# TEMPORALLY NAVIGATING SPATIO-TEMPORAL DATA IN GIS: TEMPORAL ZOOM AND PAN IN A MULTI-TOUCH ENVIRONMENT

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# TEMPORALLY NAVIGATING SPATIO-TEMPORAL DATA IN GIS: TEMPORAL ZOOM AND PAN IN A MULTI-TOUCH ENVIRONMENT


by

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A thesis submitted to the

School of Graduate Studies

in partial fulfillment of the requirements for the degree of

Master of Science


**Department of Geography**

Memorial University of Newfoundland


**September 2013**

St. John's Newfoundland

## Abstract

The temporal dimension of spatio-temporal datasets is often an important component in exploring and answering questions about geographic phenomena. With the ability of modern technologies to capture and store very large spatio-temporal datasets, being able to effectively navigate these datasets becomes increasingly important. While geographic information systems have focused on developing spatial navigation tools, approaches to temporal navigation have not received the same level of attention. Current temporal navigation tools also do not take full advantage of recent technologies such as multi-touch devices. This thesis proposes two approaches, Dynamic Radial Navigation and Multiple Linked Time Sliders, for navigating the temporal dimension of spatio-temporal data within a multi-touch environment. These approaches were evaluated, along with two more common and simple approaches, in a laboratory-based user study. This study indicated that while the proposed approaches enabled the participants to temporally navigate the data, and the participants valued the advanced visualization features, these advanced features need to be balanced with ease of use and would require additional iterations of design and testing before being put into practice.

## Acknowledgements

First, I would like to thank my two co-supervisors, Rodolphe Devillers and Orland Hoeber, for their guidance and support throughout all stages of this thesis.

I also wish to thank Xu Liu, Renyu Li, and Derek Leblanc for their assistance with the software development in this project, all of the anonymous participants who completed the user evaluation, Randal Greene for reviewing chapters one and three, Arnaud Vandecasteele for reviewing chapter three, and all of my colleagues, past and present, in the Marine Geomatics Lab.

I would also like to acknowledge the Natural Sciences and Engineering Council of Canada (NSERC), the Canadian Foundation for Innovation (CFI), Esri Canada, and Memorial University of Newfoundland for providing direct or indirect financial support.

Finally, I would like to thank my friends, family, and partner, Michael Phillips, for their encouragement throughout this process.

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# Chapter 1: Introduction

## 1.1 Research context and problem

Representations of geographic phenomena are often complex and multi-dimensional. In addition to the spatial and thematic dimensions, geographic data also usually have an intrinsic temporal dimension (Sinton, 1978). These dimensions are used by analysts to answer the questions 'where', 'what', and 'when' (Peuquet, 2002). The ability to answer all three of these questions is often important in achieving a complete view of a problem or process. The temporal dimension in particular is important in answering questions in diverse fields such as health and epidemiology (AvRuskin et al., 2004; Castronovo et al., 2009; Richardson et al., 2013), climate studies (Edsall et al., 2000), emergency management (Jern et al., 2010; MacEachren et al., 2011), urban planning (Joo et al., 2010), and natural resources management (Andrienko et al., 2006; Hoeber et al., 2011).

Tools such as geographic information systems (GIS) and virtual globes help users with their data navigation, analysis, and exploration. Navigation within large datasets is of particular importance. In large datasets, there may be too much information to coherently view it all at one time. Data may overlap if there are too many points within an area, or if data were collected multiple times at one location. If a dataset covers a large area, the data may appear too small on the screen when all of the data are viewed simultaneously. Navigation tools enable users to select and display the data that are relevant for their purpose. While GIS have developed with a focus on navigating the spatial and thematic dimensions, navigation within the temporal dimension is less developed within these systems (Kraak, 2005; Neumann, 2010).

Temporal data can be collected and visualized at different temporal granularities. The temporal granularity is the level of temporal detail that data are collected or stored at, and generally takes the form of calendar and clock units, for example, years, months, days, or hours (Bettini et al., 1998). The temporal granularity of the data must match the temporal granularity of the question that the data are being used to answer.

Zoom and pan tools are used for spatial navigation within GIS. Zooming changes the scale of the map and allows a larger or smaller area to be viewed on screen, while panning moves and re-centres the map within the display window while maintaining the same spatial scale. Zooming and panning may be done in different ways depending on the system in use (Harrower & Sheesley, 2005). For example, some typical approaches for zooming are clicking on the map with a 'magnifying glass' cursor, or typing the desired map scale into a text box. For panning, a 'pan hand' cursor might be used to move the map within the display window, or the user might click on directional arrows to change the focus of the map to an adjacent area.

Navigation within the thematic dimension can be achieved through adding or removing layers for different attributes or by using queries and filters to display or highlight data on the screen (Neumann, 2010). These queries can either be defined by the user, such as those made using structured query language (SQL), or made from a series of predefined options, such as a hierarchical menu.

Despite its recognized importance in answering geographic questions (Andrienko et al., 2007; Peuquet & Duan, 1995), temporal navigation is not as well supported. It is usually achieved either by treating time as an attribute and navigating it the way one would navigate the thematic dimension, or by using simple temporal sliders. Navigation through multiple temporal granularities (e.g., weeks, months, and years) is not always supported. With an increasing amount of spatio-temporal data available (Keim et al., 2008), it is important that users are able to navigate the temporal dimension of their data with the same ease that they currently navigate the spatial dimension. Many complex questions have a fundamental temporal component that must be addressed in order for the questions to be answered. For instance, a climate change researcher may wish to analyze changes to an area and phenomena over multiple periods of time and at multiple temporal scales. An epidemiologist may need to see outbreak locations of an illness at different time periods, as well as analyze how the locations change over time.

The popularization in recent years of interaction methods such as multi-touch has also created the opportunity to develop new approaches to interacting with spatio-temporal data (Schöning et al., 2008). Multi-touch interfaces allow users to interact directly with the screen with multiple, simultaneous points of contact (Han, 2005). While traditional temporal navigation approaches can be imported into this environment, there is still a need for multi-touch specific approaches. These interfaces have the potential to enable intuitive data interaction since pointing devices, such as a mouse, are eliminated and users are able to touch the screen directly with multiple fingers at the same time (Butkiewicz et al., 2009).

## 1.2 Research questions

This research has been guided by the overarching question 'What is an effective approach to applying the well-known spatial zoom and pan paradigm to temporal data to help analysts navigate the temporal dimension of their spatio-temporal data within a multi-touch environment?'

More detailed and specific questions that are addressed within this thesis are:

- How can the spatial zoom and pan paradigm be applied to an approach for navigating the temporal dimension of spatio-temporal data within a geospatial application?
- How can the zoom and pan paradigm be implemented to enable users to temporally navigate their spatio-temporal data within a GIS or virtual globe in a multi-touch environment?
- Do the approaches developed for temporal zoom and pan in GIS assist users in navigating the temporal dimension of spatio-temporal data?
- How do the proposed approaches compare to other approaches for temporal navigation?

## 1.3 Research objectives

The goal of this thesis is to develop an approach for navigating through multiple temporal granularities of spatio-temporal data with zoom and pan using a multi-touch interface, and to assess the degree to which it assists and supports users in locating and displaying the temporal data they require at the granularity they need to answer their temporal questions.

The specific objectives of this research are to:

- Identify existing and proposed methods for navigating through the temporal dimension of spatio-temporal data and examine how others have attempted to navigate within this dimension.
- Design new approaches that implement temporal zoom and pan capabilities in a multi-touch environment.
- Implement the approaches in software prototypes.
- Validate the approaches through user evaluations.

## 1.4 Research methods

The research methods for this thesis followed the approached outlined in Figure 1.1. The first phase consisted of a literature review that covered the fields of spatio-temporal data structure, navigation, and visualization as well as geovisual analytics and multi-touch interaction. This refined the initial thesis ideas and assisted in defining the scope of the thesis. The literature review continued throughout the life of the thesis.

The second phase consisted of incorporating the knowledge gained throughout the literature review into designs for approaches to temporal zoom and pan for navigation of the temporal dimension of spatio-temporal data. Two approaches were fully developed. This allowed the development of multiple ideas while restricting the number of approaches to an amount that would be possible to implement and test within the timeline of this thesis. The details of these approaches are discussed in detail in Section 3.3.

The third phase involved implementing the approaches into software prototypes for user evaluations. Prototypes of traditional temporal navigation approaches were also designed and implemented at this stage for comparison.

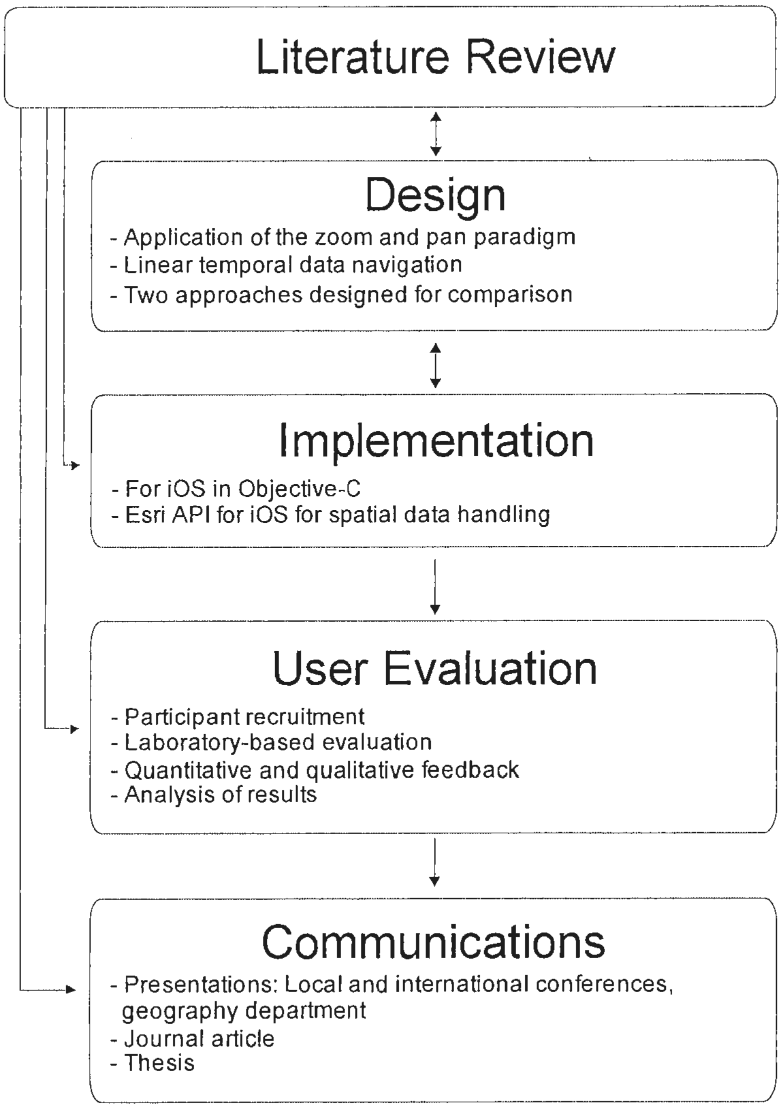



**Figure 1.1.** Flow of research methods.

The fourth phase involved testing the temporal zoom and pan approaches with a user evaluation of the prototypes. This took the form of a laboratory study involving 40 participants from the Memorial University of Newfoundland student community. The students used the prototypes with fisheries data to complete assigned tasks and answer a series of questions. They were timed during the tasks and completed a series of questionnaires that gathered information on the usability and usefulness of, as well as participants' opinions on, the prototypes.

The fifth phase involved communicating the progress and the results of this research. The initial proposal for this thesis was presented to the Department of Geography at Memorial University of Newfoundland (April 2011). The two proposed approaches were presented at the workshop 'Geovisual Analytics, Time to Focus on Time' at the GIScience 2012 Conference in Columbus, Ohio (September 2012) (Lee et al., 2012), to the Department of Geography at Memorial University of Newfoundland as a part of the department's seminar series (October 2012), and at the Esri Canada Regional User Conference in St. John's, Newfoundland and Labrador (November 2012). The proposed approaches and the results of the user evaluation were submitted as a journal article in May 2013. The final step of this phase is the submission of this thesis.

## 1.5 Thesis organization

This thesis follows a manuscript format. Chapter 2 consists of an extended literature review of spatio-temporal research in geographic information systems, and geovisual analytics while specifically focusing on temporal navigation. Chapter 3 presents two novel approaches for spatio-temporal navigation within a multi-touch system. The implementation of the approaches in prototypes and the results of a laboratory-based user evaluation of the approaches are also discussed. This chapter was submitted in May 2013 as an article to the *International Journal of Geographical Information Science* Special Issue on Space-Time Research in GIS. Chapter 4 concludes the thesis and discusses opportunities for further work. The task descriptions and questionnaires from the user evaluation are presented in Appendix A. The approval letter for the user evaluation from the Interdisciplinary Committee on Ethics in Human Research (ICEHR) is included as Appendix B.

### 1.6 Co-authorship statement

This project was primarily funded by a Natural Sciences and Engineering Research Council of Canada (NSERC) Strategic Projects Grant looking at the use of geovisual analytics in fisheries held by my co-supervisors Orland Hoeber, Department of Computer Science, and Rodolphe Devillers, Department of Geography, and was part of that overarching project. The initial concept for this thesis (i.e., navigating in a GIS through dimensions other than space) was suggested by co-supervisor Rodolphe Devillers. The candidate then refined the specific research problem during the literature review. The approaches were designed by the candidate and reviewed and refined in an iterative process with both co-supervisors. Programmers were hired and volunteered to do the majority of the programming to implement the candidate's designs into software prototypes. Xu Liu (Department of Computer Science, Memorial University of Newfoundland) did the initial programming for the Dynamic Radial Navigation prototype, Renyu Li (Department of Geomatics Engineering, University of Calgary) did the initial programming for Multiple Linked Time Sliders using Xu Liu's prototype as a base, and Derek Leblanc (Department of Computer Science, Memorial University of

Newfoundland) programmed the Date/Time Spinners and Drop-Down List prototypes, and fixed bugs in and updated the initial two prototypes. The candidate made minor changes to the prototypes and supervised the programming process. The user evaluation design was outlined by co-supervisor Orland Hoeber. The candidate created the user tasks and questionnaires for the user evaluation, recruited the participants, conducted the user evaluation, collected and analyzed the data, and interpreted the results. The initial draft of the journal article presented in Chapter 3 was written by the candidate and was then reviewed and edited in an iterative process with both co-supervisors. The candidate is listed as first author on the journal article and both co-supervisors are listed as co-authors.

### 1.7 References


Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839–857.

Andrienko, G., Andrienko, N., Fischer, R., Mues, V., & Schuck, A. (2006). Reactions to geovisualization: An experience from a European project. *International Journal of Geographical Information Science*, 20(10), 1149–1171.

AvRuskin, G. A., Jacquez, G. M., Meliker, J. R., Slotnick, M. J., Kaufmann, A. M., & Nriagu, J. O. (2004). Visualization and exploratory analysis of epidemiologic data using a novel space time information system. *International Journal of Health Geographics*, 3(1), 26.

Bettini, C., Wang, X. S., & Jajodia, S. (1998). A general framework for time granularity and its application to temporal reasoning. *Annals of Mathematics and Artificial Intelligence*, 22, 29–58.

Butkiewicz, T., Jeong, D. H., Wartell, Z., Ribarsky, W., & Chang, R. (2009). Hierarchical multi-touch selection techniques for collaborative geospatial analysis. In W. J. Tolone & W. Ribarsky (Eds.), *Proceedings of SPIE 7346, Visual Analytics for Homeland Defense and Security,* 14 May 2009 (73460D). Orlando, FL, USA: Society of Photo-Optical Instrumentation Engineers.

Castronovo, D. A., Chui, K. K. H., & Naumova, E. N. (2009). Dynamic maps: A visual-analytic methodology for exploring spatio-temporal disease patterns. *Environmental Health*, 8:61. doi:10.1186/1476-069X-8-61

Edsall, R. M., Harrower, M., & Mennis, J. L. (2000). Tools for visualizing properties of spatial and temporal periodicity in geographic data. *Computers & Geosciences*, 26(1), 109–118.

Han, J. Y. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. In P. Baudisch & M. Czerwinski (Eds.), *Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology,* 23–26 October 2005 (pp. 115–118). Seattle, WA, USA: ACM Press.

Harrower, M., & Sheesley, B. (2005). Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS*, 9(2), 77–89.

Hoeber, O., Wilson, G., Harding, S., Enguehard, R., & Devillers, R. (2011). Exploring geo-temporal differences using GTdiff. In G. Di Battista, J.-D. Fekete, & H. Qu (Eds.), *Proceedings of the Pacific Visualisation Symposium*, 1–4 March 2011 (pp. 139–146). Hong Kong, China: IEEE Computer Society Press.

Jern, M., Brezzi, M., & Lundblad, P. (2010). Geographic information and cartography for risk and crisis management. In M. Konecny, S. Zlatanova, & T. L. Bandrova (Eds.), *Geographic Information and Cartography for Risk and Crisis Management* (pp. 379–394). Berlin, Germany: Springer.

