geographic layer and attribute tables.

The explanation that can be attributed to the equal rating in the formulated hypothesis between the passive and interactive animation as highlighted in *Figure 6.16* points to their possible equal performance in exploration stages specifically when the data levels in each of the case studies is maintained at the same level. Whereas these restrictions were solely to avoid data related bias, we are of the opinion that interactivity does more than just control say the media control tools (as was the case in these tests). Their exploratory scope is unlimited when used for accessing the data behind the display.

Hypothesis 2

Inference-based animation are more enriching and provocative environments for exploratory tasks than mere passive and interactive ones.

The results show that test subjects using the inference-based animation attained a higher hypotheses yield. In general, the inference-based animation environment facilitated the formulation of a higher number of hypotheses in both groups (*Figure 6.15 & 6.16)*. Inference-based animation also generated the most practical hypothesis (with respect to the study case's domain of application as evident in *Figures 6.17 & 6.18*). The hints or information that these views provided seem to automatically challenge users to want to explore them further. It is vital to mention here that test subjects were under no obligation to pursue these hints. They could on their own initiate questions worth pursuing. Similarly these additional views did not have any extra information compared with what was provided in passive and interactive animation. They basically provided another perspective of the main view, only in this case they narrowly focused on the patterns that may be of interest to the users.

The distinct uses that each of the three types of animation are subjected to are crucial in exploration. This highlights the importance of each type of animation in the exploration process. Test subjects in *Group B* who had to confront new study cases in each evaluation session went through an initial time period of no interactivity (either through intentions in passive animation or actions as with interactive animation). This was followed by a time period when they interactively engaged the animation (as in interactive animation). Therefore in inference-based animation, test subjects went through all the elements or stages of passive and interactive animation. Thus the inference-based animation inherits the interface and use characteristics that are incorporated within both the passive and interactive animation.

Hypothesis 3

The visual methods of observation, explanation and interpretation are synonymous with the iterative phases in the exploratory cognitive model.

There is a correlation between the way the three types of animation are used and the visual methods that users employ. Passivity is a trait that characterizes the early stages of visual exploration. The use of passive animation seems to be able to contribute to the visual method of observation and partly to interpretation. These visual methods are evoked and used iteratively during the entire exploratory period. Evoking interactivity as when using interactive and inference-based animation links the already observed and/or identified features in the observation and interpretation stages to the explanation stage where hypotheses are formulated.

A similar pattern occurs when the underlying cognitive structures and processes of a user are traced. The initial observation stages as explained in *sub-section 6.4.1* in this chapter highlighted the many observations that users could make. The test subject's initial pursuits or expectations were weighed against the final outcome of the interpretations they made of the case study (data sets explored). The hypothesis formulated was characterized by the novelty of the observed patterns. By this we mean; the majority of hypotheses were centered on describing and hence explaining the *unique* patterns that were inherent in the data. The majority of hypothesis were not centered around describing the *normal* patterns, but only those that seemed *abnormal*. The point is that, the visual method of observation and interpretation seem to dominate the stages before any unique or spatial structure with appropriate pre-inventive properties is discovered. Once that is attained, the explanations seem to follow.

6.7 Summary

This chapter highlights an evaluation procedure and test results that confirm issues relating to how the three types of animation are used in typical exploratory tasks within the geosciences. It also highlights the correlation between the *use* patterns exhibited in these animation to the exploratory cognitive model discussed in *chapter 4*.

The results show: First, that interactivity in animation is a preferred and crucial exploratory tool in making interpretations and providing explanations about observed phenomena. By interactivity features are identified and interpreted. Second, exploring geospatial data structures using animation is best achieved using provocative interactive tools such as was seen with the inference-based animation. Finally, the visual methods employed using the three types of animation are all related and together these patterns confirm the exploratory cognitive structure and processes for cartographic visualization tools.

7

Conclusions & Recommendations

"We're living proof that nice guys always finish last." Matthew Cooper

The fundamental observation that guided this work is that the environment in which cartographic animation are used at present does not support the exploratory pursuits that geoscientist undertake. These environments lack or have no functionalities to enhance the exploration process. Finding out their true exploratory performance is inhibited by uses that intuitively favour embedding graphical displays with interactive and dynamic tools as a qualifying trait for exploration. This seem to crop up from the continual improvement and proliferation of graphics hardware for workstations and personal computers, where performance is characterized by fast, high quality graphics displays coupled with highly expressive interactive input devices to achieve real-time visualization. But most importantly, no research had been undertaken to define a nature or set of properties that would qualify cartographic animation environments as being self sufficient for undertaking exploratory tasks. We thought that defining these properties, would not only help in designing cartographic animation functionalities that steer exploration, but also would help to evaluate the resulting end-products. Exploratory products in this sense, are then not just abstract knowledge pop-ups, but rather are result of the purposeful and skilful use facilitated by geoscientists using visual functionalities to construct new knowledge. This knowledge has a valid construct, meaning that the results obtained can be generally perceived as unique, sensible and practical even by others not involved with the tasks.

In this regard, we are confident that this thesis is a first step towards formalizing the design and uses of temporal cartographic animation. The thesis has realized its objectives as outlined in the introductory chapter. It has reviewed the types and uses of animation within the presentational realms of cartographic visualization and formulated its exploratory uses by proposing a framework on which animation functionalities that can be defined and used. The framework encompasses inputs of understanding of temporal geospatial data typologies, exploratory cognitive structures and processes, and the extents to which interactivity can implement visualization operations. These results are described in *chapters 3 and 4*. At a glance, what one sees emerging is a cross-disciplinary approach that transcends the disciplines in cartography, cognitive science, human computer interaction (HCI), computer animation, artificial intelligence and geoscience application domains. This may seem out of place in research that is undertaken within mainstream realms of cartography. However, what it pinpoints is that dealing with such a subject as cartographic animation (or geographic visualization in general), calls for cross-disciplinary collaborative research initiatives where work and results can be shared and yet still maintain the prevailing disciplinary focus.

In this final chapter, we describe what has been accomplished so far. It also describes a number of important issues that fall on the periphery of this study, and which would make crucial research topics in the near future. Lastly, we have some recommendations for improving our results that may be beneficial to those who would like to follow up our findings.

7.1 Main contributions

Formerly there has been no explicit framework for defining functionalities in cartographic animation. We see our work as a fully-fledged attempt towards addressing this omission. We list some of our most important contributions.

Inference-based animation

By revisiting the commonly used types of animation – passive and interactive, the thesis proposes a third type – the inference based animation. Inference based animation are cognitively modeled interactive animation. They have the capability that can exhaustively explore and bring to the surface complex patterns and relationships in data sets. This optimizes the quality of possible re-expressions or alternative dynamically linked views, which the user can access. They are thus capable of alleviating some of the users cognitive workload (the mental effort that includes the interpretative and judgmental functions that a user employs whilst using a product to accomplish a task) and hence increase their exploratory performance.

Visualization operators in animation

Visualization operators are not new to studies in visualizations. They have been used in studies in information visualization. They describe the means through which a user's tasks are effectuated. They allow users to view, interact with layers of symbolized geospatial features, to access the data sets behind the display. However, in order to reinforce the framework for defining functionalities in cartographic animation, the thesis has evolved specific operators crucial for dynamic visualizations of temporal geospatial data sets. With these operators, users can adequately manipulate and explore data visually and more effectively. The generic operators of *Identify, Locate, Compare* and *Associate* are refined to encompass their specific spatial, thematic and temporal sub-components that are typical of uses with temporal cartographic animation.

Evolving an exploratory cognition model

Much of the previous hype in visual exploration tools was centered on the words dynamic and interactive. This makes sense, since by these tools users are given great power to interact with the representations on the display. Problems arise when the words connote a visual system's exploratory capability. By evolving the exploratory cognition model, one gets an understanding of the cognitive structures and processes that geoscientists utilize during exploratory tasks. Basing animation tool design on the model is practical and the surest way to delineate between tools for presentation and exploratory cartographic visualization. Not only this, but also, any resulting product of an exploratory process can be subjected to a functional evaluation to determine its exploratory validity. Functional evaluation puts the end product of a process in perspective. Free unconstrained visual exploration as defined, starts from the user having no prior knowledge about the data sets being explored. One then moves from this status to a level where knowledge is constructed and new discoveries made. One indicator of this achievement is to evaluate the validity of any hypotheses that is formulated. The hypotheses have certain indicators or properties, which can be looked at as a qualifying attribute for the end product of the exploratory visualization process. With emerging map use paradigms of exploration the need is to adapt the evaluation procedure to cater for this realm of map use.

The thesis has successfully outlined a formal evaluation methodology for identifying users thought processes and testing these against the hypothesized exploratory cognition model. A list of exploratory indicators that qualify the output products of an exploratory process seem practical and sensible for evaluating the generated hypothesis.

7.2 Conclusions

The generic types of cartographic animation as defined in this thesis play a crucial role in facilitating the visualization of geospatial data.

To be more precise, they are all capable of contributing greatly to visual data exploration tasks. This is, because they each make up part of the visual methods of observation, interpretation and explanation. The exploratory process is incomplete if no such visual capabilities are existent in the tools. Passive animation play a leading role in the early stages of exploration. Interactivity becomes crucial in the later stages of interpretation and explanation.

Inference based animation are provocative in nature. The dynamically linked view (or complementary view) that they display has the effect of capturing the user's immediate attention, in a sense distracting one from the main view. If the dynamically linked view has interesting information displayed therein, then a user's exploratory performance is enhanced. It becomes a time saving intelligent tool. Of course there are possibilities that they could also be a nuisance to users, especially if what the view offers fall short of what the user seeks to pursue. Inference based animation stands to play a major role when integrated with data mining algorithms in what may be termed a visual data mining system. Based on the extracted and interesting patterns from the raw geospatial data sets, complementary and dynamically linked views can be generated. Its role here will be to highlight those structures and patterns within the data, which could otherwise have gone unseen or taken a long time for the user to detect.

Temporal cartographic animation can be created and their contents defined based on the user's exploratory needs.

The thesis has also provided sufficient proof that creating animation as a demand driven process is practical and useful. Users no longer have to confront pre-assembled frames and known information as contents of the animation, but can indeed select frames, choose geographical layers of interest and then use the animation to work from a position of ignorance to one of new knowledge and insight.

Maintaining a link between the data sets and the animation is crucial to enabling a rich and effective exploratory environment.

Part of the motivation for this thesis was initiated by the poor or absent linkage between animation and databases. As much as this need was a practical one, there was not much information to warrant this linked environment. The results have shown that the move to maintain this link is vital and can enrich the implementation of visualization operators and enable a much richer *query* environment.

Exploratory environments are characterized by iterative queries and explanation sessions. Users will typically want to get more and specific information to qualify their explanations. While users are zealous in pursuing the many questions that arise out of the process, they can easily become frustrated when they find that their freedom to select and generate information is adversely curtailed.

The criteria for implementing and using interactive tools during an animation process should not compromise their dynamism.

Animation are about changing representations. Their real power rests in their ability to facilitate seeing the whole process of change. When implementing interactive tools in animation, designers should focus more on tools that will enhance seeing the *big picture* rather than those that may distract the user.

Re-expressions

Previously cartographers had adapted methods of visualization that were commonly used within the disciplinary realms of statistics. Re-expression is one of such methods. The term denotes an alternative graphic representation that results from a transformation of the original data. The study undertaken in this thesis incorporated re-expression in its inference-based animation. The result obtained confirms the hypothesis that providing a different view of the same data set stimulates visual thinking and understanding.

Patterns, trends and anomalies

Pro-animation researchers and users advance the notion that animation's real power is to show interrelationships amongst the geospatial data components of location, attribute and time. Whereas this remains valid, this study also reinforces the fact that their uses transcends that of enabling users discern patterns and trends, and that they are capable of enabling users detect anomalies as well. Any deviation or peculiarity is easily recognizable in an animation. The study has shown that users are drawn to patterns that look odd such as with outliers. These patterns seem to capture their immediate attention leading them to explore them more.

7.3 Recommendations

Certain issues emerged while pursuing this study. First, the thesis did not account for certain aspects of the dynamic variables, which we think, may contribute significantly to exploratory tasks (DiBiase et al., 1992; MacEachren, 1994; Blok, 1997 & 2000). Dynamic variables may influence one's ability to detect geospatial dynamics. As yet, the outcome from research dealing with dynamic variables is still very scanty. An improvement to the optimized animation as used in this thesis could account for their effects on the test subject's performance.

Second, our use of re-expression to provide an alternative view of the transformed data did not specifically distinguish between the possible re-expressions that can be attained. Though we used reordering in the inference-based animation, we think it will be appropriate to specify and investigate the contribution of the many ways that re-expressions can be effected. Part of our limitation was due to the focus on temporal aspects of animation. But the value of these methods could well be realized even with the non-temporal and successive build-up animation.

Third, temporal animation are highly suitable for implementation in a temporal GIS (TGIS) environment. To date, the development and implementation of geographical visualization (GVis) and TGIS has yet to be realized. Thus for animation and the subsequent functionalities as defined in this thesis, we anticipate initial implementation at a prototype level. The implementation should enable users to visualize the data and focus on what is relevant, thereby transcending the presentational realms of cartographic visualization. Technical considerations on the implementation should ensure that the animation is not tightly coupled to other tasks in the system, since this may slowdown the system's performance. Implementing exploratory temporal animation is synonymous with current work that seeks to integrate GVis, GIS and knowledge discovery in databases (KDD) into comprehensive systems that have interactive visual displays, temporal geospatial operations and data mining capabilities (Wachowicz, 1999).

Fourth, imbuing animation with domain intelligence is an area of study that has great significance for geo-applications dealing with disaster prevention, early warnings and emergency fields. These studies require that the phenomena and information is dynamically visualized in real time to enable a timely response by management teams. It requires dynamic visualization systems that not only utilize historical data sets, but also extrapolate data to forecast a future visual scenario of the phenomena. These intelligent traits could be utilized in research dealing in intelligent autonomous agents. In particular, we single out methods that provide a finite and succinct way of representing uncertainty in the features world and the numerous possible decision alternatives. This makes it possible to imbue features with knowledge, monitor the status and contents of the world in which they and track any possible changes that may occur.

Lastly, the use of animation should of course be within the confines of acceptable interactivity levels, graphic mix and dynamics, since the rich and rapid graphic sequences of graphics can overwhelm the eye-brain system. Future research studies should look at the influences of varying ranges of graphics and interactivity levels on the user's performance. These aspects if not controlled may have adverse cognitive influences thereby affecting learning, decision making and problem solving.

Samenvatting

(Summary in dutch)

Momenteel worden ontwikkelingen in de kartografie mede beïnvloed door trends op het gebied van de wetenschappelijke visualisatie waar nieuwe interactieve en dynamische visualisatiegereedschappen worden ontwikkeld. Met behulp van deze hulpmiddelen ontstaat één van de meest effectieve analytische strategieën, doordat men de mogelijkheid heeft data en informatie grafisch te onderzoeken, en daardoor het proces van wetenschappelijk ontdekken en begrijpen van onbewerkte data sets stimuleert.

Kartografische animatie is één van de belangrijkste hulpmiddelen geworden voor gebruik tijdens de verkenning van onbewerkte (temporele) ruimtelijke gegevens. Echter, de noodzakelijke theorie en functionaliteit om de animatie in een onderzoeksomgeving van een bepaalde toepassing daadwerkelijk te gebruiken, mist nog of is nog niet geheel ontwikkeld. Veel van de huidige kartografische animaties worden momenteel slechts gebruikt voor presentatie van ruimtelijke gegevens. Daardoor kunnen gebruikers patronen, trends en relaties waarnemen die anders vermoedelijk onopgemerkt zouden blijven. In een onderzoeksomgeving zijn de manipulatie mogelijkheden nog beperkt door het ontbreken van interactief dynamische manipulatie mogelijkheden die een onderzoeker behulpzaam kunnen zijn bij de exploratie van de gegevens. Voorbeelden zijn een gebrek aan selectiemogelijkheden op basis van bepaalde attribuutkenmerken, het niet kunnen opstellen van vragenoperaties en het uitvoeren van kwalitatieve ruimtelijke gegevensanalyse. De ontwikkeling van een dergelijke functionaliteit kan niet los gezien worden van de menselijke waarnemingscapaciteit.

Dit onderzoek richt zich op het ontwikkelen van de noodzakelijke functionaliteit van temporele kartografische animaties in een geowetenschappelijke omgeving, rekening houdend met de menselijke beperkingen zodat deze effectief als een gereedschap in een exploratieve omgeving kunnen functioneren .

Het onderzoek realiseert deze doelstellingen door een analyse van typen en gebruik van animatie binnen de (traditionele) kartografie, en trekt de bevindingen door naar een exploratieve gebruiksomgeving, waarvoor functionaliteit wordt gedefinieerd. Hierin spelen temporele ruimtelijke data typologieën, exploratieve cognitieve structuren en processen een rol om het beoogde gebruik van de animatie door geowetenschappers te ondersteunen..

De voorgestelde functionaliteit voortkomend uit dit onderzoek wordt uiteindelijk getoetst aan de hand van drie soorten van animaties, namelijk een passieve, een interactieve en één die gebaseerd is op interferentie. Zij verschillen van elkaar door de mate van interactiviteit die ze de gebruiker bieden. Om nut en bruikbaarheid binnen een exploratieve omgeving te toetsen werd een kaartgebruiksonderzoek opgezet waarin testpersonen werden geobserveerd bij het uitvoeren van bepaalde taken. Om de onderliggende cognitieve structuren en processen tijdens de activiteiten van de testpersonen te achterhalen en mogelijk te gebruiken voor het verbeteren van de voorgestelde functionaliteit wordt het *hardop-denk protocol* toegepast. Om de prestatie van het testpersonen en hun activiteiten met de verschillende animaties te beoordelen is gekeken naar indicatoren als *originaliteit, gevoeligheid* en *bruikbaarheid*.

De resultaten van het gebruikersonderzoek laten zien dat alle kartografische animatie typen zoals hierboven omschreven een belangrijke rol spelen in de visualisatie van temporele ruimtelijke gegevens. Elk speelt zijn eigen rol in de exploratie van de gegevens. De passieve animatie functioneert zinvol tijdens de aanvang van de exploratie en de animatie gebaseerd op interferentie speelt een cruciale rol bij de interpretatie en uitleg van ruimtelijke patronen en relaties. De resultaten geven bovendien aan dat animatie ook uitermate geschikt is voor het herkennen van afwijkingen en bijzonderheden in gegevenssets.

De bevindingen van het onderzoek tonen ook aan dat een op interferentie gebaseerde animatie gemaakt kan worden op basis van de behoeften van de gebruiker, iets dat voorheen niet helder was. Dit vereist overigens wel een directe link tussen de gegevensset en de animatie om de gewenste functionaliteit te kunnen realiseren, waarbij van belang is dat de relatie niet belemmerend werkt op de dynamiek van de animatie.

Hieronder worden in vogelvlucht de hoofdstukken van het proefschrift gerangschikt.

Hoofdstuk 1 geeft een overzicht van de structuur van het gehele proefschrift, waarbij de nadruk ligt op motivatie, probleemstelling, methodiek en hoe de resultaten van het proefschrift kunnen bijdragen aan de kartografische theorie.

Hoofdstuk 2 schetst de verschillende definities van termen en uitdrukkingen zoals deze worden gebruikt in het proefschrift. Het geeft een overzicht van de types en functionaliteiten van de gangbaar kartografische animatie en het schetst een algemeen ontwerp van de factoren die op animatieontwerp en -gebruik van invloed zijn.

Hoofdstuk 3 behandelt de verschillende aspecten in het ontwerp van kartografische animatie rekening houdend met de geowetenschapper (de gebruiker) en zijn/haar taken, het karakter van de ruimtelijke gegevens en interactieve interface opties. Ieder van deze factoren wordt nader besproken waarbij wordt ingegaan op de manier waarop ze kunnen worden beïnvloed en verbeterd om de ruimtelijke gegevensmanipulatie in een animatie te verbeteren. Het hoofdstuk signaleert ook de noodzaak om animaties te voorzien van enige intelligentie ter verbetering van de interactie.

Hoofdstuk 4 introduceert een totale strategie voor animatieontwerp in een exploratieve omgeving waarbij de animatie voor onderzoeksdoeleinden door geowetenschappers wordt gebruikt. De eigenschappen van een exploratieve omgeving worden nader toegelicht, waarbij de nadruk ligt op het feit dat gebruikers in zo'n omgeving omgaan met onbekende gegevenstypes en onbekende uitkomsten zoeken. Om de juiste functionaliteit te kunnen toevoegen aan een dergelijke animatie omgeving moet met de kennis te gebruiken ontleent aan studies in experimentele testen die de specifieke cognitieve structuren en processen beschrijven die leiden tot kennisconstructie, waarbij inzicht in de data wordt gegeven.

Hoofdstuk 5 laat de keuze zien van een functionele evaluatiemethode die wordt gebruikt om het succes van de voorgestelde functionaliteit te evalueren.

Hoofdstuk 6 schetst een prototype omgeving waar de concepten voortkomend uit hoofdstukken 4 en 5 verder worden ontwikkeld. Een testomgeving voor animaties wordt gebaseerd op typisch geowetenschappelijke toepassingsgebieden als stadsgeografie, demografie en epidemiologie. De resultaten worden geanalyseerd en besproken, gebaseerd op eerder genoemde onderzoeksindicatoren van originaliteit, gevoeligheid en bruikbaarheid.

Tenslotte beschrijft *hoofdstuk 7* de belangrijkste bijdragen en conclusies van het onderzoek. Aanbevelingen ter verbetering van de bereikte resultaten en voor het voortzetten van dit en gelijksoortige onderzoeksvelden worden gepresenteerd.

References

ACEVEDO, W. & MASUOKA, P. (1997). Time-Series animation techniques for visualizing urban growth. In Computers & Geoscience 23(4): 423-435.

AHLBERG, C. & SHNEIDERMAN, B. (1994).Visual Information Seeking: Tight coupling of dynamic query filters with starfield displays. Procededings of the ACM CHI '94 Conference, Boston, MA: 313-317.

ALBRECHT, J. (1994). Universal Elementary GIS Tasks - Beyond Low-Level Commands. Proceedings of the 6th Symposium of Spatial Data Handling, Edinburgh: 209-222.

ALLEN, J.F. (1981). An interval-based representation of temporal knowledge. Proceedings of the 7th International Joint Conference on IA : 221-226.

ANDRIENKO, G.L. & ANDRIENKO, N.V. (1998). Visual data exploration by dynamic manipulation of maps. Proceedings of the 8th International symposium on spatial data handling, Vancouver, Canada: 533-542.