Joo, Y., Jang, M., & Jun, C. (2010). Developing a time-series visualization technique using a temporal GIS database for urban growth simulation. *International Journal of Urban Sciences*, 14(1), 98–110.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., & Melançon, G. (2008). Visual analytics: Definition, process, and challenges. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization–Human Centered Issues in Visual Representation, Interaction, and Evaluation* (pp. 154–175). Berlin, Germany: Springer.

Kraak, M.-J. (2005). Timelines, temporal resolution, temporal zoom. In *Proceedings of the International Cartographic Conference,* 9–16 July 2005 (CDROM). A Coruña, Spain.

Lee, C., Devillers, R., & Hoeber, O. (2012, September). *Interactive temporal zoom and pan within a multi-touch geo-visual analytics environment.* Paper presented at GIScience '12 Workshop Geovisual Analytics—Time to Focus on Time, Columbus, OH, USA.

MacEachren, A. M., Robinson, A. C., Jaiswal, A., Pezanowski, S., Savelyev, A., Blanford, J., & Mitra, P. (2011). Geo-Twitter analytics: Applications in crisis management. In A. Ruas (Ed.) *Proceedings of the International Cartographic Conference*, 3–8 July 2011. Paris, France.

Neumann, A. (2010). *Spatial, temporal and thematic navigation: Visualizing biographies of European artists using a task oriented user interface design approach.* (Doctoral dissertation). Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland.

Peuquet, D. J. (2002). *Representations of Space and Time*. New York, NY, USA: The Guilford Press.

Peuquet, D. J., & Duan, N. (1995). An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. *International Journal of Geographical Information Systems*, 9(1), 7–24.

Richardson, D. B., Volkow, N. D., Kwan, M.-P., Kaplan, R. M., Goodchild, M. F., & Croyle, R. T. (2013). Spatial turn in health research. *Science*, *339*(6126), 1390–1392.

Schöning, J., Brandl, P., Daiber, F., Echtler, F., Hilliges, O., Hook, J., Löchtefeld, M., Motamedi, N., Muller, L., Olivier, P., Roth. T., & von Zadow, U. (2008). *Multi-touch Surfaces: A technical guide*. Technical Report TUM-I0833: Technical Reports of the Technical University of Munich.

Sinton, D. (1978). The inherent structure of information as a constraint to analysis: Mapped thematic data as a case study. *Harvard Papers on Geographic Information Systems*, 7, 1–17.

# Chapter 2: Literature Review

## 2.1 Introduction

This chapter presents a review of the relevant literature of several fields relating to this research. In the first section, basic properties of temporal data are reviewed to provide a context for the rest of the review and a foundation on which the proposed approaches are built. The next section discusses spatio-temporal data in GIS and looks at its importance in answering research questions. Temporal frameworks that can be used to conceptualize ways of working with spatio-temporal data in GIS are also reviewed. Spatial and temporal navigation in GIS are then discussed and existing approaches are reviewed. The chapter ends with a section on the importance of spatio-temporal data in the field of geovisual analytics.

## 2.2 Properties of temporal data

Time is not directly observable by any of the senses and is only indirectly observable through changes in the environment (Langran & Chrisman, 1988; Ott & Swiaczny, 2001). Different ways of structuring time assist people in working with temporal data. The way in which time is structured depends on the nature of the topic under consideration.

There are two types of temporal primitives: time points and time intervals (Figure 2.1). Time points represent a single moment in time while time intervals represent a continuous period of time. Time intervals may be either absolute (or anchored) or relative (or unanchored) (Snodgrass, 1996). An absolute interval has specific starting and ending points, for example June 5, 2000 to June 10, 2000. A period with unspecified start and end dates, for example 5 days, is a relative interval and is sometimes referred to as a time span (Goralwalla et al., 1998). A time point, or instant, is absolute, for example, May 25, 2002 at 5:00 am.

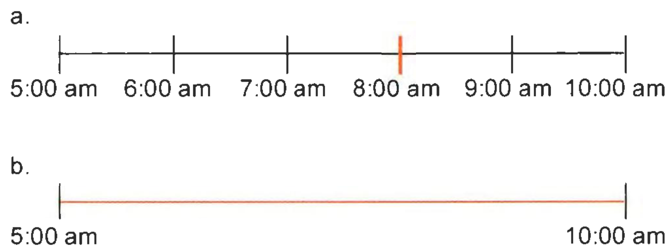



**Figure 2.1.** Temporal primitives: time point (a), time interval (b).

Temporal data can be represented and collected at different granularities such as months, days, or hours (Figure 2.2). The temporal granularity that is used will depend on the scale of the phenomena under observation, the purpose of the analysis, and the capabilities of the technologies used for data collection and for data analysis (Kemp & Kowalczyk, 1994; Ott & Swiaczny, 2001). Data can be aggregated to a coarser resolution (e.g., days to weeks) but cannot usually be decomposed to a finer resolution than they were collected at (e.g., days to hours) (Lee & Kemp, 1998).

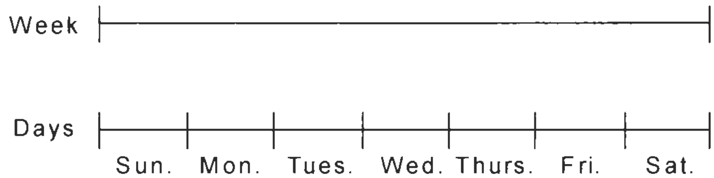



**Figure 2.2.** Example of temporal granularities: one week (top), seven days (bottom).

Time can be structured in multiple ways. Three of the most applicable models for GIS are linear, cyclic, and branching (Frank, 1998). Linear time corresponds to the perception that time moves as an ordered series of events from the past to the future (Aigner et al., 2007) (Figure 2.3a). It is the basis of temporal data models used for systems implementing time sliders. Cyclic time is a way of structuring time for reoccurring events (e.g., seasons of the year, hours of the day) that have occurred at regular intervals in the past and will continue at regular intervals into the future (Hajnicz, 1996) (Figure 2.3b). In order to perform cyclic queries within a system, a cyclic data model needs to be used during development and the cyclic variations need to be incorporated into the database (Hornsby et al., 1999). Branching time consists of multiple branches of time extending from the current time and representing possible alternative scenarios (Aigner et al., 2008) (Figure 2.3c). Data do not always fit neatly within these three structures and can sometimes be represented in more than one way (Aigner et al., 2007). For example, the seasons can represented using cyclic time as a cycle that repeats on a yearly basis, but can also be viewed on a linear axis as each season coming after the previous. Temporal structures can also be combined. For example, a linear representation of the known past can be combined with a branching representation of possible scenarios for the unknown future (Schreiber, 1994).

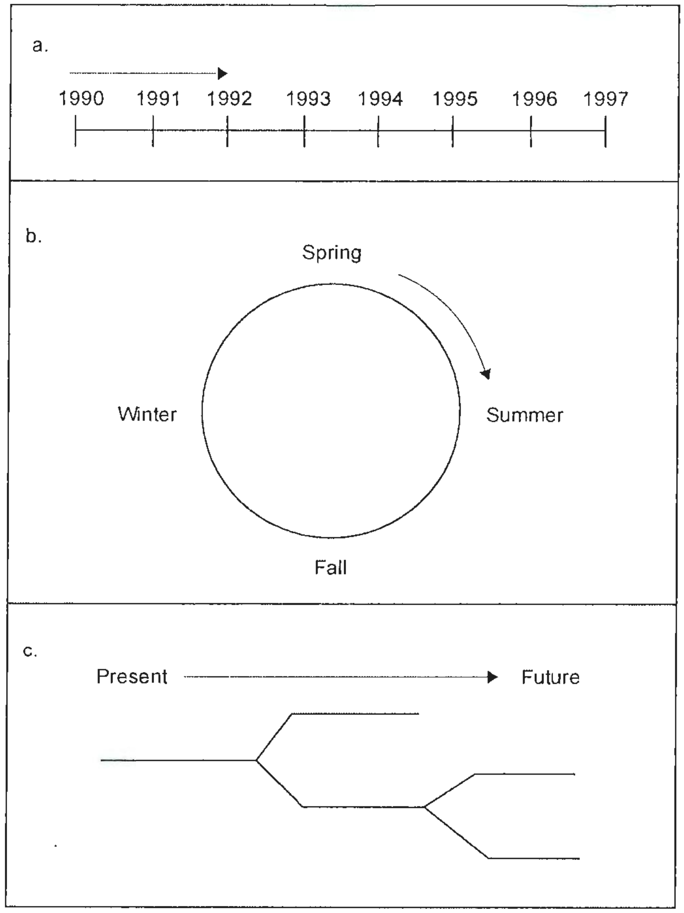



**Figure 2.3.** Different ways to structure time: linear (a), cyclic (b), and branching (c).

## 2.3 Spatio-temporal data in GIS

Although the focus in GIS is often on the spatial dimension, geographic data can be characterised using other dimensions. Sinton (1978) discussed how geographic data consist of three components (or dimensions): the theme (or attribute), being the nature of the phenomenon or object that is being observed or measured; the location of the phenomenon or object; and the time the observation or measurement was made. Sinton (1978) illustrated that if one dimension is being measured, then one dimension is controlled and one dimension is held constant. Due to the evolution of GIS from traditional paper maps, it has generally been the temporal dimension that has been held constant (Langran & Chrisman, 1988).

As GIS developed, researchers brought a temporal focus to the discipline and developed conceptual frameworks for spatio-temporal GIS and how to incorporate temporal data into spatial databases (e.g., Langran, 1989; Abraham & Roddick, 1999). This became more practical as technology advanced and as systems were able to store and process large temporal datasets and temporal changes to datasets, which can require significant memory and processing power (Peuquet, 2002).

One framework that can be applied in the context of this research is the triad framework (Peuquet, 1994). This framework was developed as a way to integrate time-based representation with object-based representation and location-based representation of the dual representation framework. This enables users to examine their questions related to 'when' in addition to questions about 'what' and 'where' (Figure 2.4). This framework has since been the basis for other frameworks such as the pyramid framework (Mennis et al., 2000).

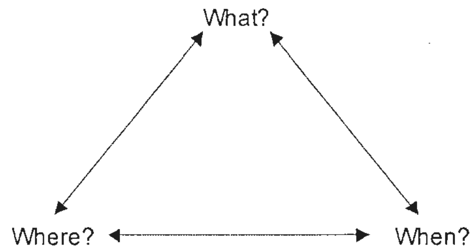



**Figure 2.4.** Components of the triad framework, adapted from Peuquet (1994).

## 2.4 Navigating data in GIS

### 2.4.1 Navigating spatial data in GIS

Spatial navigation within GIS and digital maps is mostly done using zoom and pan tools. Zooming changes the scale of a map. Zooming in makes the data displayed within the data frame appear larger, and often more detailed, while zooming out makes the data appear smaller, and often less detailed. Panning moves and re-centres the map within the data frame, keeping it at a constant scale. There are multiple approaches to implementing zoom and pan within GIS and digital maps and multiple approaches can also be combined within one system.

Battersby (2008) suggested several common ways spatial zooming can be implemented including zoom 'slider bars', zoom 'icons', and the 'scroll wheel'. 'Slider bars' display a range of zoom levels along their axis and users move a slider along, or select a segment of, the bar to change the zoom level. Zoom 'icons' are buttons, often labelled with an icon such as a + or –, that users click to zoom in or out on the map by specific predefined scales. The 'scroll wheel' allows users to zoom in or out on a map by rolling the scroll wheel of a mouse. If the users know the scale at which they wish to view their map, some systems also offer a text box where the scale can be typed in directly (Harrower & Sheesley, 2005).

Battersby (2008) also identifies multiple methods for panning. Direct repositioning involves clicking on a point on the map to 'grab' it and move the map within the data frame. Navigation tabs are buttons or tabs within a display that can be clicked to move a map in the direction indicated on the button/tab. Point and click allows the user to click a point within the data frame and have the map re-centre itself on that point.

Panning and zooming can also be combined. For example, a zoom box allows users to draw a box on the map display and have the map zoom and pan within the data frame to match the extents of the box; zoom and re-centre under mouse click allows users to click on an area in the data frame, often with a cursor that looks like a magnifying glass, and have the map zoom in by a set amount and pan so that it is centred on the point that was clicked (Harrower & Sheesley, 2005).

Spatial navigation in multi-touch systems (e.g., smartphones and tablets) does not always use cartographic tools but can be done with hand gestures performed on the screen. Zooming spatially is done with a 'pinch' gesture where users move their thumb and forefinger together to zoom out, or apart to zoom in. Although they have only recently gained popularity with the rise in use of portable computing devices, research on gestural interaction and multi-touch systems has been going on since the early 1980s (Buxton, 2013). Using the pinch gesture to scale digital items was originally developed by Krueger (1985) and later adapted to other programs and systems. To pan, users simply touch the screen and use their finger to move the map in whatever direction they wish.

### 2.4.2 **Navigating temporal data in GIS**

GIS technologies have typically handled temporal navigation by treating time as an attribute and by querying the temporal dimension of the data in the same way other attributes are queried. Navigation was also possible by having individual layers representing maps at given times (e.g., different years) and adding or removing layers or turning layers on or off. More recently, time sliders have started to be included in commonly used commercial mapping software (e.g., ArcGIS, Google Earth). These time sliders are steps towards having more time-specific navigation tools incorporated into mainstream software.

Although they have not necessarily been adopted by mainstream GIS software, there have been several approaches proposed for temporal navigation of both linear and cyclic time (Table 2.1). The approaches discussed here are visual navigation approaches. These have a benefit over text-based selection in that they can also often be used as temporal legends as they indicate the location of the selected data within the larger dataset (Edsall et al., 1997). Visual navigation approaches do have limitations as well. For example, large dataset may be too complex or the number of points may be too overwhelming for people to visualize without additional data processing.

**Table 2.1.** General navigation approaches for different types of time.

| Type of Time | General Navigation Approaches | Example |
|---|---|---|
| Linear | Often involve a type of time slider where the data are displayed along a line (or bar). Once a selection is made the user can often 'slide' their selection along the line to change it, although in some systems users may have to reselect their data each time. | Edsall & Peuquet (1997), Brewer et al. (2000), Neumann (2010) |
| Cyclic | Data are usually displayed in a type of circle and the user selects the extent of data that they are interested in. | Edsall & Peuquet (1997), Brewer et al. (2000) |
| Combined | Some researchers have attempted to find shapes that allow the combination of both linear and cyclic time. So far these have not been adopted for common use. | Edsall & Sidney (2005), Li & Kraak (2008) |

The TEMPEST interface was developed based on the Triad conceptual framework (Edsall & Peuquet, 1997). It consisted of dedicated navigation approaches for the spatial, temporal, and thematic dimensions. By separating the navigation approaches, each approach can focus on what is unique about navigating within that dimension. The temporal navigation tool was divided into two parts: a timewheel for cyclic queries and a timeline for linear queries (Figure 2.5). These tools allowed a large range of selections to be made at different granularities but the selection could not necessarily be seen at one time. The timewheel required switching between multiple tabbed views to select different granularities. On the timeline, multiple granularities were displayed on one extent making the smallest granularities very small.

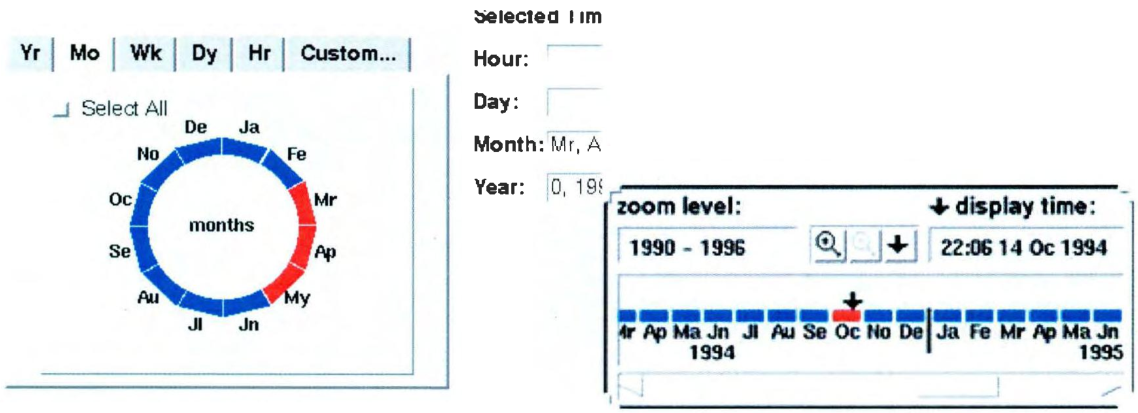



**Figure 2.5.** The TEMPEST timewheel (left) and timeline (right), from Edsall and Peuquet (1997).

Brewer et al. (2000) also implemented a tool combining linear and cyclic selections (Figure 2.6). In this tool the wheels are nested and the slider is combined in one view allowing the user to view the entire tool at once and make selections without navigating through different windows. While this tool allows detailed cyclic selections, it does not allow a detailed selection of different start and end points in a linear selection. Also, if more than two wheels were nested it would cause the tool to take up a large portion of screen space.