ANDRIENKO, G.L. & ANDRIENKO, N.V. (1999). Interactive maps for Visual Data exploration. In the International Journal for Geographical Information Systems, special issue on Visual Exploration of Spatial Data 13(4): 355-74.

BAEK, Y.K. & LAYNE, B.H. (1988). Color, graphics, & animation: Computer-Assisted learning tutorial lesson. Journal of computer-Based Instruction, 15:131-135.

Bederson, B. B. & Boltman, A. (1999). Does Animation Help Users Build Mental Maps of Spatial Information? Proceedings of Information Visualization Symposium (InfoVis 99) New York: IEEE: 28 - 35.

Beier, E. (1994). Tcl meets 3D - Interpretative access to object-oriented graphics. Proceedings: Tcl/Tk workshop '94.

Bertin, J. (1983). Semiology of Graphics, William, J. Berg (trans). Madison, University of Winconsin Press.

Beshers, C. & Feiner, S. (1993). AutoVisual: Rule-based design of interactive multivariate visualizations. IEEE Computer Graphics & Applications, 13(4): 41-49.

Beveridge, M. & Parkins, E. (1987). Visual representation in analogical problem solving. Memory & Cognition, 15(3): 230-237.

Blok, C.A. (1997). Dynamic visualization variables in a developing framework for the representation of geographic data. Paper presented at the seminar of the French Association des Cartographes et Géographes, Paris. In: Bulletin du Comité Français de Cartographie, 156: 89-97.

Blok, C.A. (1999). Monitoring of spatio-temporal changes : characteristics of dynamics for visual exploration. Proceedings of the 19th International Cartographic conference, Ottawa, CDROM.

Blok, C.A., Köbben, B. Cheng, T. & Kuterema A.A. (1999), Visualization of relationships between spatial patterns in time by cartographic animation. Cartography & Geographic Information Science, 26(2):139-151.

Blok, C.A. (2000). Monitoring change: characteristics of dynamic geo-spatial phenomena for visual exploration. In Freksa, C., Brauer, W., Habel, C., and Wender, K.F. (eds), Spatial cognition II, Integrating abstract theories, empirical studies, formal methods, and practical applications. Lecture Notes in Artificial Intelligence 1849. Berlin etc: Springer: 16-30.

Boden, M.A. (1994). Precis of The creative mind: Myths & mechanisms. Behavioral & Brain Sciences 17 (3): 519-570.

Brewer, C.A. (1989). Color chart use in map design. Cartographic perspectives 4:3-10.

Brewer, C. (1999). Hypothesis Generation Using Visualizations of Health Data. Paper presented at the 19th International Cartographic Conference, Ottawa.

Buttenfield, B. (1997). Delivering maps to the information society: A digital library for cartographic data. Proceedings of 18th International Cartographic Association Conference.3: 1409-16.

Buttimer, A. (1983). Creativity in context. Lund Studies in Geography, series B 50, Royal University of Lund, C.W.K. Gleerup.

Buziek, G. (1999). Legend-Designs for non-interactive cartographic animations. Computers and Geosciences, Elsevier, London.

Campbell, C.S. & Egbert, E.L. (1990). Animated Cartography: 30 years of scratching the surface. Cartographica, 27(2): 24-46.

Card, S. K. & Mackinlay, J. (1997). The Structure of the Information Design Space. Proceedings of the IEEE Information Visualization Conference, October 20-21, Phoenix, AZ: 92-99.

Cartwright, W. (1996). New media & its application to the production of map products: In Computers & Geosciences; 23(4): 447-456.

Casner, S.M. (1991). A task-analytic approach to the automated design of graphic presentations. ACM Transactions on Graphics, 10 (2): 111-151.

Christakos, G., Bogaert, P., & Serre, M.L. (2002). Temporal GIS: Advanced functions for field-based applications. Springer Verlag: 250pp.

Claramunt, C. & Theriault, M. (1995). Managing Time in GIS: An event-oriented approach. In Recent Advances in Temporal Databases, (eds)Clifford J. & Tuzhilin A. Springer-Verlog: 23-42

Cole, D.G. (1993). One cartographic view of American Indian l & areas. Cartographica 30(1):47-54.

Conway, E.D. (1997). An Introduction to Satellite image Interpretation. The John Hopkins University Press, London.

Cooper, L.A. (1990). Mental representations of three-dimensional objects in visual problem solving & recognition. Journal of Experimental Psychology: Learning, Memory, & Cognition, 16: 1097-1106.

CORNWELL, B. & ROBINSON, A. (1966). Possibilities for Computer Animated Films in Cartography. Cartographic Journal, 3(2): 79-82.

COTÉ, C.J. (2001). Enhancing Socio-Economic Development with Geospatial Knowledge. Proceedings of AfricaGIS, 5-9th, November, Nairobi, Kenya.

CRAMPTON, J. (1992). A cognitive analysis of wayfinding expertise. Cartographica 29(3/4):46-65.

DENT, B.D. (1999). Cartography Thematic map design., fifth edition, McGraw Hill.:417pp.

DIBIASE, D. (1990). Visualization in the Earth Sciences. Earth and Mineral Sciences Bulletin 59:2: 13-18.

DIBIASE, D., MACEACHREN, A.M., KRYGIER, J., REEVES, C. & BRENNER, A. (1991). Animated Cartographic Visualization in Earth System Science. Proceedings of the 15th Conference of ICA:.1:223-232.

DIBIASE, D., MACEACHREN, A., KYGIER, J. & REEVES, C. (1992). Animation & the Role of Map Design in Scientific Visualization. Cartography & Geographic Information Systems, 19(4): 201-214, 265-266.

DIBIASE, D., REEVES, C., MACEACHREN, A.M., VON WYSS, M., KRYGIER, J.B., SLOAN, J.L., & DETWEILER, M.C. (1994). Multivariate display of geographic data: applications in earth system sciences. MacEachren, A.M., & Taylor, D.R.F. (eds), Visualization in Modern Cartography: Pergamon, Oxford:287-312.

DIX, A. & ELLIS, G. (1998). Starting simple - adding value to static visualisation through simple interaction. Proceedings of Advanced Visual Interfaces -AVI' 98, Castello, Cinquecentesco, L'Aquila, Italy. Catarci, T., Costabile, M.F., Santucci, G., & Tarantino, L. (eds). L'Aquila, Italy, ACM Press: 124-134.

DOMIK, G.O. & GUTKAUF, B. (1994). User Modeling for Adaptive Visualization Systems. Proceedings of the IEEE Visualization 1994 Conference, Washington, DC: 217-223.

EASTMAN, J.R. (1985). Cognitive Models & Cartographic Design Research. In: The Cartographic Journal, 22(2):95-101.

ELZAKKER, C.P.J.M. VAN. (1998). The use of thematic maps in the exploration of geographic data in a GIS-environment (extended abstract)

In: B.M. Gittings & D.A. Lewis (comp.), Proceedings of the GIS Research UK 6th Annual Conference (GISRUK'98), Edinburgh: 4-15 - 4-19.

Finke, R.A. & Shepard, R.N. (1986). Visual functions of mental imagery. In K.R. Boff, L.Kaufman, & J. Thomas (eds), Handbook of perception & human performance, 2, New York, Wiley-Interscience

Finke, R.A. (1989). Principles of mental imagery. Cambridge, MA, MIT Press.

Finke, R.A., Ward, T.B. & Smith, S.M. (1992). Creative Cognition: Theory, Research & Applications. MIT press.

Fishman, B.J. & D'Amico, L.M. (1994). Which way will the wind blow? Networked computer tools for studying the weather. Paper presented at the conference on educational multimedia & telecommunications. Vancouver, B.C.: 209-216.

Flavell, J.H. (1977). Cognitive development, Prentice Hall, Englewood Cliffs.

Foley, J., van Dam, A., Feiner, S. & Hughes, J. (1990). Computer Graphics - Principles & Practice, Addison Wesley.

Freitag, U. (1993). Report om Map functions. In the ICA working group Report to define Main theortical issues on cartography for the 16th ICA conference, Cologne.

Funge, J., Tu, X. & Terzopoulos, D. (1999). Cognitive Modeling: Knowledge, Reasoning & Planning for Intelligent Characters, Proceedings of SIGGRAPH 99, Los Angeles, CA.

Gahegan M. (1998). Visual analysis of complex environmental & mineral exploration datasets: A visual feast of geographic data, Proceeding of Aurisa 1998, Perth Australia.

Gahegan, M. Wachowicz, M., Harrower, M. & Rhyne, T-M. (2001). The Integration of Geographic Visualization with Knowledge Discovery in Databases & Geocomputation . Special Issue of Cartography & Geographical Information Science, 28(1): 9-44.

Gahegan M. (2001). Visual exploration in geography. Miller, H.J. & Jiawei, H. (eds) Geographic Data Mining & Knowledge Discovery. Taylor & Francis: 260-287.

GARTNER, G. (1999). Towards a New Understanding of Maps – concerning the concepts of Quality used in Cartography. Proceedings of the 19th International Cartographic Conference, Ottawa, Canada.

GOLDSTEIN, J., ROTH, S.F., KOLOJEJCHICK, J. & MATTIS, J. (1994). A framework for knowlegde-based interactive data exploration. In Journal of Visual Languages & Computing, 5: 339-363.

GURKA, J.S., & CITRIN, W. (1996). Testing effectiveness of algorithm animation. In proceedings of IEEE symposium on visual language, 182-189. Boulder, CO:IEEE.

HALAS J. & MANWELL, R. (1968). The technique of film animation. Hastings House, New York.

HARROWER, M. & A. M. MACEACHREN (1998). Exploratory Data Analysis & map animation: Using temporal brushing & focusing to facilitate learning about global weather. Paper presented at the International Cartographic Association Commission on Visualization Workshop, Warsaw, Poland.

HAYS, T.A. (1996). Spatial abilities & the effects of computer animation on short-term & long-term comprehension. Journal of Educational Computing Research 14(2): 139-155.

HAYWARD, STAN. (1984). Computers for Animation. London: Focal Press.

HEARNSHAW, H.M., UNWIN, D. (EDS) (1994). Visualization in Geographical Information Systems. Wiley, Chichester : 243.

HIBBARD, W.L., PAUL, B.E., SANTEK, D.A. DYER, C.R. BATTAIOLA, A.L. & VOIDROT-MARTINEZ, M.-F. (1994). Interactive Visuakization of Earth & Space Science Computations. Computer 27(7): 65-72.

HOOTSMANS, R.M., (1996). Fuzzy sets and series analysis for visual decision support in spatial data exploration. Ph.D thesis, Utrecht University, The Netherlands.

HUIZING, C. & BARENBRUG, B. (1997). Interactive animation needs components. Leavens, G.T. & Sitaraman, M. (eds). Proceedings of foundations of component-based system workshop, Zurich, Switzerland.

JIANG B. (1996). Fuzzy Overlay Analysis and Visualisation in Geographic Information Systems, Universiteit Utrecht: 168pp.

Jones, K.S. (1997). Coherent approaches to evaluation. In EAGLES-II Evaluation group workshop report;, http://www.cst.ku.dk/projects/eagles2/workshop/TRECkaren.html. Evaluation in Natural Language Engineering: Standards & Sharing, Brussels.

Jones, S. (1998). Diagram representation : A comparison of animated & static formats. Cognitive science research, Brighton, UK, 493.

Judson, H.F. (1987). The search for solutions. Baltimore. John Hopkins University press.

Indrayan A. & Kumar R. (1996). Statistical choropleth cartography in epidemiology. International Journal of Epidemiology 25, 18 :1 - 189.