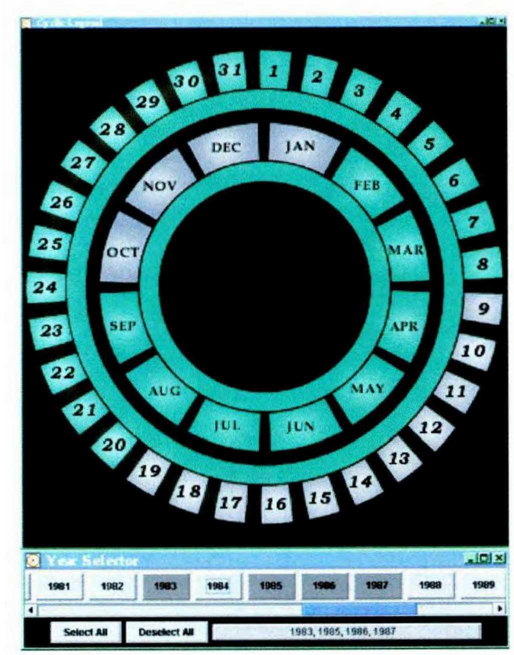



**Figure 2.6.** The temporal navigation tool of Brewer et al. (2000).

Although many navigation approaches consist of some form of timeline or timewheel, other formats have been proposed to attempt to combine both linear and cyclic time. The time coil (Edsall & Sidney, 2005) was proposed to represent different types of time when looked at directly or from the side (Figure 2.7). The front circular view represents cyclic time while the side view can be used for linear data.

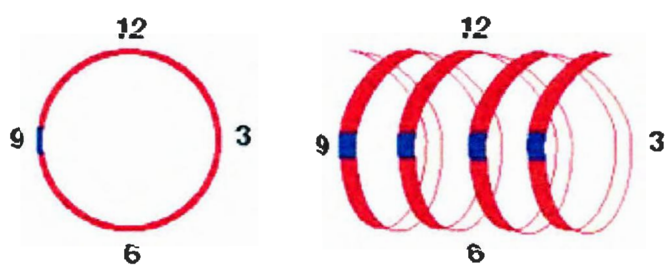



**Figure 2.7.** An example of the time coil (Edsall & Sidney, 2005).

Li and Kraak (2008) have proposed that a time wave could be used for temporal navigation (Figure 2.8). The time wave would combine elements of both the timeline and the timewheel and be represented by a series of waves where the wavelength is equivalent to the temporal granularity of the dataset. Points or spans of time on the wave could be selected to locate, compare, or select the temporal data. This method has been implemented as a visualization method (Li & Kraak, 2012) but has yet to be tested as a navigation approach.

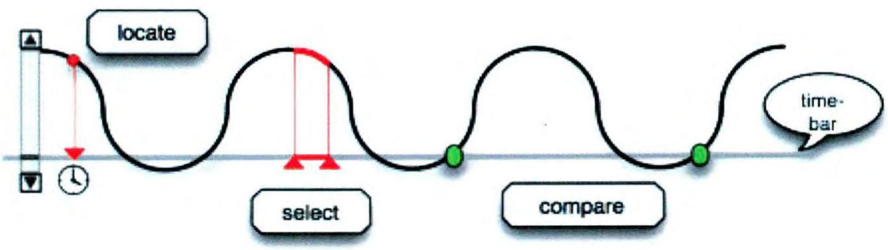



**Figure 2.8.** An example of the timewave as it could be used for temporal navigation (Li & Kraak, 2008).

As well as different approaches to temporal navigation, there are also different ways users can interact with these approaches. This is similar to navigation within the spatial dimension. Within the spatial dimension, most systems incorporate zoom and pan tools, but the users might interact with these tools in different ways in different systems. Neumann (2010) applied the paradigm of zoom and pan to temporal navigation in a system consisting of multiple timelines (Figure 2.9). Multiple ways to temporally zoom or pan along the timelines were implemented and evaluated. Tools for zooming included 'zoom buttons' to zoom in or out by specific steps, 'zoom rectangle' which zooms in to the area drawn by the box, and 'zoom wheel' which zooms in or out when the mouse wheel is spun forward or back. Four tools were implemented for panning, including pan buttons which moved the selection along the timeline in discrete steps, pan hand to 'grab' and move the selection, pan with the centre mouse button, and pan with the arrow key.

There were also two combined methods, time scrollbar allowed the user to zoom by dragging the edges of the selection box and pan by selecting the middle of the selection box and moving it along the timeline, and time input fields which allowed the user to type in specific start and end dates. Overall, Neumann (2010) found that users preferred the time scrollbar. Although this study was working within the paradigm of temporal zoom and pan and with linear timelines, there was still a wide range of options available for the specific implementation.

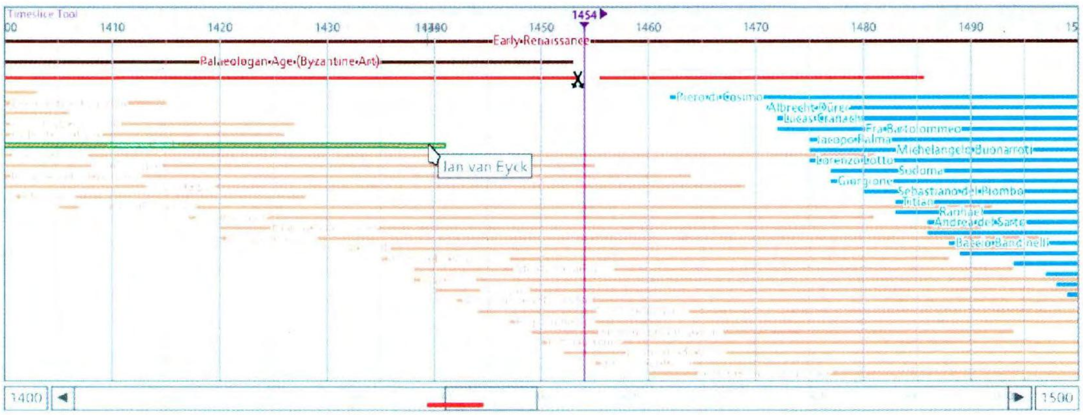


**Figure 2.9.** Interface for temporal zoom and pan from Neumann (2010).

Temporal zoom has been defined in more than one way. It can be defined as changing the temporal range of the data visualized, either narrowing the range to zoom in or widening the range to zoom out (e.g., Neumann, 2005 and 2010). It has also been defined as moving between finer temporal granularity (more detailed) and coarser temporal granularity (less detailed) views of spatio-temporal data (Hornsby & Egenhofer, 1999; Hornsby, 2001). This approach assists users in distinguishing certain activities or processes that may occur only at certain temporal granularities (Hornsby, 2001).

The various approaches in the preceding discussion on temporal navigation have all been implemented or designed in the context of a windows icons menus pointers (WIMP) environment using a standard setting where users interact with the data through a mouse or keyboard. There are now other modes of interaction that are commonly available. Multi-touch systems became popular with the increased use of smartphones and other mobile computing devices. Although most current and proposed methods of temporal navigation could be implemented in multi-touch devices, there is an opportunity to develop multi-touch specific new approaches using intuitive and non-traditional interactions (Butkiewicz et al., 2009).

Some basic temporal navigation tools are being integrated in commercial applications. For example, Esri has included basic temporal navigation tools in their ArcGIS API for iOS. Applications for data with a temporal component can be set up to display dates at the bottom of the screen and the user can tap on a date to display the data for that specific day (Figure 2.10). Only a single temporal granularity can be displayed. The research literature has not yet addressed this specific topic, although there is research into multi-touch temporal queries in non-spatial contexts (e.g., Certo et al., 2012).


**Figure 2.10.** An example of a temporal navigation tool in a commercial multi-touch application (www.arcgis.com).

## 2.5 Temporal data and geovisual analytics

Visual analytics is a field that was developed to deal with complex and often large datasets that are difficult to analyze with conventional tools and methods (Thomas & Cook, 2005). It integrates the automated processing capabilities of computers with the analytical and decision making abilities of humans (Andrienko et al., 2007; Keim et al., 2008; De Amicis et al., 2009). Visual Analytics can be defined as 'the science of analytical reasoning facilitated by interactive visual interfaces' (Thomas & Cook, 2005, p.4). Geovisual analytics is a branch of visual analytics that incorporates geography and visual analytics (Andrienko et al., 2007). The field also has a strong focus on temporal data (Andrienko et al., 2010a and 2010b).

Geovisual analytics systems are usually composed of multiple integrated tools and views. Tools for visualizing or navigating temporal data are often featured. Many systems integrate a basic linear timeslider that allows users to temporally pan through data and select a temporal point or range (Jern & Franzen, 2006; Lundblad et al., 2009; MacEachren et al., 2011). These tools assist users in the analysis of their data by allowing them to filter out extraneous information and visualize the relevant data. Some systems have also expanded on the basic timeline to include additional features. GTdiff contains a temporal view with a timeslider for temporally navigating data (Hoeber et al., 2011). In addition to making temporal data selections, users can also specify the number of bins they would like to aggregate the data into for display

## 2.6 Conclusions

This chapter began with a review of the basic elements of temporal data including temporal primitives and temporal data structures (Section 2.2). This literature provided the basis for the ways in which the proposed temporal navigation approaches would need to be structured and the types of data selections that could be made. Section 2.3 discussed frameworks that provide ways to structure questions and think about temporal data in GIS in relation to other data types.

Section 2.4 discussed navigation through both the spatial and temporal dimensions of spatio-temporal data. The review of spatial zoom and pan provides background information on the paradigm that has been adapted in this thesis for navigating the temporal dimension. The review of the navigation through the temporal dimension identified existing methods to build upon, and drawbacks of the existing approaches.

## 2.7 References


Abraham, T., & Roddick, J. F. (1999). Survey of spatio-temporal databases. *GeoInformatica*, 3(1), 61–99.

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2007). Visualizing time-oriented data—A systematic view. *Computers & Graphics*, 31(3), 401–409.

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2008). Visual methods for analyzing time-oriented data. *IEEE Transactions on Visualization and Computer Graphics*, 14(1), 47–60.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839–857.

Andrienko, G., Andrienko, N., Demsar, U., Dransch, D., Dykes, J., Fabrikant, S. I., Jern, M., Kraak, M.-J., Schumann, H., & Tominski, C. (2010a). Space, time and visual analytics. *International Journal of Geographical Information Science*, 24(10), 1577–1600.

Andrienko, G., Andrienko, N., Dykes, J., Kraak, M.-J., & Schumann, H. (2010b). GeoVA(t) – Geospatial visual analytics: Focus on time. *International Journal of Geographical Information Science*, 24(10), 1453–1457.

Battersby, S. E. (2008). User-centered design for digital map navigation tools. In *Proceedings of the 17th International Research Symposium on Computer-Based Cartography*, 8–11 September 2008 (CD-ROM). Shepherdstown, WA, USA: Cartography and Geographic Information Society with assistance by ESRI.

Brewer, I., MacEachren, A. M., Abdo, H., Gundrum, J., & Otto, G. (2000). Collaborative geographic visualization: Enabling shared understanding of environmental processes. In A. Rawlinson (Ed.), *Proceedings of the IEEE Symposium on Information Visualization,* 9–10 October 2000 (pp. 137–141). Salt Lake City, Utah, USA: IEEE Computer Society.

Butkiewicz, T., Jeong, D. H., Wartell, Z., Ribarsky, W., & Chang, R. (2009). Hierarchical multi-touch selection techniques for collaborative geospatial analysis. In W. J. Tolone & W. Ribarsky (Eds.), *Proceedings of SPIE 7346 Visual Analytics for Homeland Defense and Security,* 14 May 2009 (p. 73460D). Orlando, FL, USA: International Society for Optics and Photonics.

Buxton, B. (2013, March 19). Multi-touch systems that I have known and loved. Retrieved from http://www.billbuxton.com/multitouchOverview.html, last accessed July 12, 2013.

Certo, L., Galvão, T., & Borges, J. (2012). Time Automaton: A visual mechanism for temporal querying. *Journal of Visual Languages amd Computing*, 24(1), 24–36.

De Amicis, R., Conti, G., Piffer, S., & Simões, B. (2009). Geospatial visual analytics. In R. De Amicis, S. Radovan, & G. Conti (Eds.), *GeoSpatial Visual Analytics: Geographical Information Processing and Visual Analytics for Environmental Security* (pp. 265–286). Dordrecht, The Netherlands: Springer.

Edsall, R. M., Kraak, M.-J., MacEachren, A. M., & Peuquet, D. J. (1997). Assessing the effectiveness of temporal legends in environmental visualization. In *Proceedings of the GIS/LIS Conference and Exposition,* 28–30 October 1997 (pp. 663–671). Cincinnati, Ohio, USA.

Edsall, R. M., & Peuquet, D. J. (1997). A graphical user interface for the integration of time into GIS. In *Proceedings of the American Congress of Surveying and Mapping Annual Convention and Exhibition,* 1 April 1997 (pp. 182–189). Seattle, WA, USA.

Edsall, R. M, & Sidney, L. R. (2005). Applications of a cognitively informed framework for the design of interactive spatiotemporal representations. In J. Dykes, A. M. MacEachren, & M.-J. Kraak (Eds.), *Exploring Geovisualization* (pp. 577–589). Oxford, UK: Elsevier.

Frank, A. U. (1998). Different types of times in GIS. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems* (pp. 40–62). New York, NY, USA: Oxford University Press.

Goralwalla, I. A., Özsu, M. T., & Szafron, D. (1998). An object-oriented framework for temporal data models. In O. Etzion, S. Jajodia, & S. Sripada (Eds.), *Temporal Databases—Research and Practice* (pp. 1–35). Berlin, Germany: Springer.

Hajnicz, E. (1996). *Time Structures: Formal Description and Algorithmic Representation.* Berlin, Germany: Springer.

Harrower, M., & Sheesley, B. (2005). Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS*, 9(2), 77–89.

Hoeber, O., Wilson, G., Harding, S., Enguehard, R., & Devillers, R. (2011). Exploring geo-temporal differences using GTdiff. In G. Di Battista, J.-D. Fekete, and H. Qu (Eds.), *Proceedings of the IEEE Pacific Visualization Symposium,* 1–4 March 2011 (pp. 139–146). Hong Kong, China: IEEE.

Hornsby, K. (2001). Temporal zooming. *Transactions in GIS*, 5(3), 255–272.

Hornsby, K., & Egenhofer, M. J. (1999). Shifts in detail through temporal zooming. In A. Cammelli, A. M. Tjoa, & R. R. Wagner (Eds.), *Proceedings of the Tenth International Workshop on Database and Expert Systems Applications,* 1–3 September 1999 (pp. 487–491). Florence, Italy: IEEE Computer Society.

Hornsby, K., Egenhofer, M. J., & Hayes, P. (1999). Modeling cyclic change. In P. P. Chen, D. W. Embley, J. Kouloumdjian, S. W. Liddle, & J. F. Roddick (Eds.), *Advances in Conceptual Modeling* (pp. 98-109). Berlin, Germany: Springer.

Jern, M., & Franzen, J. (2006). "GeoAnalytics" – Exploring spatio-temporal and multivariate data. In E. Banissi, R. A. Burkhard, A. Ursyn, J. J. Zhang, M. Bannatyne, C. Maple, A. J. Cowell, G. Y. Tan, & M. Hou (Eds.), Proccedings of the *Tenth International Conference on Information Visualisation,* 5–7 July 2006 (pp. 25–31). London, UK: IEEE Computer Society.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., & Melonçon, G. (2008). Visual analytics: Definition, process, and challenges. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization–Human Centered Issues in Visual Representation, Interaction, and Evaluation* (pp. 154–175). Berlin, Germany: Springer.

Kemp, Z., & Kowalczyk, A. (1994). Incorporating the temporal dimension in a GIS. In M. F. Worboys (Ed.), *Innovations in GIS* (pp. 89–103). London, UK: Taylor & Francis.

Krueger, M. W., Gionfriddo, T., & Hinrichsen, K. (1985). VIDEOPLACE - An artificial reality. In L. Borman & B. Curtis (Eds.), *Proceedings of the Conference on Human Factors in Computing Systems,* 14–18 April 1985 (pp. 35–40). San Francisco, CA, USA: ACM Press.

Langran, G. (1989). A review of temporal database research and its use in GIS applications. *International Journal of Geographical Information Systems*, 3(3), 215–232.

Langran, G., & Chrisman, N. R. (1988). A framework for temporal geographic information. *Cartographica*, 25(3), 1–14.

Lee, H., & Kemp, Z. (1998). Supporting complex spatiotemporal analysis in GIS. In S. Carver (Ed.), *Innovations in GIS 5* (pp. 151–161). London, UK: Taylor & Francis.

Li, X., & Kraak, M.-J. (2008). The Time Wave. A new method of visual exploration of geo-data in time–space. *The Cartographic Journal*, 45(3), 193–200.

Li, X., & Kraak, M.-J. (2012). Explore multivariable spatio-temporal data with the Time Wave: Case study on meteorological data. In A. G. O. Yeh, W. Shi, Y. Leung, & C. Zhou (Eds.), *Advances in Spatial Data Handling and GIS* (pp. 79–92). Berlin, Germany: Springer.

Lundblad, P., Eurenius, O., & Heldring, T. (2009). Interactive visualization of weather and ship data. In E. Banissi, L. Stuart, T. G. Wyeld, M. Jern, G. Andrienko, N. Memon, R. Alhajj, R. A. Burkhard, G. Grinstein, D. Groth, A. Ursyn, J. Johansson, C. Forsell, U. Cvek, M. Trutschl, F. T. Marchese, C. Maple, A. J. Cowell, & A. Vande Moere (Eds.) *Proceedings of the 13th International Conference on Information Visualisation,* 15–17 July 2009 (pp. 379–386). Columbus, OH: IEEE Computer Society.

MacEachren, A. M., Robinson, A. C., Jaiswal, A., Pezanowski, S., Savelyev, A., Blanford, J., & Mitra, P. (2011). Geo-Twitter analytics: Applications in crisis management. In A. Ruas (Ed.) *Proceedings of the International Cartographic Conference*, 3–8 July 2011. Paris, France.

Mennis, J. L., Peuquet, D. J., & Qian, L. (2000). A conceptual framework for incorporating cognitive principles into geographical database representation. *International Journal of Geographical Information Science*, 14(6), 501–520.

Neumann, A. (2005). Navigation in space, time and topic. In P*roceedings of the International Cartographic Conference,* 9–16 July 2005 (CDROM). A Coruña, Spain.

Neumann, A. (2010). *Spatial, temporal and thematic navigation: Visualizing biographies of European artists using a task oriented user interface design approach.* (Doctoral dissertation). Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland.

Ott, T., & Swiaczny, F. (2001). *Time-Integrative Geographic Information Systems: Management and analysis of spatio-temporal data.* Berlin, Germany: Springer.

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

Peuquet, D. J. (2002). *Representations of Space and Time*. New York, NY, USA: The Guilford Press.

Schreiber, F. A. (1994). Is time a real time? An overview of time ontology in informatics. In W. A. Halang & A. D. Stoyenko (Eds.), *Real Time Computing , Vol F 127* (pp. 283–307). Berlin, Germany: Springer.

Sinton, D. (1978). The inherent structure of information as a constraint to analysis: Mapped thematic data as a case study. *Harvard Papers on Geographic Information Systems*, 7, 1–17.

Snodgrass, R.T. (1986). Temporal databases. *IEEE Computer*, 19(9), 35–41.

Thomas, J. J., & Cook, K. A. (Eds.). (2005). *Illuminating the Path: The Research and Development Agenda for Visual Analytics*. IEEE CS Press.

# Chapter 3: Navigating Spatio-Temporal Data with Temporal Zoom and Pan in a Multi-Touch Environment

## 3.1 Introduction

Most data used to study geographic phenomena are complex and multi-dimensional, consisting of spatial, thematic, and temporal dimensions (Sinton, 1978). The ability to manipulate the data along these dimensions using geospatial technologies allows users to answer questions about 'what' happened, 'where' it happened, and 'when' it happened (Peuquet, 2002). Exploring data and seeking answers for complex research questions requires approaches that allow users to easily navigate among the dimensions of the data.

Tools for navigating the spatial dimension have been available since early GIS systems, allowing users to zoom (in or out) and pan through data that cover an area too large to be effectively displayed at one time (Harrower & Sheesley, 2005). 'Zooming' changes the scale of the map, allowing users to see a larger or smaller spatial extent on the screen, while 'panning' moves the map in the display window while maintaining the same spatial scale.

Navigation along the thematic dimension can be accomplished by adding and subtracting layers for different attributes, or by using queries and filters. Such queries can be specified through several approaches. For example, Structured Query Language (SQL) can be used to define criteria for choosing points from a dataset, or a hierarchical menu can be used to make selections from a collection of pre-defined settings (Neumann, 2010).

The temporal dimension has been recognized as being important for answering complex questions and supporting decision-making processes (Peuquet & Duan, 1995; Andrienko et al., 2007). Pioneering work from Hägerstrand (1970) proposed using time-space prism visualizations to represent the movement of people over time, an approach that has been often used and expanded upon in temporal GIS research. Work such as that by Hornsby and Egenhofer (2002), Kraak (2003), and Kwan and Lee (2003) have their roots in Hägerstrand's time geography and focus on the visualization of the temporal dimension of spatio-temporal data. While visualization of the temporal dimension is a dominant component in spatio-temporal research, being able to temporally navigate within spatio-temporal datasets is also important.

GIS technologies have typically handled temporal data by either having different layers for different time slices (e.g., layers for each year of data), or by including temporal data such as timestamps or dates of objects' existence (e.g., 'from' and 'to') in the database. To navigate the data temporally, users could then either display the layers they require, or treat time as an attribute and create queries to select data for specific temporal ranges. The use of simple time sliders in GIS and virtual globes provides users with an interactive representation of temporal data. However, these tools do not yet allow users to navigate temporal data with the same ease as that provided by tools used to navigate the spatial dimension. These limitations call for more advanced temporal navigation tools and techniques, a need that is likely to increase as temporal data become increasingly available.

Based on the existing concept of temporal zoom and pan, this paper proposes and tests two novel approaches for navigating the temporal dimension of geographic data within a multi-touch environment. Temporal zoom and pan can be defined in multiple ways. For the purposes of this research, temporal zoom is defined as narrowing or broadening of the temporal range of data being selected and temporal pan is defined as moving the data selection to a different time period while maintaining the same temporal extent. Since the extents of the data are being selected and adjusted when navigating data either spatially or temporally, the new approaches are based on the interaction paradigm for spatial zoom and pan. The underlying hypothesis in this work is that applying a familiar data navigation paradigm may simplify temporal navigation for users. These approaches also support temporal manipulations over multiple granularities. Both approaches were implemented in software prototypes on a multi-touch tablet computer, and have been tested together with two other temporal data exploration methods using a formal user evaluation. Results from this evaluation are discussed to highlight the benefits of the approaches and to illustrate where further development needs to be done.

The remainder of this paper is organized as follows. Section 3.2 presents a review of spatio-temporal data and navigation tools in GIS, in addition to providing an overview of multi-touch navigation tools. Section 3.3 describes the design of the two novel temporal navigation approaches proposed in this research. Section 3.4 presents the methodology of the user evaluation and Section 3.5 presents the results of the evaluation. Section 3.6 discusses the positive and negative elements of each interface tested. Section 3.7 concludes the paper by summarizing the key contributions and directions for future research.

## 3.2 Related work

### 3.2.1 Geovisualization and geovisual analytics

Geovisualization and geovisual analytics tools have expanded upon the capabilities of traditional GIS navigation interfaces. Geovisualization combines approaches from multiple disciplines such as information visualization, exploratory data analysis, and cartography 'to provide theory, methods, and tools for visual exploration, analysis, synthesis, and presentation of geospatial data' (MacEachren & Kraak 2001, p. 3). Geovisual analytics is the geographic extension of the field of visual analytics, which is defined as 'the science of analytical reasoning facilitated by interactive visual interfaces' (Thomas & Cook 2005, p. 4). It combines the automated processing capabilities of computers with the analytical and decision making abilities of humans (Andrienko et al., 2007; Keim et al., 2008; De Amicis et al., 2009).

In addition to having a spatial focus, geovisual analytics also has a strong temporal focus (Andrienko et al., 2010a; Andrienko et al., 2010b). Many geovisual analytics systems involve a temporal visualization and/or navigation component, frequently implemented as some form of time slider (e.g., Jern & Franzen, 2006; Lundblad et al., 2009; Enguehard et al., 2012). A slider is an interactive-manipulation control that is easy to learn and allows users to easily make basic temporal selections (Andrienko & Andrienko, 2006). It can be incorporated as part of a larger system as a way to expand the system's capabilities and allow users to integrate time in their analysis.

### 3.2.2 **Temporal queries and navigation in GIS**

Since early GIS, scholars have focused on developing temporal data models and conceptual frameworks to allow storing, organizing, representing, and querying spatio-temporal data (Langran & Chrisman, 1988; Langran, 1989; Peuquet, 1994; Peuquet & Duan, 1995; Worboys 1994). For example, Peuquet's Triad framework (Peuquet, 1994) proposed that in order to effectively answer time-based queries, a time-based representation is needed and therefore time must be represented in addition to locations and objects. These data models and frameworks have provided new methods for visualizing and navigating the temporal dimension of geographic information. However, they have been rarely translated into tools used by mainstream commercial GIS software (e.g., ArcGIS, MapInfo).

Temporal navigation can be considered as a type of temporal data query. While queries can be performed using formal query languages such as SQL, interactive visual tools can be easier to use as they do not involve learning a query language (Andrienko & Andrienko, 2006). A visual navigation tool can also act as a temporal legend by showing where the selected data are located within the overall dataset (Edsall et al., 1997). For example, Enguehard et al. (2012) incorporated a timeline containing spaces where data were missing to allow analysts to easily identify gaps in their datasets.

The TEMPEST interface, based on Peuquet's Triad framework (Peuquet, 1994), is an example of a visual temporal query tool (Edsall & Peuquet, 1997). It provides a time line, which allows users to select a point in time or a range of time, or a time wheel, which enables the selection of cyclic data (e.g., the same two month selection every year over a period of 10 years). Brewer et al. (2000) expand this idea by making all of the tools accessible in a single view so that switching tabs to access different views is not necessary. This is done by nesting the time wheels and placing a slider at the bottom of the view. Although these methods work well for selecting portions of cyclic time, they do not allow operations such as making a detailed query over multiple levels of granularity. For example, a user can easily select 'January to February 2010' but not 'January 16$^{th}$ to February 20$^{th}$ 2010'.

In Neumann's (2010) work on navigating and visualizing biographies of European artists, linear timelines were used. Several methods were tested for zooming (i.e., zoom buttons, zoom rectangle, and zoom wheel), panning (i.e., pan buttons, pan hand, pan with middle mouse button pressed), and combined zooming and panning (i.e., time scrollbar) along the timelines. The time scrollbar, which zooms in or out by manually adjusting the start and end points on the slider and pans by pulling the entire selection along the slider, was preferred by users. These results illustrate that the interactive features provided by the tool are as important as the type of navigation tool itself (e.g., slider vs. wheel).

### 3.2.3 **Spatial and temporal navigation in multi-touch environments**

The spatio-temporal navigation tools discussed so far have been designed in Windows Icons Menus Pointers (WIMP) environments, and are used with a mouse (or other pointer) or text-based commands (Schöning et al., 2009). The recent popularization of alternative interfaces, such as multi-touch technologies (Schöning et al., 2008), has not only opened new opportunities for user interaction, but also calls for new methods for navigating geographic data. Multi-touch tablet GIS applications are being developed for several fields such as geology (Malinconico et al., 2011) and archaeology (Smith & Levy, 2012), and practitioners in other fields such as urban planning (Vishkaie & Levy, 2012) have identified multi-touch applications as potentially useful. Users in such fields may need to navigate their spatio-temporal data temporally. For example, an urban planner may wish to show participants in a community consultation the developments that have occurred during different periods of time.

Multi-touch interfaces allow users to interact directly with the screen through touch actions using multiple points of simultaneous contact (Han, 2005). Such direct interaction can be more intuitive than other methods as it eliminates the need for an intermediate device between the user and the object they are trying to interact with and can mimic real world interaction that the user is already familiar with (Ingram et al., 2012). As a consequence, these types of interfaces have the potential to enable intuitive and non-traditional interactions for navigating data (Butkiewicz et al., 2009).

Standard spatial zooming in multi-touch systems is typically done using a pinch gesture, originating from the work of Krueger et al. (1985). Panning is done by placing a single finger on the screen and moving it in the direction the user wants the map to move. While multi-touch systems are in the early stages of adopting temporal navigation methods and tools for geospatial applications, many of the existing tools designed for WIMP interfaces are available but do not specifically take advantage of the multi-touch capability.

## 3.3 Novel approaches for temporal navigation

### 3.3.1 Temporal zoom and pan

Temporal zoom and pan is an approach for enabling users to easily navigate within their temporal data to find the data located within the timeframe they require and thereby assist them in their data analysis activities. It follows on Peuquet's Triad Framework (Peuquet, 1994), where a temporal-based view is needed for answering temporal-based questions. Temporal zoom changes the temporal range of the data that are displayed onscreen, essentially acting as a filter on the data. The user can either 'zoom in' to select a narrower temporal range or 'zoom out' to select a wider range. This allows users to quickly and easily expand or contract their temporal selections and prevents users from having to reconceptualise their entire selection each time a change is required.

Temporal pan allows the user to change their temporal selection while maintaining the same temporal extent. This can be especially useful when a temporal range is selected, but then must be modified. The range can easily be moved through time without the user having to re-specify the entire selection. The user can interactively control the selection move instead of having to mentally recalculate the dates.

Temporal data can often be described at multiple temporal granularities (e.g., months, days, hours); users need to be able to navigate such data at a granularity that is appropriate for their data analysis needs (Bertino et al., 2010). In the following approaches, temporal zoom and pan may be conducted with a tool representing a single temporal granularity or dynamically with a tool representing multiple granularities (Table 3.1). For example, the user may just need to use one slider that represents a single level of granularity such as months or they may need to use multiple sliders that represent different granularities such as one slider for months and one slider for days.

**Table 3.1.** Examples of temporal zoom and pan using a tool displaying a single granularity (i.e., months) and using a tool displaying multiple granularities (i.e., months and days).

| Action | Single Granularity | Multiple Granularities |
|---|---|---|
| Pan | January → April | January 15th → February 15th |
| Zoom In | January to March → February | January → January 15th |
| Zoom Out | February → January to March | January 15th → January |

Temporal data can be visualized as time points or as time intervals (Aigner et al., 2008) and users may require different options depending on the analysis they would like to conduct. Zooming and panning can occur using both point and interval selections. Users may wish to zoom from a range of data to a narrower or wider data range, or from a point to a range (or vice versa). Users may also wish to pan using a point selection or with a range of data.

Temporal zoom and pan may be considered forms of querying or data filtering, allowing for the display of the data for the desired temporal extent and eliminating extraneous data from the field of view. This allows users to eliminate visual clutter and focus on the data that are important for their analysis (Andrienko & Andrienko, 2006). Such an approach follows Shneiderman's (1996) Visual Information Seeking Mantra design guideline: 'overview first, zoom and filter, then details on demand'.

### 3.3.2 Proposed approaches for implementing temporal zoom and pan

Both of the proposed approaches to temporal zoom and pan, Multiple Linked Time Sliders and Dynamic Radial Navigation, have been designed as visual temporal navigation tools. Since the inability to support precise temporal selections has been a critique of this type of navigation approach in the past (Andrienko & Andrienko, 2006), the use of temporal zoom and pan within these approaches is intended to address this shortcoming and allow precise date and time selections.

Both approaches have been designed for, and implemented in, a multi-touch environment on a tablet computer. Many tablet computers offer a larger screen size than smartphones and include global positioning system (GPS), gyroscopes, and the capability to connect to the Internet, allowing users to access their data in the field and relate them spatially. For example, a fisheries officer in a port may want to access data on ship movements for the days before inspecting it. Since tablet computers are often characterised by smaller screen sizes compared to desktop computers, the screen size limitation has been a guiding issue during the design of both approaches.

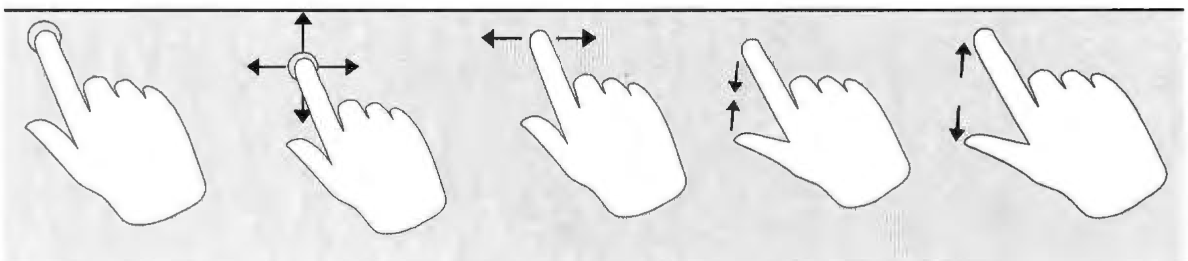
The interfaces for each approach are located at the bottom of the screen and are intended to occupy a minimal amount of screen space to provide maximum space for the map view where data will be displayed. By minimizing the amount of screen space that the zoom and pan interfaces occupy, the Information-to-Interface ratio is increased (Harrower & Sheesley, 2005). By doing so, there is a risk of making the interfaces too compact, since the touch-points have to be large enough so that users can easily select them with their fingers.

#### 3.3.2.1 Multiple Linked Time Sliders

Multiple Linked Time Sliders is a linear temporal navigation approach that consists of a series of user-controlled time sliders (Figure 3.1). This approach is based on traditional time sliders frequently used in geospatial technologies (e.g., Google Earth, ArcGIS) but was expanded to provide users with the ability to easily make a more detailed selection than most time sliders allow. Sliders are available for each level of temporal granularity within the dataset; finer granularity sliders are accessed by using a drag up gesture (Table 3.2) from the parent slider. Since all of the data cannot always be displayed on the finer grained sliders at once, they are designed to automatically scroll through the remaining data when the users approach the end of the slider with their finger. Users only need to bring up as many sliders as is required for their specific selection, resulting in an efficient use of display space and maximizing the area available for viewing the selected data.