Kaiser, M., Proffitt, D., Whelan, S. & Hecht, H. (1992). Influence of animation on dynamical judgements. Journal of Experimental Psychology: Human Perception & Performance. 18: 669-690.

Karl, D. (1992) Cartographic Animation: Potential & Research Issues. Cartographic Perspectives, 13: 3-9.

Kaufman, Y. J., Justice, C. O., Flynn, L. P., Kendall, J. D., Prins, E. M,, Giglio, L., Ward, D. E., Menzel, P., & Setzer, A. W. (1998). Potential global fire monitoring from EOS-MODIS. Journal of Geophysical Research, 103, (31955): 32215-32238.

Keates, J.S. (1996). Understanding maps, second edition. Addison-Wesley-Longman, Harlow, 334pp.

Keim, D.A. (1997). Visual Techniques for Exploring Databases. Invited Tutorial, Int. Conference on Knowledge Discovery in Databases (KDD'97), Newport Beach, CA.

Keller, P. R. & Keller, M.M. (1992). Visual cues, practical data visualization. Piscataway (NJ): IEEE Press.

Keller, P.C. & Wood, C.H. (1996). Advances in cartographic design. In Cartographic design, theory & practical perspectives, ed. Wood, H. & Keller, C.P. John Wiley & Sons: 279-285

Knapp, L. (1995). A task analysis approach of geographic data. In Cognitive aspects of human-computer interaction for Geographic Information

Systems. Nyerges, T.L., Mark, D.M, Laurini, R. & Egenhofer, M.J. (eds). Kluver, Netherlands, Nato ASI 83: 355-371..

Kraak, M.J. & Klomp, A. (1995). A classification of cartographic animations: Towards a tool for the design of dynamic maps in a GIS environment. In Proceedings of the seminar on Teaching animated Cartography, Madrid, Spain.: 29-37.

Kraak, M. J. & Ormeling, F. J. (1996). Cartography, visualization of spatial data: Addison-Wesley-Longman, Harlow: 222pp

Kraak, M.J., Edsall, R. & MacEachren, A.M.(1997). Cartographic animation & Legends for temporal maps: Exploration & or Interaction. Proceedings of the 18th ICA/ACI international conference, Stockholm, Sweden

Kraak, M.J. (1998). Exploratory Cartography : Maps as tools for discovery, ITC Journal 1: 46-54.

Kraak, M.J. & MacEachren, A.M. (1999) Visaulization for exploration of spatial data. International Journal of Geographical Information Sciences 13 (4): 285-287.

Kulhavy, R.W., Pridemore,D.R. & Stock, W.A. (1992). Cartographic experience & thinking aloud about thematic maps. Cartographica 29(1):1-9.

Langley, P. (1998). The Computer-Aided Discovery of Scientific Knowledge. Proceedings of the first International conference on discovery science, Fukuoka, Japan: Springer.

Langley, P., Simon, H., Bradshaw, G. & Zytkow,J. (1987). Scientific Discovery: Computational Explorations of the Creative Processes. Cambridge, MA:MIT press.

Langran, G. (1992). Time in Geographic Information Systems. Philadelphia, Pennsylvania: Taylor & Francis.

Larkin, J.H. & Simon, H.A. (1987). Why a diagram is (sometimes) worth ten thousand words. Cognitive Science, 11: 65-99.

Lowe, R.K. (1996). Interactive animated diagrams: what information is extracted? Proceedings of the Using Complex Information Systems Seminar, Poitiers, France.

MacEachren, A. M. & Taylor, D.R. F. (eds). (1994). Visualization in Modern Cartography. Pergamon, Oxford: 345pp.

MacEachren, A.M. & Ganter, J.H. (1990). A pattern Identification approach to cartographic visualization. In Cartographica, 27(2): 64-81.

MacEachren, A.M. & Monmonier, M.S. (1992). Introduction . Cartography & Geographic Information Systems, 19(4): 197-200.

MacEachren, A.M. (1992). Application of environmental learning theory to spatial knowledge acquisition from maps. Annals of the Association of American Geographers, 82(2): 245-274.

MacEachren, A. M. (1994), Visualization in modern cartography: setting the agenda. In, MacEachren, A. M., & Taylor, D. R. F., Visualization in Modern Cartography: Pergamon, Oxford:1-12.

MacEachren, A.M. (1995). How maps work. New York, Guildford.

MacEachren A.M. & Kraak M.J. (1997). Exploratory cartographic visualization: advancing the agenda. In Computers & Geosciences, 23(4): 335-344.

MacEachren, A.M., Wachowicz, M., Edsall, R. & Haug, D. (1999). Constructing knowledge from multivariate spatiotemporal data : intergrating geographical visualization with knowledge discovery in database methods. In International Journal for Geographical Information Science, 13(4): 311-334.

MacEachren, A.M. (2000). An evolving cognitive-semiotic approach to geographic visualization & knowledge construction . To appear in a special issue of the Information Design Journal. http://www.geovista.psu.edu/storage/alan/amm_InfoDesign.pdf.

MacEachren A.M. & Kraak M.J. (2001) Research challenges in geovisualization. Cartography & Geographic Information Science, 28, (1): 3-12.

Malczewski, J. (1999). GIS and multicriteria decision analysis. J. Wiley & Sons, New York.

Marshall, R., Kempf, J., Dyer, S. & Yen, C-C., (1990). Visualization methods and simulation steering for 3-D turbulence model of Lake Erie. Computer Graphics, 24(2): 89-97.

McCaslin, P. T. & McDonald, P. A. (1996). A promising forecast: Colorado Researchers add dimension to weather. Geo info systems, October .

McCormick, B. H., DeFanti, T. A. & Brown, M. D. (1987). Visualization in scientific computing. Computer Graphics, 21(6):1--14.

Medyckyj-Scott, D. & Board, C. (1991). Cognitive cartography : A new heart for a lost soul. In Advances in cartography, ICA publication, ed. Muller, J.C. Elsevier Applied science: 201-230.

Mitas, L., Brown, W.M. & Mitasova, H. (1997). Role of dynamic cartography in simulations of landscape processes based on multivariate fields. In Computers & Geoscience, .23(4):437-446.

Moellering, H. (1972). Traffic Crashes in Washtenaw County Michigan, 1968-70. Highway Safety Research Institute, University of Michigan.

Moellering, H. (1973a). The Computer Animated Film: A Dynamic Cartography. Proceedings, Association for Computing Machinery: 64-69.

Moellering, H. (1973b). The Potential Uses of Computer Animated Film in the Analysis of Geographical Patterns of Traffic Crashes. Accident Analysis & Prevention, 8: 215-227.

Moellering, H. (1980). Strategies for real time cartography, Cartographic Journal, 17: 12-15.

Moellering, H. (1990). The real-time animation of three-dimensional maps. The American Cartographer, 7(1):67-75.

Monmonier, M. S. (1989). Geographic Brushing: Enhancing Exploratory Analysis of the Scatterplot Matrix. Geographical Analysis, 21(1): 81-84.

Monmonier, M. S. (1990). Strategies for the Visualization of Geographic Time-Series Data. Cartographica, 27(1): 30-45.

Monmonier, M. (1992). A Summary graphics for integrated visualization in dynamic cartography. Cartography & Geographic Information Systems, 19(1): 23-36.

Monmonier, M. & Gluck, M. (1994). Focus groups for design improvement in dynamic cartography. In Cartography & Geographic Information Systems, .21(1):37-47.

MONMONIER, M. & JOHNSON, B.B. (1991). Using qualitative data gathering techniques to improve the design of environmental maps. Proceedings of 15th International Cartographic Association Conference, Bournemouth, 1:364-373.

MORRISON, J.B., BETRANCOURT, M. & TVERKSY, B.(2000). Animation: Does it facilitate learning? Papers from the 2000 AAAI Spring Symposium Smart Graphics . AAAI Press, Stanford, CA: 53-60.

MORRISON, J.L. (1997). Topographic mapping for the twenty first century. In: Rhind, D. (Ed) Framework of the world. Cambridge: Geoinformation International.

NEISSER, U. (1967). Cognitive psychology. New York, Appleton-Century-Crofts.

NELSON, E.S. (1996). A Cognitive map experiment : Mental representations & the encoding process. In Cartography & Geographical Information Systems, 23(4): 229-248.

NIELSEN, J. (1993). Usability engineering. Academic Press. London. 358pp.

OGAO, P.J. (1999). Visualization of Urban Growth Using Temporal Cartographic Animation: A proposed case study of Nairobi, Kenya. Proceedings of the 19th International Cartographic Conference, CDROM, August 14-21, Ottawa, Canada.

OGAO, P.J. & KRAAK, M-J. (2000). Dynamic data presentation & the WWW. Proceedings of the ISPRS congress, July 16-23, Amsterdam, The Netherlands, 33, B4/2:755-761.

OGAO, P.J. & BLOK, C.A. (2001). Cognitive aspects on the representation of dynamic environmental phenomena using animations. Rautenstrauch, C. & Patig, S. (eds). Environmental Information Systems in Industry & Public Administration, Idea Group Publishers, USA:.13-24.

OGAO, P.J. (2001a). Collaborative geospatial data exploration & the WWW. Proceedings of AfricaGIS, 5-9th, November, Nairobi, Kenya.

OGAO, P.J. (2001b). Applying a creative cognition approach in exploratory cartography tool development. Proceedings of the International cartographic conference, August 6–10, Beijing, China: 2649 - 2657.

OGAO, P.J. & KRAAK, M-J. (2001a). Geospatial data exploration using interactive & intelligent cartographic animations. Proceedings of the International cartographic conference, August 6-10, Beijing, China: 965 - 973.

OGAO, P.J. & KRAAK, M-J. (2001b). Interactive & dynamic visual exploitation of raw geospatial data sets using exploratory cartographic tools. Proceedings of AfricaGIS, 5-9th, November, Nairobi, Kenya.

OGAO, P.J. & KRAAK, M-J. (2002). *(In press)*. Defining visualization operations for temporal cartographic animation design. International Journal of Applied Earth Observations & Geoinformation, Elsevier.

OKAZAKI D. (1993). Visualizing Geographic Data Through Animation, Proceedings of AutoCarto 11.

OLSON, J.M. (1979). Cognitive cartographic experimentation. The Canadian Cartographer 16(1):34-44.

ORMELING, F.J. (1989). Environmental mapping in transition. Proceedings in ICA seminar on teaching cartography for environmental information management, Enschede, The Netherlands: 11-25.

ORMELING, F.J. (1995). Teaching animation cartography. Proceedings of the seminar on Teaching animated cartography, Madrid, Spain.

ORMELING, F.J., KOBBEN, B., GOMEZ, R.P. (EDS.). (1995). Proceedings of the seminar on Teaching animated cartography held in Madrid, Spain.118pp.

PAPATHOMAS, T.V., SCHIAVONE, J.A. & JULESZ, B. (1988). Applications of computer graphics to the visualization of meteorological data. Computer Graphics, 22(4): 327-34.

PAPATHOMAS, T.V., SCHIAVONE, J.A. & JULESZ, B. (1990). Stereo animation for very large data bases: Case study - Meteorology. In IEEE Computer Graphics and animation, 7, (9): 18-27.

PARENT R. & PARENT R. (2001). Computer Animation: Algorithms & Techniques. Morgan Kaufmann Publishers.560pp.

PERKINS, D.N. (1988). Creativity & the quest for mechanism. In R.J. Sternberg & E.E. Smith (eds), The Psychology of Human Thought, Cambridge, Cambridge University Press.

PETERSON, M.A. (1987). The mental image in cartographic communication. Cartographic Journal, 24(1): 35-41.

PETERSON, M.P. (1993). Interactive Cartographic Animation. Cartography & Geographic Information Systems, 20(1): 40-44.

PETERSON, M. P. (1995). Interactive & animated cartography: Prentice Hall, Englewood Cliffs, New Jersey: 257pp.

PETERSON, M.P. (1999). Active legends for interactive cartographic animation. International Journal for Geographical Information Science, special issue on Visual Exploration of Spatial Data. 13(4).

PEUQUET, D.J. (1994). It's about time: A conceptual framework for the representation of temporal dynamics in Geographical Information Systems. In Annals of the Association of American Geographers 84(3):441-61.

PEUQUET, D. (1999). Making Space for Time: Issues in Space-Time Data Representation. DEXA Workshop: 404-408.

PINKER, S. (1984). Visual cogntion: An introduction. Cognition, 18: 1-63.

RAM, A. & LEAKE, D. (1991). Evaluation of explanatory hypothesis. Proceedings of the Thirteenth Annual Conference of the Cognitive Science Society, August 1991, Chicago, IL:867-871.

RANSDELL, S. E. (1993). Educational software evaluation research: Balancing internal, external & ecological validity. Behavior Research Methods. Instruments. & Computers, 25: 228-232.

REX, B. & RISCH, J. (1996). Animation Query Language for the Visualization of Temporal Data. In Third International Conference/Workshop on Integrating GIS & Environmental Modeling CD-ROM.

RIEBER, L.P., BOYCE, M.J. & ASSAD, C. (1990). The effects of computer animation on adult learning & retrieval tasks. Journal of Computer-Based Instruction, 17: 46-52.

ROBINSON, A.H., MORRISON, J.L., MUEHRCKE, P.C. & GUPTILL, S.C. (1995). Elements of Cartography, 6th edition. John Wiley & Sons: 674pp.

Robbins K. A. & Robbins, S. (1998). Web-based dynamic information visualization using exact-time animation. In Proceedings of the 13th Annual ACM Symposium on Applied Computing: 744-751.

Rogowitz, B. & Treinish, L. (1996). How Not to Lie with Visualization. Computers in Physics, 10(3): 268-274.

Roncarelli, R. (1988). A Computer Animation Dictionary, New York; Berlin: Springer Verlag, 124 pp.

Rundstrom, R.A. (1993). The role of ethics, mapping, & the meaning of place in relations between Indians & Whites in the United States. Cartographica 30(1):21-28.

Scaife, M., & Rogers, Y. (1996). External Cognition : How do graphical representations work? Journal of Human-Computer Studies, 45: 185-213.

Shepard, R.N. (1978). The mental image. American Psychologist, 33: 125-137.

Shepherd, I.D.H. (1995), Putting time on the map: Dynamic displays in data visualization & GIS: Fisher, P.F., ed., In Innovations in GIS 2: Taylor & Francis, London:169-187.

Shneiderman, B. (1983). Direct Manipulation : A step beyond programming languages. IEEE computer:57-69.

Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualization. Technical report, Institute for systems research, University of Maryland, USA.

Shneiderman, B. (1999). Creating creativity : User Interfaces for Supporting innovation. ftp://ftp.cs.umd.edu/pub/hcil/Reports-Abstracts-Bibliography/99-01html/99-01.html

Slocum, T.A. (1995). Introduction to the special content issue, 1995 U.S. National Report to the International Cartographic Assciation. Cartography & Geographic Information systems, 22(2):109-14.

Slocum, T.A., Armstrong, M.P., Bishop, I, Carron, J. Dungan, J., Egbert, S.L. Knapp, L., Okazaki, D., Rhyne, T.M. Rokos, D-K. D., Ruggles, A.J. & Weber, C.R. (1994). Visualization software tools. In Visualization in modern cartography, MacEachren, A.M. & Taylor, D.R.F. (eds), Pergamon: 91-122.

SLOCUM, T.A., YODER, S.C., KESSLER, F.C. & SLUTER, R.S. (2001). MapTime : Software for Exploring Spatiotemporal Data Associated with Point Locations. In Cartographica, 37(1):15-31.

STORA, D., AGLIATI, P., CANI, M., NEYRET, F., & GASCUEL, J. (1999). Animating Lava Flows. Proceedings of Graphics Interface'99, Ontario, Canada.

SUCHAN, T.A. & BREWER, C.A. (2000). Qualitative Methods for Research on Mapmaking & Map Use. In the Professional Geographer, 52(1): 145-154.

TALASLI, U. (1990). Simultaneous manipulation of propositional & analog codes in picture memory. Perceptual & Motor Skills, 70:403-414.

THAGARD, P. & C.P. SHELLEY. (1997). Abductive reasoning: Logic, visual thinking, & coherence. In M.-L. Dalla Chiara et al. (eds), Logic & scientific methods. Dordrecht: Kluwer:413-427.

THALMANN, N. M. & THALMANN, D. (1996). ComputerAnimation. In Handbook of Computer Science, CRC Press: 1300-1318

THOMAS, B. H. & DEMCZUK, V. (1999). Evaluation of Animation Effects to Improve Indirect Manipulation. In Technical Report ACRC-99-005. Advanced Computing Research Centre School of Computer & Information Science, University of South Australia.

THROWER, N. (1961). Animated Cartography in the United States. International Yearbook of Cartography, 1: 20-29.

TOBLER, W. (1970). A Computer Movie Simulating Urban Growth in the Detroit Region. Economic Geography, 46:234-240. Treinish, L.A., (1999). Task-Specific Visualization Design, In IEEE Computer Graphics & Applications, 19(5).

TRYFONA, N. (1998). Modeling Phenomena in Spatiotemporal Applications: Desiderata & Solutions. Proceedings of the 9th International Conference on Database & Expert Systems Applications, (DEXA). Lecture Notes in Computer Science.

TURRISI, P. (1990). Peirce's Logic of Discovery: Abduction and Universal Categories. Transactions of the Charles Sanders Peirce Society, 26: 465-497.

TWEEDIE, L. (1995). Interactive visualization artifacts : how can abstractions inform design? In people & computers x, Proceedings of the HCI'95 conference, Huddersfield. M.A.R., Kirby, A.J. Dix, & J.E. Finlay, (eds): 247-265.

van der Wel, F. J. M., Hootsman, R. M., and Ormeling, F. J. (1994). Visualization of data quality, in MacEachren, A. M., and Taylor, D. F., (eds), Visualization in Modern Cartography: Elsevier, Amsterdam: 67-92.

Wachowicz, M. (1999). Object-Oriented Design for Temporal GIS, London: Taylor and Francis.

elzakker, C.P.j.m. (1999). Thinking aloud about exploratory cartography. In the CDROM proceedings of the 19th ICA Conference, Ottawa, August 14-21.

Wachowicz, M. (2001). An approach for developing a knowledge construction process based on the integration of Gvis & KDD methods. Miller, H.J. & Jiawei, H. (eds) Geographic Data Mining & Knowledge Discovery. Taylor & Francis: 239-259.

Weber C.R. & Buttefield, B.P. (1993). A cartographic animation of average yearly surface temperatures for the contiguous united states : 1897-1986. . In Cartography & Geographic Information Systems, .20(3):141-150.

Wehrend, S. & Lewis, C. (1990). A problem oriented classification of Visualization Techniques, First IEEE Conference on Visualization: 139-143.

Yattaw, N.J. (1999). Conceptualizing space & time : A classification of geographic movement. In Cartography & Geographic Information Science, 26(2): 85-98.

Zhang, J. & Norman, D. (1994). Representations in distributed cognitive tasks. Cognitive Science 18: 87-122

Zhou, M.X. & Feiner, S.K. (1998). Visual task characterization for automated visual discourse synthesis. Proceedings of CHI'98, Los Angeles, CA.

URLS

URL 2.1: http://www.macromedia.com/software/
URL 2.3: http://www.3dnature.com/
URL 2.3: http://www.curious-software.com/products/animate.htm
URL 6.1: http://www.itc.nl/personal/kraak/overijssel/
URL 6.2: http://www.ciesin.org/datasets/cdc-nci/cdc-nci.html

Abbreviations

AV	Advanced Visualizer
AVI	Audio Video Interleave
AIDS	Acquired Immune Deficiency Syndrome
ACM SIGGRAPH	Association for Computing Machinery in Special Interest Groups in Graphics
DX	Data Explorer
GIS	Geographical Information System
HCI	Human-Computer Interface
ICA	International Cartographic Association
IDL	Interactive Data Language
IRIS	An Intelligent Tool Supporting Visual Exploration of Spatially Referenced Data
ITC	International Institute for Geo-Information Science & Earth Observations
KDD	Knowledge Discovery in Databases
Khoros	A Software integration and development environment that emphasizes information processing and data exploration
MODIS	Moderate Resolution Imaging Spectroradiometer
MPEG	Moving Pictures Expert Groups
S	SpyGlass
SWF	Shockwave file
TGIS	Temporal Geographical Information System
VRML	Virtual Reality Modeling Language
WCS	World Construction Set
WWW	World Wide Web

Curriculum vitae

Patrick Job Ogao was born on the 27th October, 1967 in Tabora, Tanzania. He had his early education in Nairobi and the coastal city of Mombasa in Kenya. Thereafter he proceeded to the University of Nairobi where obtained a degree in Surveying and Photogrammetry in 1990. In 1996 he joined the International Institute for Geo-information Science and Earth Observations in Enschede to pursue a course in Geoinformatics, where upon completion he was awarded a Masters of Science degree in Integrated Map and Geo-information Production. He has previously worked both with licensed survey consortiums, the national mapping organization of Kenya and the Kenya Institute of Surveying and Mapping. He was a team member of the Kenyan computer assisted mapping project and the Kenya Rift Deformation Monitoring project. His present research interests are in application themes in visualization & virtual environments.