**Table 3.2.** A guide to multi-touch gestures used in the prototypes.

| Click | Drag | Swipe | Pinch | Reverse Pinch |
|---|---|---|---|---|



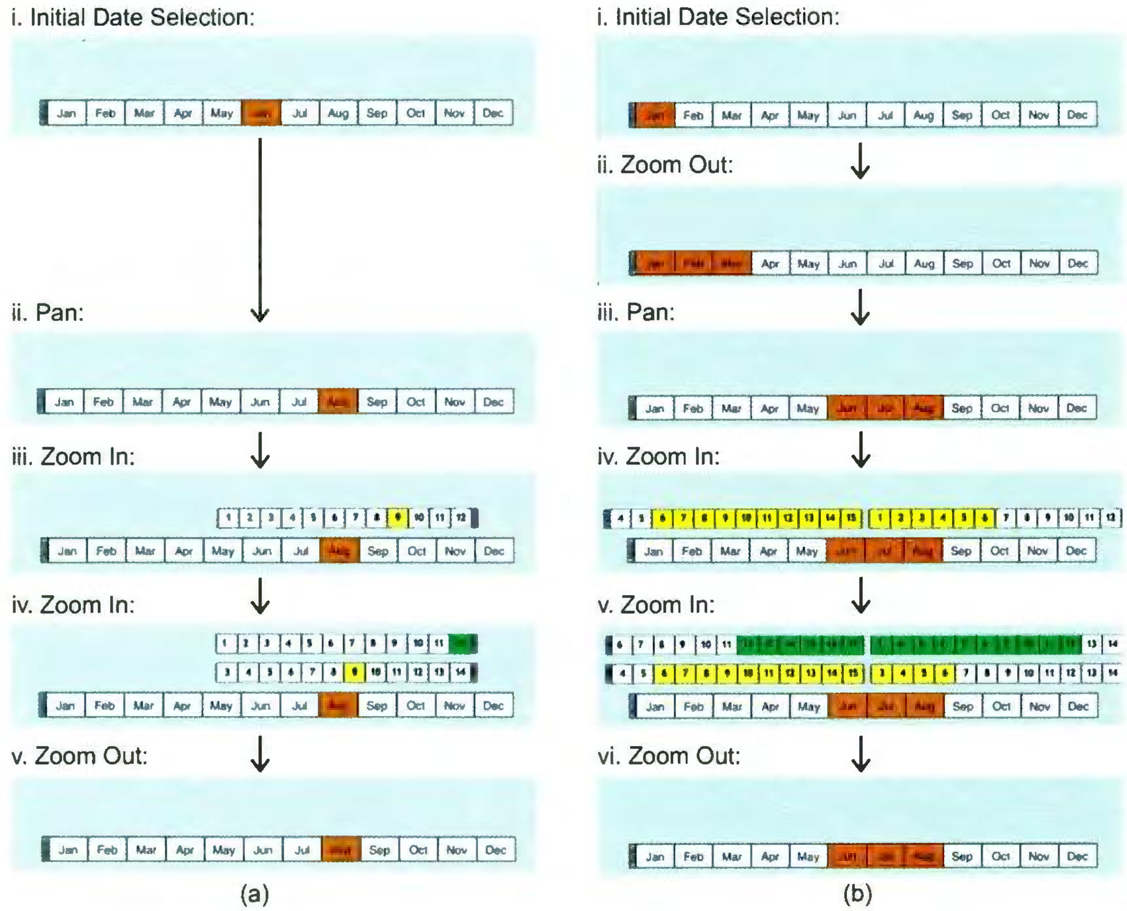



**Figure 3.1.** Zooming and panning with Multiple Linked Time Sliders using a single date/time selection (a) and a range date/time selection (b). The bottom (initial) slider is displaying months, the middle slider(s) is(are) displaying days, and the top slider(s) is(are) displaying hours.

A single point of time on the initial slider can be selected with a tap, after which a finer level of temporal granularity can be readily accessed by performing a drag up gesture on the point (Figure 3.1a). The data selected on the initial slider are then displayed on the new slider at a finer level of resolution. The users can then tap on the date/time they wish to select. If they wish to access an even finer level of temporal granularity, they can pull up additional sliders (to the limit of the temporal granularity of the dataset).

A range of time on the initial slider can be selected with a reverse pinch gesture. In order to access finer levels of temporal granularity, drag up gestures can be performed on the range, resulting in two side by side sliders showing finer levels of resolution (Figure 3.1b). One slider displays the data from the starting point of the main selection (e.g., all of the days in June if the previous selection is June to August) and the second displays the data from the end point (e.g., all of the days from August). The users can then select their desired selection start point from the first slider and selection end point from the second slider. Additional sliders can be pulled up if the users wish to further refine their selection. By allowing the use of simple gestures to interactively 'move' their selections, we are intending to provide users with a quick way of altering their selections and navigating through their data.

The pinch and reverse pinch gestures are used for zooming out and in (narrowing or expanding the selection) along each slider, while panning is achieved by using a drag gesture along the slider. Note that even though panning might be done at a coarse level of granularity, the selections made at finer levels of granularity are preserved. This is similar to the method that Neumann (2010) found was preferred for temporal zooming and panning but applied to a multi-touch interface.

To further enhance the awareness of the different levels of temporal granularity on the different sliders, the selected data point/data range is highlighted in a different colour on each granularity of slider. In the current examples, orange is used for the months, yellow is used for the days, and green is used for the hours. Additional perceptually-distinct colours can be used for datasets with more levels of granularity.

#### 3.3.2.2 Dynamic Radial Navigation

Dynamic Radial Navigation is a temporal navigation approach that consists of a time slider for the coarsest temporal granularity and radial selectors for finer levels of granularity (Figures 3.2 and 3.3). The slider works the same as the initial slider in the previously described approach, allowing a single selection with a tap gesture, a range selection with a reverse pinch gesture, and panning with a dragging gesture. What is different is the way in which the finer levels of temporal granularity are represented.

After tapping to select a single point of time on the initial slider, a single radial selector can be accessed by performing the drag up gesture on the selection. The radial selector displays the data from the initial selection at a finer resolution (Figure 3.2a). Only a subset of the data is displayed on the selector at once, the selector can be rotated to access the rest of the dataset. A date/time on the radial selector can be selected with a tap. If finer levels of temporal granularity are required, and are available within the dataset, additional nested selectors can be accessed with the drag up gesture.

To access finer temporal resolutions with a range of time, the drag up gesture is performed on the initial range selection on the slider. Two radial selectors are accessed, one over the beginning of the initial selection and one over the end (Figure 3.2b). Tapping is used to select a starting time/date from the first selector and an end time/date from the second selector. To further refine their selection, the drag up gesture can be used to access additional nested selectors.

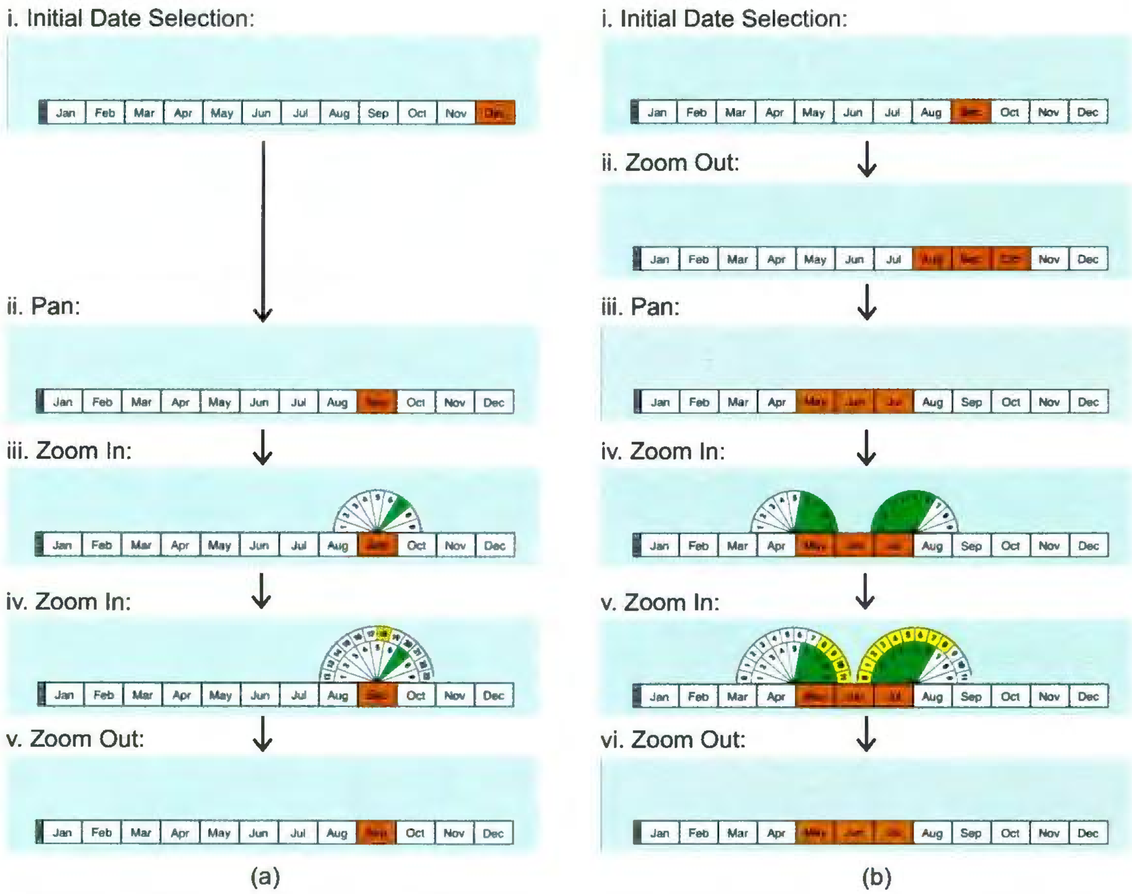
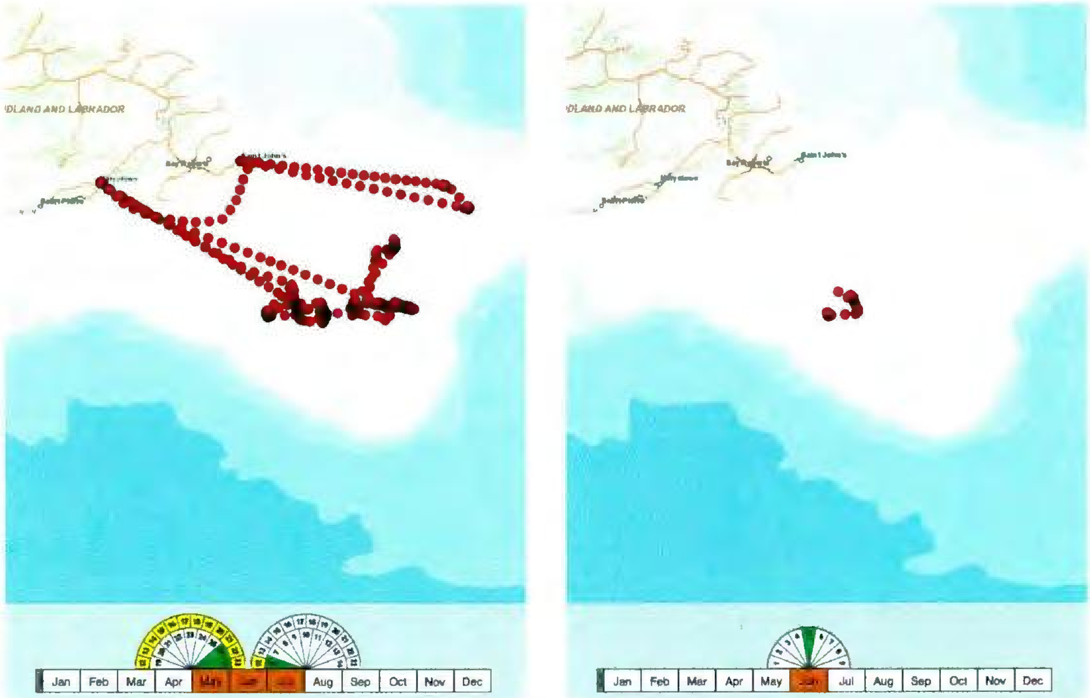



**Figure 3.2.** Zooming and panning with Dynamic Radial Navigation using a single date/time selection (a) and a range date/time selection (b). The slider is displaying months, the initial selector(s) is(are) displaying days, and the outer selector(s) is(are) displaying hours.




(a) (b)

**Figure 3.3.** (a) A full screen view of Dynamic Radial Navigation with the data from May 26$^{th}$ at 12:00 pm to July 12$^{th}$ at 12:00 pm selected. (b) A full screen view of Dynamic Radial Navigation zoomed in to select June 5$^{th}$.

The semi-circular shape of the selectors was chosen because it is compact and helps to prevent occlusions of the data by the user's hand (Brandl et al. 2009). The use of a shape that is different from that of a traditional time slider also allows the users to spin the selectors and interact with them in a different way than they could interact with a time slider. As with the previously described approach, the selected data point/data range is highlighted on the slider using a different colour for each level of granularity in order to assist users in visualizing the granular features of the data selection that they have made.

## 3.4 User evaluation settings and methods

### 3.4.1 Prototype development

The two approaches described in Section 3 were implemented as software prototypes in order to study them via user evaluations. The software was developed for the Apple iPad multi-touch tablet computer using the Objective-C programming language and the ArcGIS SDK for iOS (Esri, 2012) for the mapping portion of the interfaces. The iPad selected for this study had a 9.7" screen and a pixel resolution of 1024 by 768 at 132 pixels per inch. However, the approach itself is generic and may be implemented on other tablet computers of a similar size. The prototypes were developed for the sole purpose of evaluating the proposed approaches and were not intended to operate as fully functioning, usable software. The data consisted of a set of co-ordinates and the time of collection. They were imported into a database from a .csv file and the database was accessed using SQL.

Two additional data selection methods based on more commonly used temporal selection approaches were also implemented for comparison. The first method, 'Date/Time Spinners', is based on picker wheels that are the most commonly used method for selecting time in mobile devices (e.g., smartphones and tablet computers), found for instance in many calendar and alarm clock applications. The 'Date/Time Spinners' consists of two picker wheel widgets that are made up of a series of wheels of temporal values. Users can spin the wheels using a swipe gesture and then tap to stop the wheels from spinning and select the desired value (Figure 3.4a). There are two picker wheels, each one allowing a selection of temporal information at different levels of temporal granularity (i.e., months, days, and hours). The first wheel is used to select a single time or the beginning of a temporal range and the second wheel is used to select the end of a temporal range.

The second method, 'Drop-Down List', is based on drop-down menus, and uses a series of drop-down menus, which are commonly used for selecting data in pointer-based devices, for selecting dates and date ranges (Figure 3.4b). There are two groups of drop-down menus, each of which contain a menu for each level of temporal resolution in the data. The first group allows the users to select a single date or the start of a date range and the second group allows the user to select the end date of range. The Date/Time Spinners and Drop-Down List were implemented using components from the iOS SDK, whereas the Linked Time Sliders and Dynamic Radial Navigation were custom-built due to the lack of availability of suitable SDK components.


(a) (b)

**Figure 3.4.** The Drop-Down List prototype (a) and the Date/Time Spinners prototype (b).

### 3.4.2 Method

A laboratory based user evaluation was used so that the researchers could maintain control of multiple design aspects of the study and create measurable and comparable tasks (Carpendale, 2008). The user evaluation employed a 4 x 4 (interface x task type) between-subjects design where each participant used each interface once and completed each task type once. A Graeco-Latin square method was used to vary which interface would be used for each task type, as well as to vary the order of task and interface exposure. Such an approach is important to reduce the influence of learning effects or fatigue (Tague-Sutcliffe, 1992). With a total of 40 participants, this resulted in 10 participants for each interface/task combination and the subsequent statistical analyses were performed with this group size in mind.

The time to task completion was measured to provide an indication of the efficiency of the prototypes. After completing the tasks, the participants' answers were marked to assess their accuracy, providing an indication of the effectiveness of the interfaces for each of the different task types. Perceived ease of use and perceived usefulness were measured using the Technology Acceptance Model (TAM) instrument (Davis, 1989), providing evidence of the overall usability of the prototypes. Each TAM questionnaire consisted of six questions addressing ease of use and six addressing usefulness. Participants' likes, dislikes, and general opinions were also gathered through open ended questions at the conclusion of the study to assess overall participant satisfaction.

### 3.4.3 **Task types and tasks**

Participants completed four different task types that varied in complexity. Multiple task types were used and compared to assess if there was a difference in user performance or preference between the interfaces depending on task complexity, as some interfaces may be more appropriate for specific types of tasks than others. Task types were defined by whether the participants had to select a single time/date or a range of times/dates and whether they had to perform the task at a single temporal granularity (e.g., year) or across multiple temporal granularities (e.g., year, month, day). The four task types were classified as:

- Single Time/Date Selection-Single Granularity (SS-SG)
- Single Time/Date Selection-Multiple Granularities (SS-MG)
- Range Time/Date Selection-Single Granularity (RS-SG)
- Range Time/Date Selection-Multiple Granularities (RS-MG)

Each task consisted of several components: initial date selection, pan, zoom in, and zoom out. The tasks required users to explore the data and answer questions about one year of Vessel Monitoring System (VMS) data for a vessel that was fishing off the south-east coast of the island of Newfoundland, Canada. These data were recorded every hour and each point contains the location of the vessel and the time and date the data point was collected. For example, the SS-SG task instructed participants to 'Pan through each month to see in which months the vessel stops in St. John's and write these months down in the space below'. The RS-SG task required users to pan and zoom through different months to see which ports the fishing vessel was using at different times of the year. The scenario for the SS-MG task involved participants zooming and panning to specific dates and times to confirm or reject what the vessel had reported it was doing at the time. The RS-MG task was based on the premise that an area was closed to fishing during a specific time period and required participants to see where the fishing vessel was located during and around that time period.

### 3.4.4 Procedure

At the beginning of the evaluation, a pre-study questionnaire was administered to assess the participants' experience with multi-touch devices and with online mapping programs, virtual globes, and GIS. After completing the pre-study questionnaire, the participants were introduced to each of the prototypes and shown how to temporally zoom and pan in each one.

The participants then completed the four tasks. Before completing each task, the participants were briefly trained to use the prototype specified for the task. They were verbally instructed on how to zoom and pan while using the prototype. This was done using the same dataset as was used for the evaluation, but focusing on a different temporal and geographic aspect of the data. While completing each task, participants recorded their answers, either by circling a multiple choice option or writing down single word responses, as required by the task. They were also timed. After each task, the participant completed an in-task questionnaire to measure the perceived ease of use and perceived usefulness of the prototype for each component of the task (i.e., initial data selection, zoom in, zoom out, and pan) using a five-point Likert scale. After completing all of the tasks, participants completed an open-ended post-study questionnaire that sought their general opinions and suggestions regarding each interface. The whole procedure took between 45 and 60 minutes per participant. After the participants completed the evaluation their answers were marked for accuracy.

### 3.4.5 **Participant demographics**

Forty participants were recruited from our university community. These participants were both undergraduate and graduate students from a variety of faculties across the campus. To ensure participants possessed the basic background skills to complete the tasks, they were screened to ensure they had used a multi-touch device and at least one of the following: an online mapping tool (e.g., Google Maps), a virtual globe (e.g., Google Earth), a mapping application, or a GIS. This also ensured that the participants were learning to use the specific prototypes, not the underlying technology or a basic map, and represented at least a base level knowledge that the target user population would have. The participants' experience levels were recorded and the participants were asked additional detailed questions such as whether they had performed similar analysis in a non-multi-touch environment in case there were wide variations in performance between participants. The pre-study questionnaire indicated that participants were generally frequent users of touch screens and geospatial technology (Figure 3.5). The majority of participants used touch screens on a daily basis and online maps, virtual globes, or mapping applications weekly. Participants were less experienced with GIS, although the majority had some exposure to it.

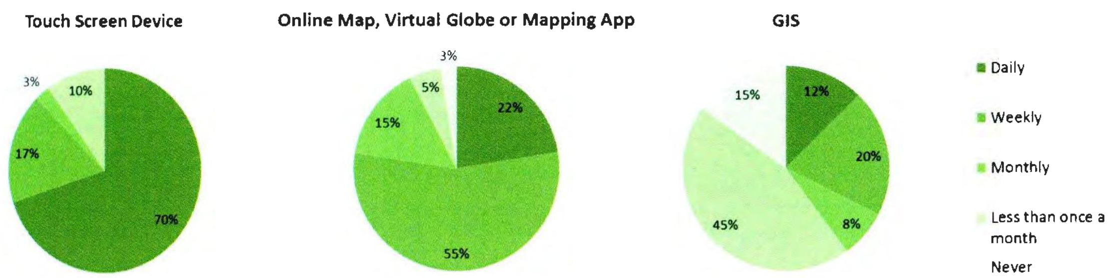



**Figure 3.5.** Participants' frequency of use of touch screen devices (left), online maps, virtual globes, and mapping applications (centre), and GIS (right).

## 3.5 Results

### 3.5.1 Efficiency

The average completion times for each task for each interface are illustrated in Figure 3.6. These data were statistically analyzed using analysis of variance (ANOVA). The RS-MG task was the only task with a statistically significant difference in completion times between the prototypes ($F$ (3,36) = 19.414, $p < .001$). Post hoc Tukey Honestly Significant Difference (HSD) comparisons showed that completion times with the Date/Time Spinners were significantly faster than completion times using Dynamic Radial Navigation ($p < .001$) and the Linked Time Sliders ($p = .006$) for this task type. Completion times using Dynamic Radial Navigation were significantly slower than completion times for all other prototypes (Linked Time Sliders, $p = .003$; Drop-Down List, $p < .001$).

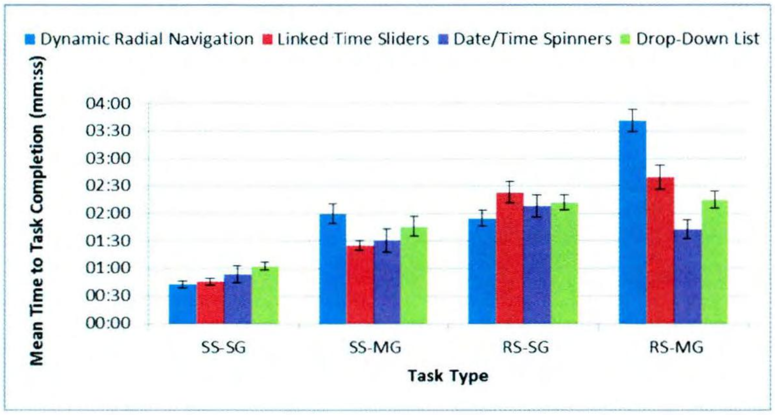



**Figure 3.6.** Mean time to task completion for each prototype for each task type: single date/time selection-single granularity (SS-SG), single date/time selection-multiple granularities (SS-MG), range date/time selection-single granularity (SS-SG), and range date/time selection-multiple granularities (SS-MG). Error bars represent the standard error from the mean.

### 3.5.2 **Effectiveness**

The mean task score was calculated for each prototype and each task (Figure 3.7), and ANOVA was used to test for significant differences. Effectiveness was not statistically analyzed for the RS-MG task type as every participant answered all of the questions correctly. No significant differences were found for any of the other task types (SS-SG, $F(3,36) = 1.320$, $P = .283$; SS-MG, $F(3,36) = .667$, $P = .578$, RS-SG, $F(3,36) = 1.714$, $P = .181$), indicating that all of the methods are equally effective at completing all of the tasks.

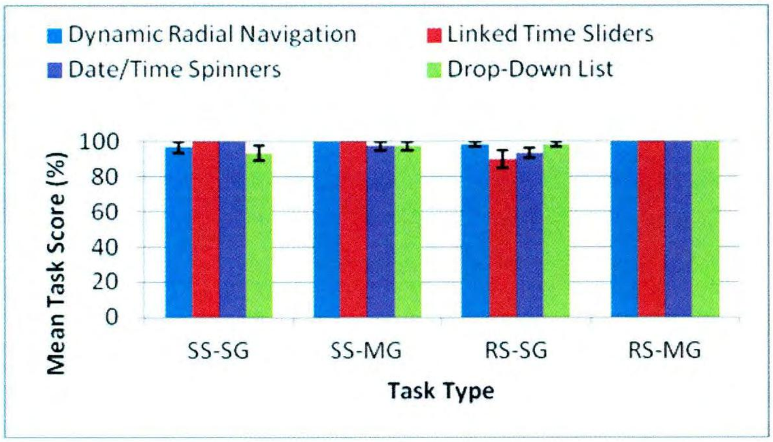



**Figure 3.7.** Mean task scores by prototype for each task type: single date/time selection-single granularity (SS-SG), single date/time selection-multiple granularities (SS-MG), range date/time selection-single granularity (SS-SG), and range date/time selection-multiple granularities (SS-MG). Error bars represent the standard error from the mean.

### 3.5.3 **Perceived ease of use and perceived usefulness**

For analysis, TAM questions for ease of use and usefulness were aggregated into their respective categories for each task component. The non-parametric Mann-Whitney U test was used to analyse the ordinal data. Tests were run pairwise for each component of each task to evaluate the perceptions of the participants of each prototype to all others.

#### 3.5.3.1 Single date/time selection-single granularity (SS-SG) task type

Overall, participants perceived all of the prototypes to be easy to use and useful for all components of the task (i.e., initial date/time selection and pan), as shown in Figure 3.8. This was the least complicated of the four tasks and did not require any zooming or changing granularities. However, some significant differences were identified in the perceived ease of use and the perceived usefulness between the prototypes for some of the SS-SG task components. The Drop-Down List was perceived as harder to use for panning (Dynamic Radial Navigation, $p < .001$ Date/Time Spinners, $p < .001$) as well as less useful for making an initial date/time selection (Dynamic Radial Navigation, $p = .018$; Linked Time Sliders, $p < .001$; Date/Time Spinners, $p < .001$) and panning (Dynamic Radial Navigation, $p < .001$; Linked Time Sliders, $p = .001$; Date/Time Spinners, $p < .001$).

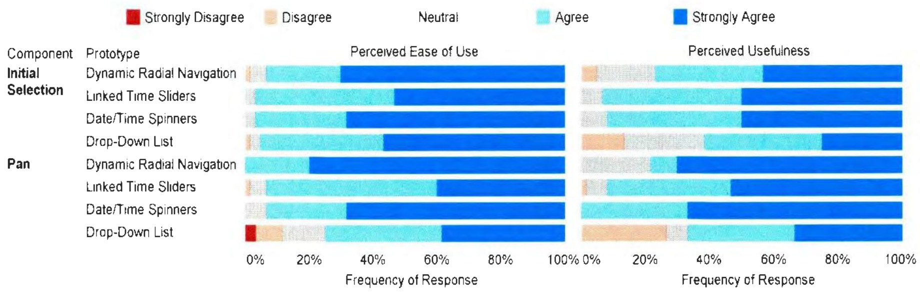



**Figure 3.8.** Perceived ease of use (left) and perceived usefulness (right) for the SS-SG task by prototype and task component.

### 3.5.3.2 Single date/time selection-multiple granularities (SS-MG) task type

There was a larger variance in perceived ease of use and perceived usefulness of the prototypes for completing the components of the SS-MG task than for the simpler SS-SG task (Figure 3.9). This task was more complicated than the SS-SG task, as it required zoom operations to be performed by the participants and it required switching between multiple granularities. Overall, the mean responses are positive, but some of the responses for Dynamic Radial Navigation were neutral and negative.

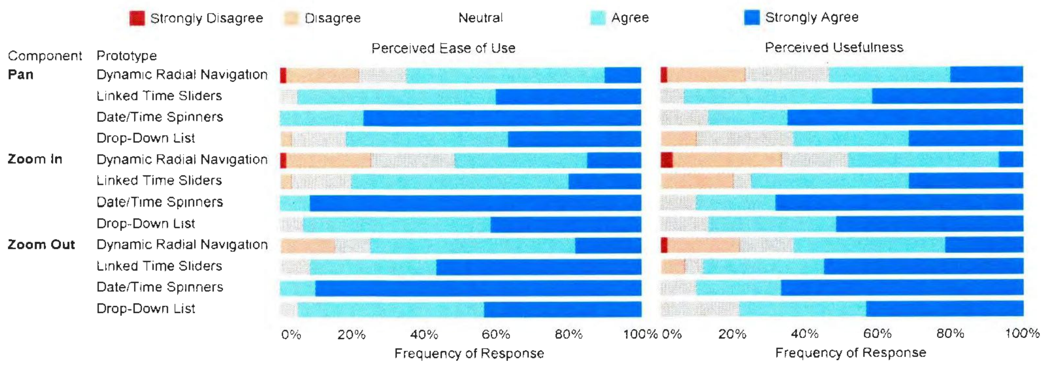



**Figure 3.9.** Perceived ease of use (left) and perceived usefulness (right) for the SS-MG task by prototype and task component.

The Date Time Spinners were rated significantly higher ($p < .05$) for perceived ease of use than all of the other prototypes for each component of the task, and Dynamic Radial Navigation was rated significantly lower ($p < .05$). For perceived usefulness, the Date/Time Spinners were rated significantly higher ($p < .05$) than all other prototypes for zooming in, and Dynamic Radial Navigation and Linked Time Sliders for zooming out.

### 3.5.3.3 Range date/time selection-single granularity (RS-SG) task type

For the RS-SG task, all of the prototypes were perceived to be easy to use and useful for all components of the task (Figure 3.10). This task was more complicated than the SS-SG task, as it required zoom operations to be performed by the participants. The results showed that the Date Time Spinners and the Drop-Down List were rated significantly higher ($p < .05$) than Dynamic Radial Navigation and Linked Time Sliders in perceived ease of use and perceived usefulness for zooming in, and perceived ease of use for panning and zooming out. There were no differences in perceived ease of use for panning, and the Date/Time Spinners were rated significantly higher ($p < .05$) than the

Linked Time Sliders and Dynamic Radial Navigation in perceived usefulness for zooming out.

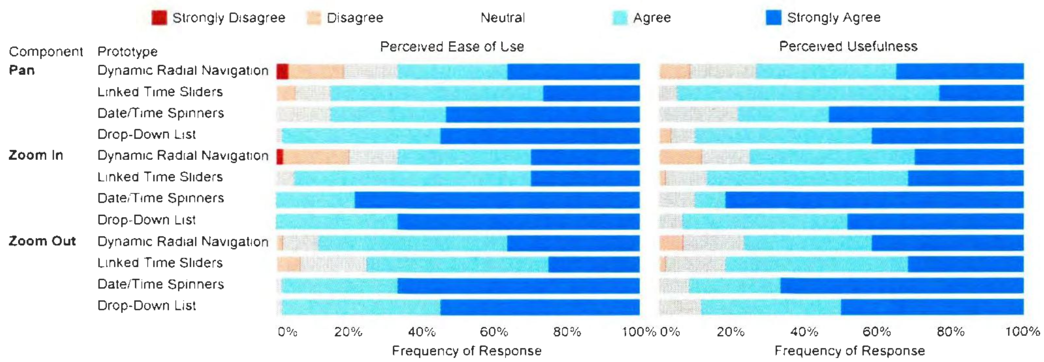



**Figure 3.10.** Perceived ease of use (left) and perceived usefulness (right) for the RS-SG task by prototype and task component.

### 3.5.3.4 Range date/time selection-multiple granularities (RS-MG) task type

For the RS-MG task, there was much more negative sentiment from the participants regarding the perceived ease of use and usefulness for most components of the task, especially for the Linked Time Sliders (Figure 3.11). This task type required the most use of the finer granularity time sliders and the radial selectors. The Date/Time Spinners and Drop-Down List were rated significantly higher ($p < .05$) than Dynamic Radial Navigation and Linked Time Sliders in perceived ease of use in each task component. The Linked Time Sliders were rated significantly lower ($p < .05$) than all other prototypes in perceived usefulness in each task component. Dynamic Radial Navigation was rated significantly lower ($p < .05$) in perceived usefulness than the Date/Time Spinners in each task component and significantly lower ($p < .05$) than the Drop-Down List for zooming in.

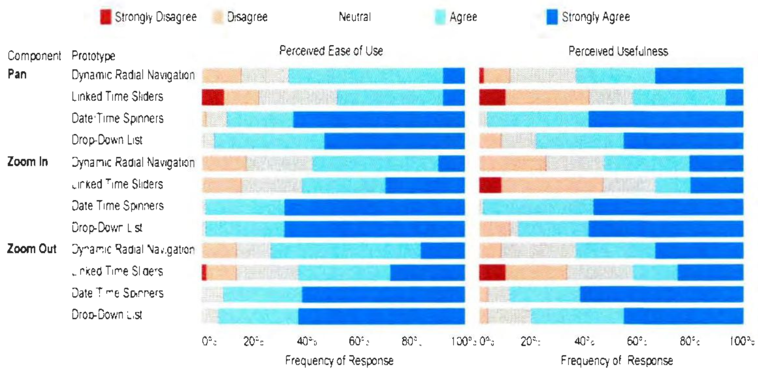



**Figure 3.11.** Perceived ease of use (left) and perceived usefulness (right) for the RS-MG task by prototype and task component.

### 3.5.4 Participant satisfaction

The post-study questionnaire asked participants open-ended questions regarding what they liked and disliked about each prototype as well as providing a space for general comments. A number of common themes were identified in the participants' responses. The participants found Multiple Linked Time Sliders visually appealing and liked the use of different colours for identifying selections at different granularities, but disliked the way the finer granularity sliders would scroll automatically and found the touch points on the sliders to be too small. Participants found Dynamic Radial Navigation visually appealing, liked how they could visualize all of the data at once and how the colours helped identify the temporal granularities of the data that were selected. Participants disliked the small size of the touch points and the difficulty in spinning the radial selectors. For the Date/Time Spinners, participants liked that it was familiar and easy to use, while they disliked how much screen space the prototype took up and found it was difficult to conceptualize selections when both components were needed. Participants also found the Drop-Down List familiar and easy to use but disliked the amount of time it took to scroll through the data and found it did not use the touch screen capabilities effectively.