Appendix A

Questionnaire

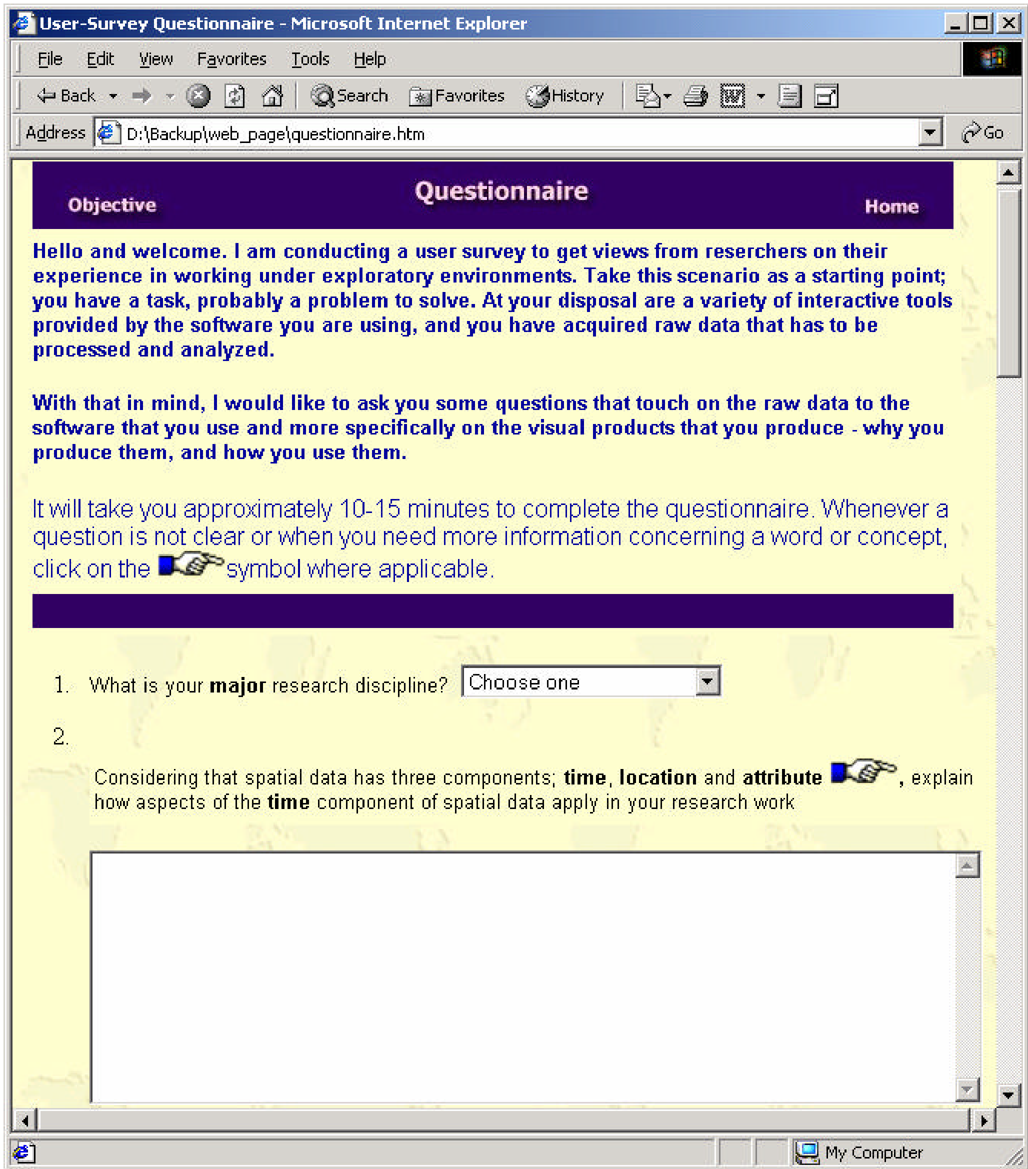
ITC's aims at providing international education through knowledge exchange directed primarily at capacity building and institutional development in the knowledge fields of geo-information science and earth observation. Respondents to a questionnaire sent out to PhD researchers in the institute sort to understand the typical working environments that geo-scientists are exposed to – the tasks, use of map based application software and the uses that the final visual products are subjected to. The respondents are representative of geo-scientists, having a specialized geo-domain background knowledge and average minimum of 5 years professional experience.

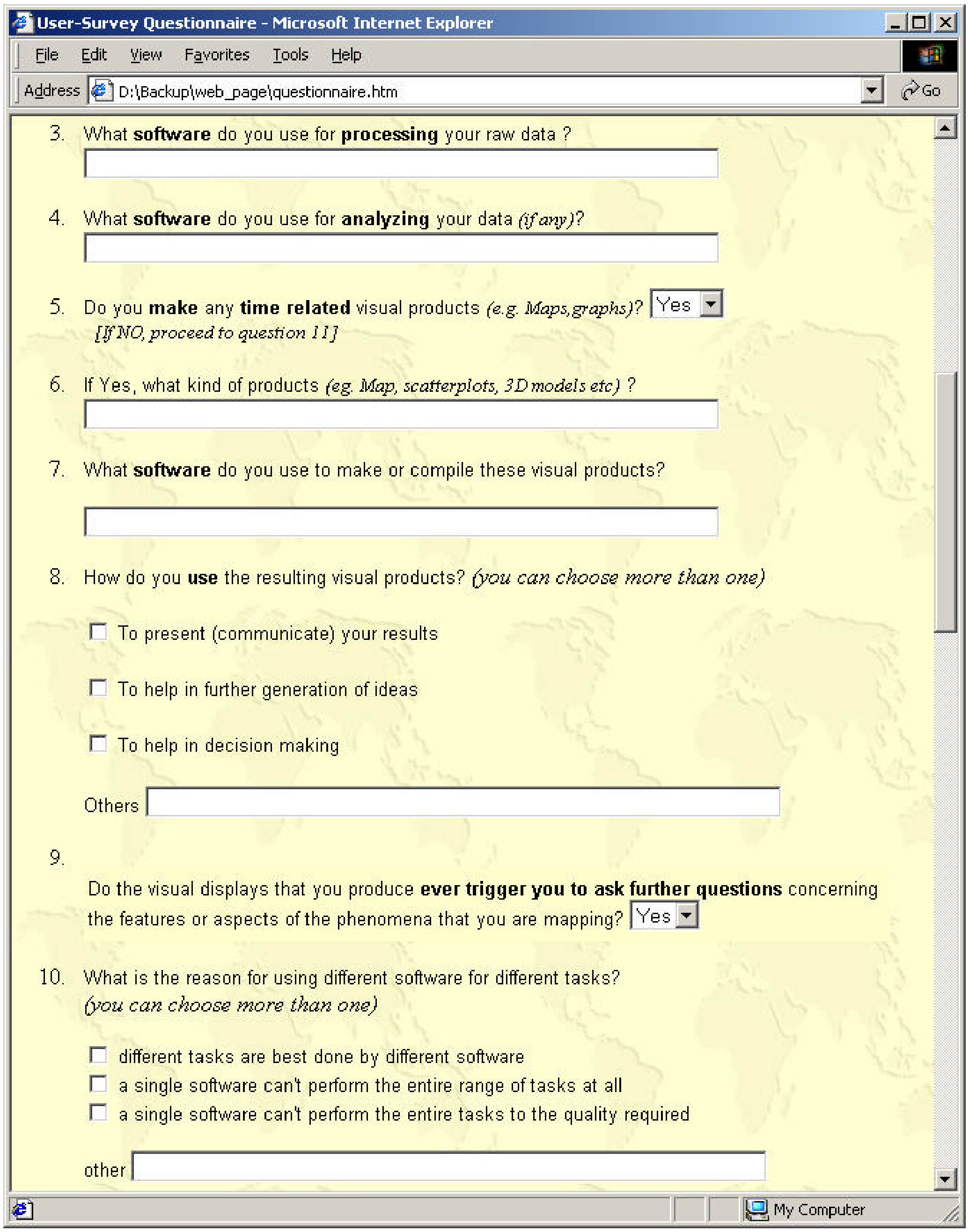
There were 16 respondents to the questionnaire. They were all involved in active researches in the period 1999-2000. They are representatives of ITC's researchers carrying out problem-oriented multidisciplinary research programmes that are focused on strengthening organizations involved in survey, management and planning for sustainable development of natural resources.

First, we present a questionnaire form that was available online and then we present a summary of the findings. They are highlighted under three categories

i. Data
ii. Visualization goals
iii. Dynamic and Interactive aspects of the display.

Figure A-1. Questionnaire





User-Survey Questionnaire - Microsoft Internet Explorer

File Edit View Favorites Tools Help

Address D:\Backup\web_page\questionnaire.htm Go

3. What **software** do you use for **processing** your raw data ?

4. What **software** do you use for **analyzing** your data *(if any)*?

5. Do you **make** any **time related** visual products *(e.g. Maps,graphs)?* Yes
   [If NO, proceed to question 11]

6. If Yes, what kind of products *(eg. Map, scatterplots, 3D models etc)* ?

7. What **software** do you use to make or compile these visual products?

8. How do you **use** the resulting visual products? *(you can choose more than one)*

   - ☐ To present (communicate) your results
   - ☐ To help in further generation of ideas
   - ☐ To help in decision making

   Others

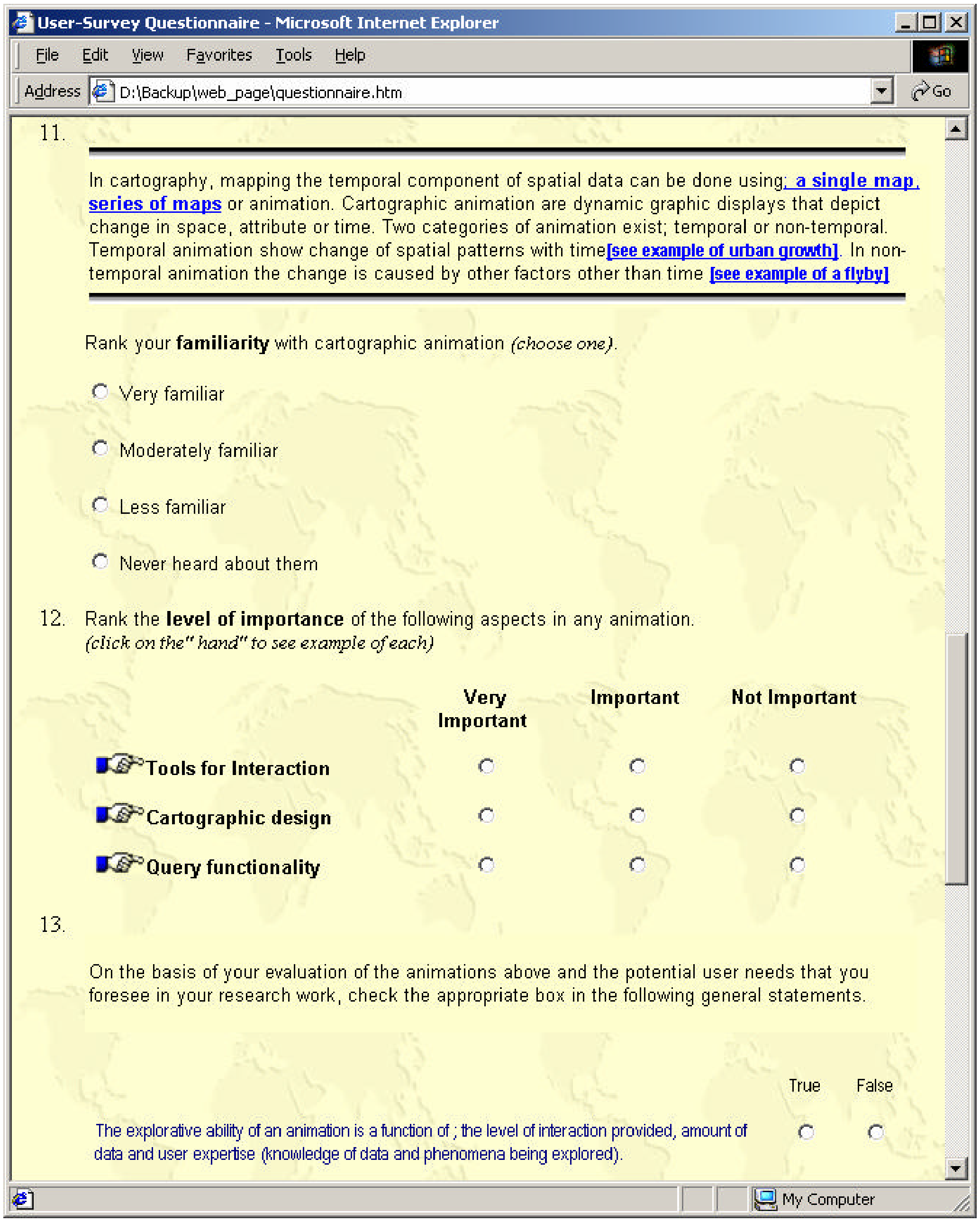
9. Do the visual displays that you produce **ever trigger you to ask further questions** concerning the features or aspects of the phenomena that you are mapping? Yes

10. What is the reason for using different software for different tasks?
    (you can choose more than one)

    - ☐ different tasks are best done by different software
    - ☐ a single software can't perform the entire range of tasks at all
    - ☐ a single software can't perform the entire tasks to the quality required

    other

My Computer



User-Survey Questionnaire - Microsoft Internet Explorer

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11.

In cartography, mapping the temporal component of spatial data can be done using; **a single map**, **series of maps** or animation. Cartographic animation are dynamic graphic displays that depict change in space, attribute or time. Two categories of animation exist; temporal or non-temporal. Temporal animation show change of spatial patterns with time**[see example of urban growth]**. In non-temporal animation the change is caused by other factors other than time **[see example of a flyby]**

Rank your **familiarity** with cartographic animation *(choose one)*.

- Very familiar
- Moderately familiar
- Less familiar
- Never heard about them

12. Rank the **level of importance** of the following aspects in any animation.
(click on the" hand" to see example of each)

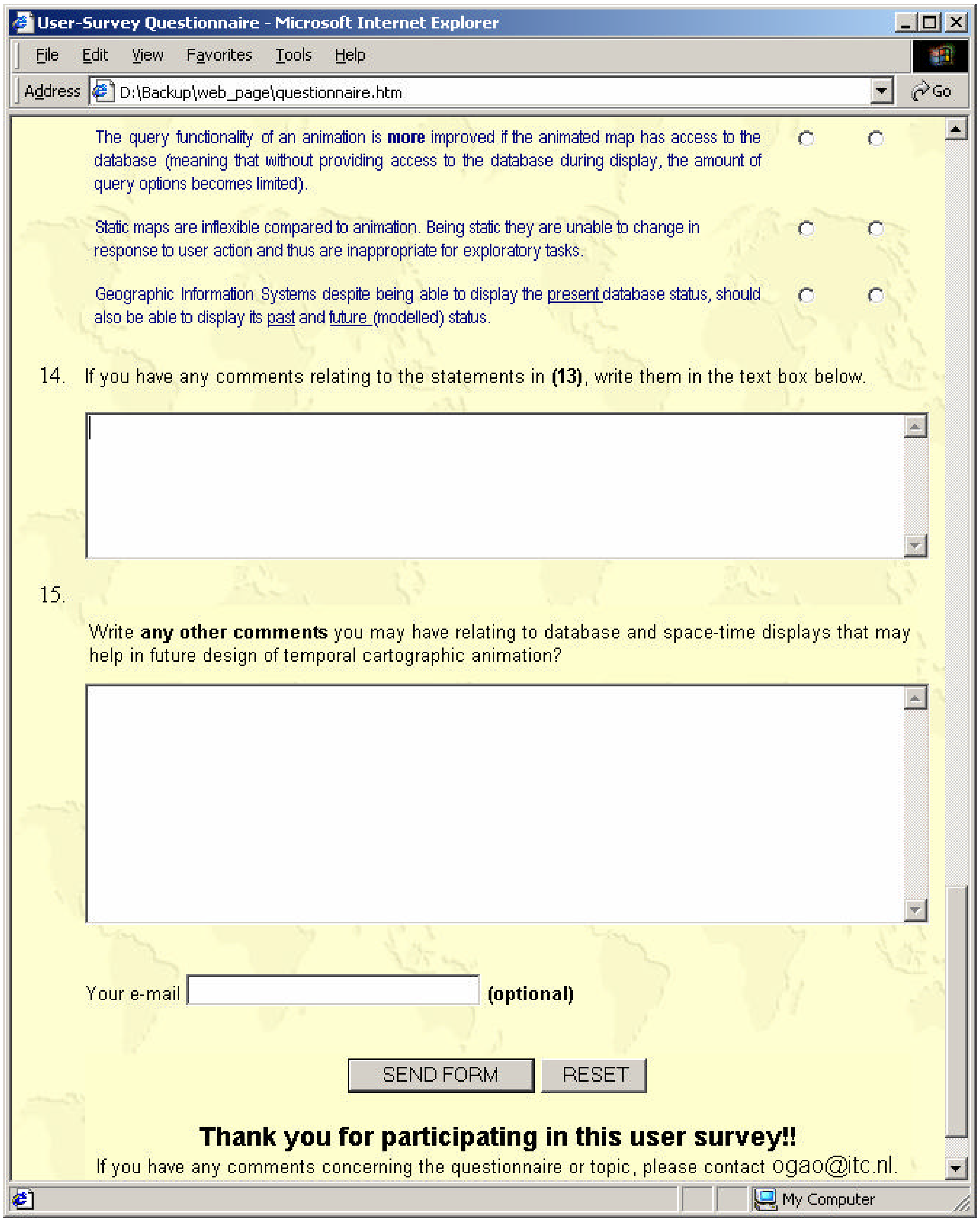
	Very Important	Important	Not Important
Tools for Interaction	○	○	○
Cartographic design	○	○	○
Query functionality	○	○	○

13.

On the basis of your evaluation of the animations above and the potential user needs that you foresee in your research work, check the appropriate box in the following general statements.

	True	False
The explorative ability of an animation is a function of ; the level of interaction provided, amount of data and user expertise (knowledge of data and phenomena being explored).	○	○

My Computer



User-Survey Questionnaire - Microsoft Internet Explorer

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The query functionality of an animation is **more** improved if the animated map has access to the database (meaning that without providing access to the database during display, the amount of query options becomes limited).

Static maps are inflexible compared to animation. Being static they are unable to change in response to user action and thus are inappropriate for exploratory tasks.

Geographic Information Systems despite being able to display the present database status, should also be able to display its past and future (modelled) status.

14. If you have any comments relating to the statements in **(13)**, write them in the text box below.

15.

Write **any other comments** you may have relating to database and space-time displays that may help in future design of temporal cartographic animation?

Your e-mail **(optional)**

SEND FORM RESET

Thank you for participating in this user survey!!

If you have any comments concerning the questionnaire or topic, please contact ogao@itc.nl.

My Computer

Data

The researches are characterized by data that come in a variety of formats; raster, vector and alphanumeric. They exist in different scales/resolutions, but are then integrated in pursuing answers to the research questions. In general, research questions do address issues occurring in a range of disciplines.

The use of particular software to accomplish certain tasks is attributed to their abilities to perform within the required or expected results and cost. Most respondents were quite happy with the traditional forms of processing and presenting their results.

Visualization goals

They accomplish this through the use of a range of visual products together with analytical techniques and methods in pattern analysis. Presentations are mostly in form of maps, charts and numerical statistical descriptors.

For exploratory purposes, the need is for the visual products to invoke thought processes as one looks at the patterns and their relationships. This is accomplished by use of charts and rarely do they involve maps at this stage.

Dynamic & Interactive aspects of the display

The provision of interactive tools and dynamic data displays in real-time is a vital need when working in exploratory environments. As much as users may want to interact with the displayed images and objects, it is crucial to address issues relating to developing graphical user interfaces and specifically dynamic interfaces as this might obscure the revelation of patterns and their relationships.

New dynamic visualization techniques have not been fully tested or introduced into most geo-science disciplines. People don't know the capability of these techniques (as with animations) and thus are not sure about their use and effectiveness. On user expectations to the design of animations, a high level of interactivity and the ability of the display to give answers to user queries are preferred.

Appendix B

Study area

Figure B-1 Map of the Netherlands showing Overijssel province and the town of Enschede

Figure B-2. Overijssel province 2000 (Source : http://www.prv-overijssel.nl/)

Other links to Overijssel case study

Andrienko, G. L. & Andrienko, N. V. (1999). Interactive maps for visual data exploration. International Journal for Geographic Information Sciences, 13, (4): 355-374

Beekink, E. & P. Ekamper. (1999). De grenzen verlegd, twee eeuwen herindeling nederlandse gemeenten. Demos, Vol. 15,Nr. 6 (in dutch)

Beekink, E. & P. v. Cruyningen (1995). Demografische databank nederlandse gemeenten. NiDi, Den Haag 40 (in dutch)

Blok, P. J. (1924). Geschiedkundige atlas van Nederland

Boonstra, O. (1990). Nlkaart, a dynamic map of the netherlands, 1830-1990, in Montpellier Computer Conference 1990 - Cartographie. Montpellier.

Engelen van der Veen, G. A. J., G. J. ter Kuile, & R. Schuiling. (1931). Overijssel (in dutch)

Hendriks, F. M. (1960). De grenzen van Overijssel en van de Overijsselse gemeenten van 1807 (1811) - 1842. Zwolle: Stichting Edwina van Heek / Provincie Overijssel

Jansma, K., L. Jansma, & M. Schroor. (1990). Tweeduizend jaar geschiedenis van overijssel. Inter-Combi van Seijen, Leeuwarden. (in dutch)

Knippenberg, H. & J. Mathijse. (1990) An historical-ecological database, in Computer science and the historical discipline / Proceedings of the Tinbergen Conference on History and Computing. Leuven

Slicher van Bath, B. H., G. D. v. d. Heide, & C. C. W. J. Hijszeler. (1970) Geschiedenis van Overijssel. Kluwer, Deventer (in dutch)

URLS

History of Overijssel: http://www.geschiedenisoverijssel.nl/

Province of Overijssel: http://www.prv-overijssel.nl/

ITC Overijssel project: http://www.itc.nl/personal/kraak/overijssel/

APPENDIX C

ITC'S DISSERTATIONS LIST

1. **Akinyede**, 1990, Highway cost modelling and route selection using a geotechnical information system
2. **Pan He Ping**, 1990, 90-9003757-8, Spatial structure theory in machine vision and applications to structural and textural analysis of remotely sensed images
3. **Bocco Verdinelli, G.**, 1990, Gully erosion analysis using remote sensing and geographic information systems: a case study in Central Mexico
4. **Sharif, M**, 1991, Composite sampling optimization for DTM in the context of GIS
5. **Drummond, J.**, 1991, Determining and processing quality parameters in geographic information systems
6. **Groten, S.**, 1991, Satellite monitoring of agro-ecosystems in the Sahel
7. **Sharifi, A.**, 1991, 90-6164-074-1, Development of an appropriate resource information system to support agricultural management at farm enterprise level
8. **Zee, D. van der**, 1991, 90-6164-075-X, Recreation studied from above: Air photo interpretation as input into land evaluation for recreation
9. **Mannaerts, C.**, 1991, 90-6164-085-7, Assessment of the transferability of laboratory rainfall-runoff and rainfall - soil loss relationships to field and catchment scales: a study in the Cape Verde Islands
10. **Ze Shen Wang**, 1991: 90-393-0333-9, An expert system for cartographic symbol design