## 3.6 Discussion

While all prototypes enabled the participants to complete all of the assigned tasks accurately, there were differences in the efficiency, perceived ease of use, and perceived usefulness between the prototypes. The differences varied by task and sub-task component. Participant comments and observations made during the study provide indicators regarding the source of these differences and what might be done to improve the approaches.

Although the participants' efficiency did not vary significantly for three of the tasks, the RS-MG task showed a significant difference in completion times between prototypes. Completion times with Dynamic Radial Navigation were significantly slower, and with the Date/Time Spinners, significantly faster. Observations during the study and comments by participants in the post-study questionnaires indicated that many participants found it difficult to spin the radial selectors; the RS-MG task required the most spinning, which could explain why participants took so much more time. Some participants also experienced difficulty in scrolling through the finer resolutions using the Linked Time Sliders. The sliders were designed to scroll automatically when the user reached the edge of the slider. The participants appeared to want full control when moving the data along the sliders and found it difficult to get used to the automatic scrolling. This suggests that additional training and improvements to the implementation could reduce, or eliminate, the differences in completion times.

Although the prototypes were perceived, on average, as easy to use and useful for most task components, there were statistically significant differences in ratings between the prototypes and over the different tasks. For all but the simplest of tasks, the perceived ease of use and perceived usefulness was rated significantly higher for the Date/Time Spinners and lower for Dynamic Radial Navigation. Once again, this was reflected in the user comments and observations, as the Date/Time Spinners were often referred to as 'familiar' and 'easy to use' while users commented that they had difficulty spinning the radial selectors and some users appeared to be visibly frustrated.

As previously mentioned, time sliders are a common form of temporal navigation and different forms of the time slider are included in many applications. It is interesting to note that throughout this study, this popular approach was rated significantly lower than Date/Time Spinners. This may be due in part to the increased complexity added by having sliders for each level of temporal granularity, or the difficulty in making precise selections and adjustments within a multi-touch environment. The aforementioned concern with scrolling in the finer levels of granularity may have also been an issue.

Many of the participants had previously used similar interfaces to the Date/Time Spinners and the Drop-Down List, which likely influenced their ratings in the perceived ease of use and usefulness of the prototypes. Within user studies, the interfaces that participants have used the most may be preferred whether or not they are the best design or use of the technology (Harrower & Sheesley, 2005). The Date/Time Spinners were also referred to as 'smooth functioning' while many participants had issues with spinning and scrolling the components of Dynamic Radial Navigation and the Linked Time Sliders. The latter two prototypes were developed with custom components while the other prototypes were developed using existing components available in iOS. Clearly the existing drop-in components would have gone through extensive testing and refinement before release, while this was the first user evaluation for the components that were created for this project.

The visual appearance of the prototypes and the ability of the prototypes to allow one to visualize the selected data were common positive themes in the participants' comments. Participants indicated that they found Dynamic Radial Navigation visually appealing, that different colours for highlighting the selections at different temporal granularities helped them to easily see what data they had selected, and that it allowed them to see everything at once. Comments about the Linked Time Sliders also stated that it was easy to see what was selected and that different colours for different granularities were useful. Drop-Down List was criticized for not being able to view the data all at once although some participants liked its compact size. Some participants stated that Date/Time Spinners was not as visually appealing and that it took up too much screen space. Although Dynamic Radial Navigation and Linked Time Sliders received many comments about how their features assisted the participants in viewing their data selections, this did not seem to influence their opinions of the perceived usefulness of the prototypes in comparison to the more familiar alternatives. This indicates that perhaps with sufficient training, the participants' positive general views of the novel features may translate into positive impressions of ease of use and usefulness.

A common negative comment regarding Dynamic Radial Navigation and Linked Time Sliders was in regards to the size of the touch points for navigating through the finer granularities. The Date/Time Spinners and Drop-Down List received conflicting comments about their size. For the Date/Time Spinners, the participants liked the large touch points but disliked how much space it took up on the screen, and for the Drop-Down List participants liked how it was compact on the bottom of the screen but disliked how all of the data were not visible at once. The generally high perceived ease of use and perceived usability rankings for the Date/Time Spinners appear to indicate that a large interface is preferred to the touch points being considered too small. These comments emphasize the challenges of designing a compact, useful, and novel approach to temporal navigation that is also easy to control within a multi-touch interface.

### 3.7 Conclusion

Navigating the temporal dimension of spatio-temporal data is important for helping users explore their data and answer their research questions. The ability to discover 'when' an event took place or an object or person was in an area is part of answering complex questions and needs to be incorporated along with the ability to answer 'where' and 'what' (Peuquet, 2002). The temporal dimension is part of exploring questions from fields as diverse as health and epidemiology (AvRuskin et al., 2004; Castronovo et al., 2009; Richardson et al., 2013) to urban planning (Joo et al., 2010). Previous studies have developed methods for spatio-temporal navigation but not for temporal zoom and pan at multiple granularities within a multi-touch environment. This gives users greater control over the detail of their temporal data selections and explores the potential benefits of adopting a technology that is growing in popularity. This study has presented two novel and interactive methods for navigating through the temporal dimension of spatio-temporal data. These methods allow users to make and modify single or range date/time selections in a multi-touch environment.

These approaches were evaluated using a laboratory-based user study along with two additional ways of navigating time and date selections. Although two approaches were selected, additional approaches, such a calendar widgets, could have been also selected and could be considered for future evaluation. This evaluation found that overall, all of the approaches were perceived as useful and easy to use although Date/Time Spinners were often rated higher than other prototypes and Dynamic Radial Navigation was often rated lower. There was no difference in accuracy between any of the approaches. While there was no difference in time to task completion for three of the tasks, the Date/Time Spinners were faster to use and Dynamic Radial Navigation was slower to use than the rest of the approaches for the most complicated task. Specific issues that affect the usability and ease of use of the proposed approaches were identified. These included difficulty in spinning the radial selectors, confusion about scrolling the fine grained time sliders, and small touch points on the radial selectors and fine grained time sliders. Participant comments indicated that while they tended to find the Date/Time Spinners and Drop-Down List familiar and easy to use, they liked the appearance and visualization capabilities of the Dynamic Radial Navigation and Linked Time Sliders.

A key outcome in this study is in relation to the trade-offs between the sizes of the controls, their utility, and the novelty of the approach. Although the Date/Time Spinners showed all levels of temporal granularity in full at all times, wasting valuable space in the display, the sizes of the touch points and the familiarity with its operation lead to positive impressions. The new approaches that were designed to be compact, and provided dynamic access to the temporal granularity as necessary, were deemed to be less desirable because of the difficulty of interacting with the small touch points and the novelty of the interaction. While we remain confident in the value of supporting temporal zoom and pan in an interactive manner, further work is required to find an appropriate balance between providing the user control over the manipulation of the temporal aspect of the data and the usability constraints present within multi-touch tablet computers.

Possible further work could consist of modifying some of the features of Dynamic Radial Navigation and Linked Time Sliders that study participants reported as difficult to use. For dynamic radial navigation, this could involve reprogramming the radial dials and making them more responsive to users' gestures and easier to rotate, as well as increasing the touch point size of the radial dials without making the interface too large on the screen. For the Linked Time Sliders, the automatic scrolling of the finer granularity sliders could be eliminated and users could be allowed to drag the sliders themselves. The touch point size for the finer granularity sliders could be increased. To increase the size of the touch points on the radial dials or the fine grained sliders, the dial or slider that the user is working with could dynamically increase in size to make precise selections easier. While individual colours were used in both approaches to differentiate temporal granularities, there are other options available to do this, such as using a range of intensities of the same colour. Various colour and intensity combinations could be tested to see if one method is preferred over others. An additional user evaluation with experts using their own data could also be attempted to see how the approaches perform outside of a controlled laboratory setting and under conditions where extensive training is appropriate.

## 3.8 References


Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2008). Visual methods for analyzing time-oriented data. *IEEE Transactions on Visualization and Computer Graphics*, 14(1), 47–60.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839–857.

Andrienko, G., Andrienko, N., Demsar, U., Dransch, D., Dykes, J., Fabrikant, S. I., Jern, M., Kraak, M.-J., Schumann, H., & Tominski, C. (2010). Space, time and visual analytics. *International Journal of Geographical Information Science*, 24(10), 1577–1600.

Andrienko, G., Andrienko, N., Dykes, J., Kraak, M.-J., & Schumann, H. (2010). GeoVA(t) – Geospatial visual analytics: Focus on time. *International Journal of Geographical Information Science*, 24(10), 1453–1457.

Andrienko, N., & Andrienko, G. (2006). *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach.* Berlin, Germany: Springer.

AvRuskin, G. A., Jacquez, G. M., Meliker, J. R., Slotnick, M. J., Kaufmann, A. M., & Nriagu, J. O. (2004). Visualization and exploratory analysis of epidemiologic data using a novel space time information system. *International Journal of Health Geographics*, 3(1), 26.

Bertino, E., Camossi, E., & Bertolotto, M. (2010). Multi-granular spatio-temporal object models: concepts and research directions. In M. C. Norrie & M. Grossniklaus (Eds.), *Object Databases* (pp. 132–148). Berlin, Germany: Springer.

Brewer, I., MacEachren, A. M., Abdo, H., Gundrum, J., & Otto, G. (2000). Collaborative geographic visualization: Enabling shared understanding of environmental processes. In A. Rawlinson (Ed.), *Proceedings of the IEEE Symposium on Information Visualization,* 9–10 October 2000 (pp. 137–141). Salt Lake City, Utah, USA: IEEE Computer Society.

Brandl, P., Leitner, J., Seifried, T., Haller, M., Doray, B., & To, P. (2009). Occlusion-aware menu design for digital tabletops. In *Proceedings of CHI EA '09 Human Factors in Computing Systems,* 4–9 April 2009 (pp. 3223–3229). Boston, MA, USA: ACM Press.

Butkiewicz, T., Jeong, D. H., Wartell, Z., Ribarsky, W., & Chang, R. (2009). Hierarchical multi-touch selection techniques for collaborative geospatial analysis. In W. J. Tolone & W. Ribarsky (Eds.), *Proceedings of SPIE 7346 Visual Analytics for Homeland Defense and Security,* 14 May 2009 (p. 73460D). Orlando, FL, USA: International Society for Optics and Photonics.

Carpendale, S. (2008). Evaluating information visualizations. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization: Human Centered Issues and Perspectives* (19–45). Berlin, Germany: Springer.

Castronovo, D. A., Chui, K. K. H., & Naumova, E. N. (2009). Dynamic maps: A visual-analytic methodology for exploring spatio-temporal disease patterns. *Environmental Health*, 8:61. doi:10.1186/1476-069X-8-61

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *Management Information Systems*, 13(3), 319–340.

De Amicis, R., Conti, G., Piffer, S., & Simões, B. (2009). Geospatial visual analytics. In R. De Amicis, S. Radovan, & G. Conti (Eds.), *GeoSpatial Visual Analytics: Geographical Information Processing and Visual Analytics for Environmental Security,* (pp. 265–286). Dordrecht, The Netherlands: Springer.

Edsall, R. M., Kraak, M.-J., MacEachren, A. M., & Peuquet, D. J. (1997). Assessing the effectiveness of temporal legends in environmental visualization. *In Proceedings of* the *GIS/LIS Conference and Exposition,* 28–30 October 1997 (pp. 663–671). Cincinnati, OH, USA.

Edsall, R. M., & Peuquet, D. J. (1997). A graphical user interface for the integration of time into GIS. In *Proceedings of American Congress of Surveying and Mapping Annual Convention and Exhibition,* 1 April 1997 (pp. 182–189). Seattle, WA, USA.

Enguehard, R., Hoeber, O., & Devillers, R. (2012). Interactive exploration of movement data: A case study of geovisual analytics for fishing vessel analysis. *Information Visualization*, 12(1), 65–84.

Esri. (2012). ArcGIS Runtime SDK for iOS. Retrieved from http://resources.arcgis.com/content/arcgis-iphone/api, last accessed July 12, 2013.

Hägerstrand, T. (1970). What about people in regional science? *Papers of the Regional Science Association*, 24, 7–21.

Han, J. Y. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. In P. Baudisch & M. Czerwinski (Eds.), *Proceedings of the 18th Annual*

*ACM Symposium on User Interface Software and Technology,* 23–26 October 2005 (pp. 115–118). Seattle, WA, USA: ACM Press.

Harrower, M., & Sheesley, B. (2005). Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS*, 9(2), 77–89.

Hornsby, K. & Egenhofer, M. J. (2002). Modeling objects over multiple granularities. *Annals of Mathematics and Artificial Intelligence*, 36, 177–194.

Ingram, A., Wang, X., & Ribarsky, W. (2012). Towards the establishment of a framework for intuitive multi-touch interaction design. In International Working Conference on Advanced Visual Interfaces, 22–25 May 2012 (pp. 66–73). Capri Island, Italy: ACM Press.

Jern, M., & Franzen, J. (2006). "GeoAnalytics" – Exploring spatio-temporal and multivariate data. In E. Banissi, R. A. Burkhard, A. Ursyn, J. J. Zhang, M. Bannatyne, C. Maple, A. J. Cowell, G. Y. Tan, & M. Hou (Eds.), Proceedings of the *Tenth International Conference on Information Visualisation,* 5–7 July 2006 (pp. 25–31). London, UK: IEEE Computer Society.

Joo, Y., Jang, M., & Jun, C. (2010). Developing a time-series visualization technique using a temporal GIS database for urban growth simulation. *International Journal of Urban Sciences*, 14(1), 98–110.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., & Melonçon, G. (2008). Visual analytics: Definition, process, and challenges. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization–Human Centered Issues in Visual Representation, Interaction, and Evaluation* (pp. 154–175). Berlin, Germany: Springer.

Kraak, M.-J. (2003). The space-time cube revisited from a geovisualization perspective. In *International Cartographic Conference*, 10–16 August 2003 (pp. 10–16). Durban, South Africa.

Krueger, M. W., Gionfriddo, T., & Hinrichsen, K. (1985). VIDEOPLACE – An artificial reality. In L. Borman & B. Curtis (Eds.), *Proceedings of the Conference on Human Factors in Computing Systems,* 14–18 April 1985 (pp. 35–40). San Francisco, CA, USA: ACM Press.

Kwan, M.-P. & Lee, J. (2003). Geovisualization of human activity pattern using 3D GIS: A time-geographic approach. In M. F. Goodchild and D.G. Janelle (Eds.), *Spatially Integrated Social Science: Examples in Best Practice* (pp. 48–66). Oxford, UK: Oxford University Press.

Langran, G. (1989). A review of temporal database research and its use in GIS applications. *International Journal of Geographical Information Systems*, 3(3), 215–232.

Langran, G., & Chrisman, N. R. (1988). A framework for temporal geographic information. *Cartographica*, 25(3), 1–14.

Lundblad, P., Eurenius, O., & Heldring, T. (2009). Interactive visualization of weather and ship data. In E. Banissi, L. Stuart, T. G. Wyeld, M. Jern, G. Andrienko, N. Memon, R. Alhajj, R. A. Burkhard, G. Grinstein, D. Groth, A. Ursyn, J. Johansson, C. Forsell, U. Cvek, M. Trutschl, F. T. Marchese, C. Maple, A. J. Cowell, & A. Vande Moere (Eds.) *Proceedings of the 13th International Conference on Information Visualisation,* 15–17 July 2009 (pp. 379–386). Columbus, OH: IEEE Computer Society.

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

Malinconico, L.L., Sunderlin, D. Liew, C., Ho, A.S., & Bekele, K.A. (2011). An iPad and Android-based application for digitally recording geologic field data. In *American Geophysical Union Fall Meeting Abstracts*, 5–9 December 2011 (on-line database). San Francisco, CA.

Neumann, A. (2010). *Spatial, temporal and thematic navigation: Visualizing biographies of European artists using a task oriented user interface design approach.* (Doctoral dissertation). Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland.

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

Peuquet, D. J. (2002). *Representations of Space and Time*. New York, NY, USA: The Guilford Press.

Peuquet, D. J., & Duan, N. (1995). An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. *International Journal of Geographical Information Systems*, 9(1), 7–24.

Richardson, D. B., Volkow, N. D., Kwan, M.-P., Kaplan, R. M., Goodchild, M. F., & Croyle, R. T. (2013). Spatial turn in health research. *Science*, *339*(6126), 1390–1392.

Schöning, J., Brandl, P., Daiber, F., Echtler, F., Hilliges, O., Hook, J., Löchtefeld, M., Motamedi, N., Muller, L., Olivier, P., Roth. T., & von Zadow, U. (2008). *Multi-*

*touch Surfaces: A technical guide.* Technical Report TUM-I0833: Technical Reports of the Technical University of Munich.

Schöning, J., Daiber, F., Krüger, A., & Rohs, M. (2009). Using hands and feet to navigate and manipulate spatial data. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems,* 4–9 April 2009 (pp. 4663–4668). Boston, MA, USA: ACM Press.

Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations. In M. Burnett & W. Citrin (Eds.), *Proceedings of the IEEE Symposium on Visual Languages,* 3–6 September 1996 (pp. 336–343). Piscataway, NJ: IEEE Computer Society.

Sinton, D. (1978). The inherent structure of information as a constraint to analysis: Mapped thematic data as a case study. *Harvard Papers on Geographic Information Systems*, 7, 1–17.