11. **Zhou Yunxian**, 1991, 90-6164-081-4, Application of Radon transforms to the processing of airborne geophysical data
12. **Zuviria, M. de**, 1992, 90-6164-077-6, Mapping agro-topoclimates by integrating topographic, meteorological and land ecological data in a geographic information system: a case study of the Lom Sak area, North Central Thailand
13. **Westen, C. van**, 1993, 90-6164-078-4, Application of Geographic Information Systems to landslide hazard zonation
14. **Shi Wenzhong**, 1994, 90-6164-099-7, Modelling positional and thematic uncertainties in integration of remote sensing and geographic information systems
15. **Javelosa, R.**, 1994, 90-6164-086-5, Active Quaternary environments in the Philippine mobile belt
16. **Lo King-Chang**, 1994, 90-9006526-1, High Quality Automatic DEM, Digital Elevation Model Generation from Multiple Imagery
17. **Wokabi, S.**, 1994, 90-6164-102-0, Quantified land evaluation for maize yield gap analysis at three sites on the eastern slope of Mt. Kenya
18. **Rodriguez, O.**, 1995, Land Use conflicts and planning strategies in urban fringes: a case study of Western Caracas, Venezuela
19. **Meer, F. van der**, 1995, 90-5485-385-9, Imaging spectrometry & the Ronda peridotites
20. **Kufoniyi, O.**, 1995, 90-6164-105-5, Spatial coincidence: automated database updating and data consistency in vector GIS
21. **Zambezi, P.**, 1995, Geochemistry of the Nkombwa Hill carbonatite complex of Isoka District, north-east Zambia, with special emphasis on economic minerals
22. **Woldai, T.**, 1995, The application of remote sensing to the study of the geology and structure of the Carboniferous in the Calañas area, pyrite belt, SW Spain
23. **Verweij, P.**, 1995, 90-6164-109-8, Spatial and temporal modelling of vegetation patterns: burning and grazing in the Paramo of Los Nevados National Park, Colombia
24. **Pohl, C.**, 1996, 90-6164-121-7, Geometric Aspects of Multisensor Image Fusion for Topographic Map Updating in the Humid Tropics
25. **Jiang Bin**, 1996, 90-6266-128-9, Fuzzy overlay analysis and visualization in GIS

26. **Metternicht, G.**, 1996, 90-6164-118-7, Detecting and monitoring land degradation features and processes in the Cochabamba Valleys, Bolivia. A synergistic approach
27. **Hoanh Chu Thai**, 1996, 90-6164-120-9, Development of a Computerized Aid to Integrated Land Use Planning (CAILUP) at regional level in irrigated areas: a case study for the Quan Lo Phung Hiep region in the Mekong Delta, Vietnam
28. **Roshannejad, A.**, 1996, 90-9009284-6, The management of spatio-temporal data in a national geographic information system
29. **Terlien, M.**, 1996, 90-6164-115-2, Modelling Spatial and Temporal Variations in Rainfall-Triggered Landslides: the integration of hydrologic models, slope stability models and GIS for the hazard zonation of rainfall-triggered landslides with examples from Manizales, Colombia
30. **Mahavir, J.**, 1996, 90-6164-117-9, Modelling settlement patterns for metropolitan regions: inputs from remote sensing
31. **Al-Amir, S.**, 1996, 90-6164-116-0, Modern spatial planning practice as supported by the multi-applicable tools of remote sensing and GIS: the Syrian case
32. **Pilouk, M.**, 1996, 90-6164-122-5, Integrated modelling for 3D GIS
33. **Duan Zengshan**, 1996, 90-6164-123-3, Optimization modelling of a river-aquifer system with technical interventions: a case study for the Huangshui river and the coastal aquifer, Shandong, China
34. **Man, W.H. de**, 1996, 90-9009-775-9, Surveys: informatie als norm: een verkenning van de institutionalisering van dorp - surveys in Thailand en op de Filippijnen
35. **Vekerdy, Z.**, 1996, 90-6164-119-5, GIS-based hydrological modelling of alluvial regions: using the example of the Kisaföld, Hungary
36. **Pereira, Luisa**, 1996, 90-407-1385-5, A Robust and Adaptive Matching Procedure for Automatic Modelling of Terrain Relief
37. **Fandino Lozano, M.**, 1996, 90-6164-129-2, A Framework of Ecological Evaluation oriented at the Establishment and Management of Protected Areas: a case study of the Santuario de Iguaque, Colombia
38. **Toxopeus, B.**, 1996, 90-6164-126-8, ISM: an Interactive Spatial and temporal Modelling system as a tool in ecosystem management: with two case studies: Cibodas biosphere reserve, West Java Indonesia: Amboseli biosphere reserve, Kajiado district, Central Southern Kenya
39. **Wang Yiman**, 1997, 90-6164-131-4, Satellite SAR imagery for topographic mapping of tidal flat areas in the Dutch Wadden Sea

40. **Asun Saldana-Lopez**, 1997, 90-6164-133-0, Complexity of soils and Soilscape patterns on the southern slopes of the Ayllon Range, central Spain: a GIS assisted modelling approach
41. **Ceccarelli, T.**, 1997, 90-6164-135-7, Towards a planning support system for communal areas in the Zambezi valley, Zimbabwe; a multi-criteria evaluation linking farm household analysis, land evaluation and geographic information systems
42. **Peng Wanning**, 1997, 90-6164-134-9, Automated generalization in GIS
43. **Lawas, C.**, 1997, 90-6164-137-3, The Resource Users' Knowledge, the neglected input in Land resource management: the case of the Kankanaey farmers in Benguet, Philippines
44. **Bijker, W.**, 1997, 90-6164-139-X, Radar for rain forest: A monitoring system for land cover Change in the Colombian Amazon
45. **Farshad, A.**, 1997, 90-6164-142-X, Analysis of integrated land and water management practices within different agricultural systems under semi-arid conditions of Iran and evaluation of their sustainability
46. **Orlic, B.**, 1997, 90-6164-140-3, Predicting subsurface conditions for geotechnical modelling
47. **Bishr, Y.**, 1997, 90-6164-141-1, Semantic Aspects of Interoperable GIS
48. **Zhang Xiangmin**, 1998, 90-6164-144-6, Coal fires in Northwest China: detection, monitoring and prediction using remote sensing data
49. **Gens, R.**, 1998, 90-6164-155-1, Quality assessment of SAR interferometric data
50. **Turkstra, J.**, 1998, 90-6164-147-0, Urban development and geographical information: spatial and temporal patterns of urban development and land values using integrated geo-data, Villaviciencia, Colombia
51. **Cassells, C.**, 1998, Thermal modelling of underground coal fires in northern China
52. **Naseri, M.**, 1998, 90-6164-195-0, Characterization of Salt-affected Soils for Modelling Sustainable Land Management in Semi-arid Environment: a case study in the Gorgan Region, Northeast, Iran
53. **Gorte B.G.H.**, 1998, 90-6164-157-8, Probabilistic Segmentation of Remotely Sensed Images
54. **Tenalem Ayenew**, 1998, 90-6164-158-6, The hydrological system of the lake district basin, central main Ethiopian rift
55. **Wang Donggen**, 1998, 90-6864-551-7, Conjoint approaches to developing activity-based models

56. **Bastidas de Calderon, M.**, 1998, 90-6164-193-4, Environmental fragility and vulnerability of Amazonian landscapes and ecosystems in the middle Orinoco river basin, Venezuela
57. **Moameni, A.**, 1999, Soil quality changes under long-term wheat cultivation in the Marvdasht plain, South-Central Iran
58. **Groenigen, J.W. van**, 1999, 90-6164-156-X, Constrained optimisation of spatial sampling: a geostatistical approach
59. **Cheng Tao**, 1999, 90-6164-164-0, A process-oriented data model for fuzzy spatial objects
60. **Wolski, Piotr**, 1999, 90-6164-165-9, Application of reservoir modelling to hydrotopes identified by remote sensing
61. **Acharya, B.**, 1999, 90-6164-168-3, Forest biodiversity assessment: A spatial analysis of tree species diversity in Nepal
62. **Akbar Abkar, Ali**, 1999, 90-6164-169-1, Likelihood-based segmentation and classification of remotely sensed images
63. **Yanuariadi, T.**, 1999, 90-5808-082-X, Sustainable Land Allocation: GIS-based decision support for industrial forest plantation development in Indonesia
64. **Abu Bakr**, Mohamed, 1999, 90-6164-170-5, An Integrated Agro-Economic and Agro-Ecological Framework for Land Use Planning and Policy Analysis
65. **Eleveld, M.**, 1999, 90-6461-166-7, Exploring coastal morphodynamics of Ameland (The Netherlands) with remote sensing monitoring techniques and dynamic modelling in GIS
66. **Yang Hong**, 1999, 90-6164-172-1, Imaging Spectrometry for Hydrocarbon Microseepage
67. **Mainam, Félix**, 1999, 90-6164-179-9, Modelling soil erodibility in the semiarid zone of Cameroon
68. **Bakr, Mahmoud**, 2000, 90-6164-176-4, A Stochastic Inverse-Management Approach to Groundwater Quality
69. **Zlatanova, Z.**, 2000, 90-6164-178-0, 3D GIS for Urban Development
70. **Ottichilo, Wilber K.**, 2000, 90-5808-197-4, Wildlife Dynamics: An Analysis of Change in the Masai Mara Ecosystem
71. **Kaymakci, Nuri**, 2000, 90-6164-181-0, Tectono-stratigraphical Evolution of the Cankori Basin (Central Anatolia, Turkey)
72. **Gonzalez, Rhodora**, 2000, 90-5808-246-6, Platforms and Terraces: Bridging participation and GIS in joint-learning for watershed management with the Ifugaos of the Philippines

73. **Schetselaar, Ernst**, 2000, 90-6164-180-2, Integrated analyses of granite-gneiss terrain from field and multisource remotely sensed data. A case study from the Canadian Shield
74. **Mesgari, Saadi**, 2000, 90-3651-511-4, Topological Cell-Tuple Structure for Three-Dimensional Spatial Data
75. **Bie, Cees A.J.M. de**, 2000, 90-5808-253-9, Comparative Performance Analysis of Agro-Ecosystems
76. **Khaemba, Wilson M**., 2000, 90-5808-280-6, Spatial Statistics for Natural Resource Management
77. **Shrestha, Dhruba**, 2000, 90-6164-189-6, Aspects of erosion and sedimentation in the Nepalese Himalaya: highland-lowland relations
78. **Asadi Haroni, Hooshang**, 2000, 90-6164-185-3, The Zarshuran Gold Deposit Model Applied in a Mineral Exploration GIS in Iran
79. **Raza, Ale**, 2001, 90-3651-540-8, Object-oriented Temporal GIS for Urban Applications
80. **Farah, Hussein**, 2001, 90-5808-331-4, Estimation of regional evaporation under different weather conditions from satellite and meteorological data. A case study in the Naivasha Basin, Kenya
81. **Zheng, Ding,** 2001, 90-6164-190-X, A Neural - Fuzzy Approach to Linguistic Knowledge Acquisition and Assessment in Spatial Decision Making
82. **Sahu, B.K.**, 2001, Aeromagnetics of continental areas flanking the Indian Ocean; with implications for geological correlation and Gondwana reassembly
83. **Alfestawi, Y.,** 2001, 90-6164-198-5, The structural, paleogeographical and hydrocarbon systems analysis of the Ghadamis and Murzuq Basins, West Libya, with emphasis on their relation to the intervening Al Qarqaf Arch
84. **Liu, Xuehua,** 2001, 90-5808-496-5, Mapping and Modelling the Habitat of Giant Pandas in Foping Nature Reserve, China
85. **Oindo, Boniface Oluoch**, 2001, 90-5808-495-7, Spatial Patterns of Species Diversity in Kenya
86. **Carranza, Emmanuel John**, 2002, 90-6164-203-5, Geologically-constrained Mineral Potential Mapping
87. **Rugege, Denis**, 2002, 90-5808-584-8, Regional Analysis of Maize-Based Land Use Systems for Early Warning Applications
88. **Liu, Yaolin**, 2002, 90-5808-648-8, Categorical Database Generalization in GIS