Smith, N.G. & Levy, T.E. (2012). Real-time 3D archaeological field recording: ArchField, and open-source GIS system pioneered in southern Jordan. *Antiquity*, 86(331).

Tague-Sutcliffe, J. (1992). The pragmatics of information retrieval experimentation, revisited. *Information Processing & Management*, *28*(4), 467–490.

Thomas, J. J., & Cook, K. A. (Eds.). (2005). *Illuminating the Path: The Research and Development Agenda for Visual Analytics*. IEEE CS Press.

Vishkaie, R.S. & Levy, R. (2012). Perception and reality: Exploring urban planners' vision on GIS tasks for multi-touch displays. In *International Conference on Interactive Tabletops and Surfaces,* 11–14 November 2012 (pp. 265–270). Cambrige, MA: ACM Press.

Worboys, M. F. (1994). A unified model for spatial and temporal information. *The Computer Journal*, 37(1), 26–34.

# Chapter 4: Conclusions

## 4.1 Summary

Spatio-temporal data are an important component in answering modern research questions in a wide variety of fields. Users need to be able to effectively navigate the temporal dimension of their data to allow them to be able to fully utilize all components of their data when performing data exploration and analysis. Temporal navigation approaches implemented in commercial software are often very basic and do not permit a large range of types of queries. Most of the approaches proposed in the academic literature have been developed in WIMP interfaces and do not take advantage of currently available interaction technologies such as multi-touch devices.

This research aimed to support users in navigating the temporal dimension of their spatio-temporal data by designing, implementing in software prototypes, and testing with a user evaluation two novel approaches to temporal zoom and pan while taking advantage of multi-touch technologies. These approaches were designed to navigate both temporal primitives, points and intervals, and were structured for linear temporal data. They were intended to be compact on the screen while providing the users with access to a large range of temporal granularities to allow them to use the appropriate granularity for exploring their research questions. The approaches were also designed to allow the users to visually see the selections they have made and operate as a type of temporal legend (Edsall et al., 1997), as well as to enable the users to move quickly, accurately, and easily through their temporal data. The approaches were implemented in software prototypes and evaluated along with two traditional approaches in a user evaluation.

While all of the approaches enabled the user evaluation participants to temporally navigate through the given spatio-temporal dataset and accurately respond to the task questions, there were differences between user preferences for the different approaches. Participants frequently rated the Date/Time Spinners approach highest in perceived ease of use and perceived usefulness. Users also commented that this prototype was easy to use and familiar. The familiarity with this interface from its ubiquity on smartphones could have influenced participants opinions as people often prefer interfaces that they are already familiar with (Harrower & Sheesley, 2005). The proposed approaches were appreciated for their visualization capabilities, particularly how they allowed participants to see what they had selected within the dataset. Attempting to keep the approaches compact to leave maximum screen space for the data display resulted in touch points that were too small for some of the participants. Participants also found it difficult to operate some of the components at the finer resolutions. This indicates that the proposed approaches have benefits, but need to be further refined and balanced with the elements that make the existing approaches easy to use. Throughout the study the participants easily grasped the concept of zooming and panning as it was applied to the temporal dimension.

Four research questions were posed in Section 1.2 and have been addressed as follows:

- **How can the spatial zoom and pan paradigm be applied to an approach for navigating the temporal dimension of spatio-temporal data within a geospatial application?**

Users of geospatial systems are familiar with navigating through the spatial dimension of their data using spatial zoom and pan tools (Harrower & Sheesley, 2005), as discussed in Section 2.4.1. By adapting and applying this way of conceptualizing data navigation to the temporal dimension, users will already be familiar with the basic concepts. This provides users with a quick way to construct and move through their temporal data selections instead of having to take time to re-structure every selection they make.

Zooming within the spatial dimension either increases the area viewed in the map display through zooming out, or decreases the area viewed on the map display through zooming in (see Section 2.4.1). This was translated to the temporal context by using zoom out to increase the temporal range of data viewed in the map display and using zoom in to decrease the temporal range of the data viewed on the map display (see Section 2.4.2). While in a spatial context panning re-centres the map within the display window while maintaining the same spatial scale, in a temporal context this was applied as re-centring the temporal selection window while still maintaining the same temporal extent. This paradigm has been successfully implemented for temporal navigation in other systems (Neumann, 2010).

- **How can the zoom and pan paradigm be implemented to enable users to temporally navigate their spatio-temporal data within a GIS or virtual globe in a multi-touch environment?**

Two approaches, Multiple Linked Time Sliders and Dynamic Radial Navigation, were designed as ways to temporally zoom and pan through spatio-temporal data in a multi-touch environment (see Section 3.3.2). These approaches are both linear navigation methods and are both capable of navigating through spatio-temporal data with multiple temporal granularities. Multiple Linked Time Sliders adapts the traditional time slider to the interactive capabilities of a multi-touch environment. In Dynamic Radial Navigation, the slider for navigating the coarsest level of granularity of data is based on a traditional time slider, the radial selectors used for finer granularities are designed to be more compact and to see if there is any benefit in interacting with the semi-circular shape over a traditional linear slider (e.g., speed, user preference). The gestures used for interacting with these approaches were based on the interaction paradigm of spatial zoom and pan.

- **Do the approaches developed for temporal zoom and pan in GIS assist users in navigating the temporal dimension of spatio-temporal data?**

A laboratory-based user evaluation conducted with 40 participants from the Memorial University of Newfoundland student community was used to assess the four approaches (see Section 3.4). This evaluation consisted of three parts. First, the participants were required to complete a pre-study questionnaire to obtain background information regarding their experience with GIS and mapping software and multi-touch screen devices. Second, the participants used the prototypes to complete assigned tasks and answered questionnaires, based on Davis' (1989) Technology Acceptance Model, to measure perceived usefulness and perceived ease of use. Third, the participants completed a post-study questionnaire to gather their opinions on what they liked and disliked about each approach. The participants were also timed and their tasks were graded after they study was complete.

The participants all completed the tasks given to them with high rates of accuracy illustrating that that the approaches enable users to temporally navigate their data (see

Section 3.5.2). Both approaches were, on average, rated as easy to use and useful for most components of the tasks (see Section 3.5.3). While for some task components the approaches received average ratings close to neutral, neither of them had negative average ratings for any task components.

- **How do the proposed approaches compare to other approaches for temporal navigation?**

Two additional prototypes, Date/Time Spinners and Drop-Down List, were developed for the user evaluation process (see Section 3.4.1). These were tested in the user evaluation along with the two proposed approaches. There were no significant differences between any of the approaches in accuracy of task completion for any of the task types (see Section 3.5.2). This illustrates that all of the prototypes are equally capable of completing each task. For time to task completion, there was no significant difference between the prototypes for three of the task types but for the most complicated task type, range selection-multiple granularity, Date/Time Spinners was significantly faster than the other approaches and Dynamic Radial Navigation was significantly slower (see Section 3.5.1). Overall, Date Time Spinners tended to be rated higher in perceived ease of use and perceived usefulness than the other prototypes and Dynamic Radial Navigation tended to be rated lower (see Section 3.5.3). Participant comments indicated that they liked the ease of use and familiarity of Date/Time Spinners and Drop-Down List and they liked the appearance and the visualization capabilities of Multiple Linked Time Sliders and Dynamic Radial Navigation (see Section 3.5.4).

## 4.2 Limitations and opportunities

This research identified ways to navigate the temporal dimension of spatio-temporal data and many benefits of the different approaches were identified with the user evaluation. However, there were also several limitations identified. Many of these limitations relate to the technical restrictions of the prototypes or the design of certain components.

The prototypes for the proposed methods were developed from custom made components. The designs of the some of the components, particularly the radial selectors in the Dynamic Radial Navigation prototype were difficult to implement in a software prototype. The radial selectors ended up being difficult to spin for many study participants, several participants appeared visibly frustrated during the evaluation, and this appears to have influenced the perception of the usefulness and ease of use of this approach. There were also other technical issues, such as the fine granularity sliders popping up or down too easily, that one would expect to find during the first full evaluation of a software prototype. Since the two comparison prototypes were made with existing components they had less technical issues and this may have influenced the ratings of perceived usefulness and perceived ease of use. While efforts were made to develop interfaces that could be used to test the research concepts, the development of effective user interfaces represents a significant effort in fully developed software industry projects, requiring several steps of testing, work that was beyond the scope of a M.Sc. thesis.

One of the main limitations identified with the proposed approaches was the size of the touch points on the radial selectors of the Dynamic Radial Navigation approach and, to a lesser degree, the size of the touch points on the finer granularity sliders in the Linked Time Sliders approach. One way to solve this would be to make the components, and therefore the touch points, larger. Since one of the design goals was to make the components compact in order to maximize screen space for the map display, a dynamic approach to increasing the size of the components when the user needs it could be taken. For example, this could consist of a component increasing in size when the user interacts with it, or using the fish eye effect when a finger hovers over a component. This would require a thorough literature review to determine the available options.

Another common complaint from participants was that the fine grained sliders for Multiple Linked Time Sliders scrolled on their own. While this feature was implemented to try to simplify scrolling through the dataset, almost every participant was observed to have some difficulty with this feature. Full control could be given to the user so that they could move the sliders along themselves.

Due to the number of prototypes that needed to be tested and the number of task types that needed to be completed, a between subjects study design was used for the evaluation as a within subjects design would have taken too much time per participant. Because of this structure, participants were unable to make direct comparisons between the prototypes and rank them for each task. Since most of the variation in participant opinion and performance was for the most difficult task type, if the above mentioned changes were implemented, then a subsequent user evaluation could potentially use a within subjects design and a single task type. Participants would then be able to make direct comparisons between the approaches.

The user evaluation was a laboratory study where each participant used the same data and performed assigned tasks. If further modifications were made to the prototypes, a field study where expert users use their own data and explore their own research questions may be a useful tool for further evaluation (Duh et al., 2006). A field study would be able to assess how the approaches perform with different data types. It would also be able to assess the potential of the approaches to assist users in exploring their own research questions. Field studies have the potential to identify issues that may not surface within the confines of a laboratory, particularly on mobile devices (Duh et al., 2006). Testing with different sizes of datasets may also help to indicate the limits of the effectiveness of the approaches.

There is also the opportunity to expand this research to incorporate different types of time. The proposed approaches and the comparison prototypes were all designed to work with linear time. Cyclic time can also be important for answering research questions if the questions are about recurring events (Frank, 1998). Attempts could be made to incorporate cyclic time into the approaches. This could potentially be done expanding the existing components or may require additional components to be added.

### 4.3 References

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *Management Information Systems*, 13(3), 319–340.

Duh, H. B.-L., Tan, G. C. B., & Chen, V. H. (2006). Usability evaluation for mobile device: A comparison of laboratory and field tests. In M. Nieminen & M. Röykkee

(Eds.), *Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services,* 12–15 September 2006 (pp. 181–186). Espoo, Finland: ACM Press.

Edsall, R. M., Kraak, M.-J., MacEachren, A. M., & Peuquet, D. J. (1997). Assessing the effectiveness of temporal legends in environmental visualization. In *Proceedings of* the *GIS/LIS Conference and Exposition,* 28–30 October 1997 (pp. 663–671). Cincinnati, Ohio, USA.

Frank, A. U. (1998). Different types of times in GIS. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems* (pp. 40–62). New York, NY, USA: Oxford University Press.

Harrower, M., & Sheesley, B. (2005). Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS*, 9(2), 77–89.

Neumann, A. (2010). *Spatial, temporal and thematic navigation: Visualizing biographies of European artists using a task oriented user interface design approach.* (Doctoral dissertation). Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland.

## Bibliography

Abraham, T., & Roddick, J. F. (1999). Survey of spatio-temporal databases. *GeoInformatica*, 3(1), 61–99.

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2007). Visualizing time-oriented data—A systematic view. *Computers & Graphics*, 31(3), 401–409.

Aigner, W., Miksch, S., Müller, W., Schumann, H., & Tominski, C. (2008). Visual methods for analyzing time-oriented data. *IEEE Transactions on Visualization and Computer Graphics*, 14(1), 47–60.

Andrienko, G., Andrienko, N., Demsar, U., Dransch, D., Dykes, J., Fabrikant, S. I., Jern, M., Kraak, M.-J., Schumann, H., & Tominski, C. (2010a). Space, time and visual analytics. *International Journal of Geographical Information Science*, 24(10), 1577–1600.

Andrienko, G., Andrienko, N., Dykes, J., Kraak, M.-J., & Schumann, H. (2010b). GeoVA(t) – Geospatial visual analytics: Focus on time. *International Journal of Geographical Information Science*, 24(10), 1453–1457.

Andrienko, G., Andrienko, N., Fischer, R., Mues, V., & Schuck, A. (2006). Reactions to geovisualization: An experience from a European project. *International Journal of Geographical Information Science*, 20(10), 1149–1171.

Andrienko, G., Andrienko, N., Jankowski, P., Keim, D., Kraak, M.-J., MacEachren, A., & Wrobel, S. (2007). Geovisual analytics for spatial decision support: Setting the research agenda. *International Journal of Geographical Information Science*, 21(8), 839–857.

Andrienko, N., & Andrienko, G. (2006). *Exploratory Analysis of Spatial and Temporal Data: A Systematic Approach*. Berlin, Germany: Springer.

AvRuskin, G. A., Jacquez, G. M., Meliker, J. R., Slotnick, M. J., Kaufmann, A. M., & Nriagu, J. O. (2004). Visualization and exploratory analysis of epidemiologic data using a novel space time information system. *International Journal of Health Geographics*, 3(1), 26.

Battersby, S. E. (2008). User-centered design for digital map navigation tools. In *Proceedings of the 17th International Research Symposium on Computer-Based Cartography*, 8–11 September 2008 (CD-ROM). Shepherdstown, WA, USA: Cartography and Geographic Information Society with assistance by ESRI.

Bertino, E., Camossi, E., & Bertolotto, M. (2010). Multi-granular spatio-temporal object models: concepts and research directions. In M. C. Norrie & M. Grossniklaus (Eds.), *Object Databases* (pp. 132–148). Berlin, Germany: Springer.

Bettini, C., Wang, X. S., & Jajodia, S. (1998). A general framework for time granularity and its application to temporal reasoning. *Annals of Mathematics and Artificial Intelligence*, 22, 29–58.

Brandl, P., Leitner, J., Seifried, T., Haller, M., Doray, B., & To, P. (2009). Occlusion-aware menu design for digital tabletops. In *Proceedings of CHI EA '09 Human Factors in Computing Systems,* 4–9 April 2009 (pp. 3223–3229). Boston, MA, USA: ACM Press.

Brewer, I., MacEachren, A. M., Abdo, H., Gundrum, J., & Otto, G. (2000). Collaborative geographic visualization: Enabling shared understanding of environmental processes. In A. Rawlinson (Ed.), *Proceedings of the IEEE Symposium on Information Visualization,* 9–10 October 2000 (pp. 137–141). Salt Lake City, Utah, USA: IEEE Computer Society.

Butkiewicz, T., Jeong, D. H., Wartell, Z., Ribarsky, W., & Chang, R. (2009). Hierarchical multi-touch selection techniques for collaborative geospatial analysis. In W. J. Tolone & W. Ribarsky (Eds.), *Proceedings of SPIE 7346, Visual Analytics for Homeland Defense and Security,* 14 May 2009 (73460D). Orlando, FL, USA: Society of Photo-Optical Instrumentation Engineers.

Buxton, B. (2013, March 19). Multi-touch systems that I have known and loved. Retrieved from http://www.billbuxton.com/multitouchOverview.html, last accessed July 12, 2013.

Carpendale, S. (2008). Evaluating information visualizations. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization: Human Centered Issues and Perspectives* (19–45). Berlin, Germany: Springer.

Castronovo, D. A., Chui, K. K. H., & Naumova, E. N. (2009). Dynamic maps: A visual-analytic methodology for exploring spatio-temporal disease patterns. *Environmental Health*, 8:61. doi:10.1186/1476-069X-8-61

Certo, L., Galvão, T., & Borges, J. (2012). Time Automaton: A visual mechanism for temporal querying. *Journal of Visual Languages amd Computing*, 24(1), 24–36.

Davis, F. D. (1989). Perceived usefulness, perceived ease of use, and user acceptance of information technology. *Management Information Systems*, 13(3), 319–340.

De Amicis, R., Conti, G., Piffer, S., & Simões, B. (2009). Geospatial visual analytics. In R. De Amicis, S. Radovan, & G. Conti (Eds.), *GeoSpatial Visual Analytics: Geographical Information Processing and Visual Analytics for Environmental Security* (pp. 265–286). Dordrecht, The Netherlands: Springer.

Duh, H. B.-L., Tan, G. C. B., & Chen, V. H. (2006). Usability evaluation for mobile device: A comparison of laboratory and field tests. In M. Nieminen & M. Röykkee (Eds.), *Proceedings of the 8th Conference on Human-Computer Interaction with Mobile Devices and Services,* 12–15 September 2006 (pp. 181–186). Espoo, Finland: ACM Press.

Edsall, R. M., Kraak, M.-J., MacEachren, A. M., & Peuquet, D. J. (1997). Assessing the effectiveness of temporal legends in environmental visualization. In *Proceedings of* the *GIS/LIS Conference and Exposition,* 28–30 October 1997 (pp. 663–671). Cincinnati, Ohio, USA.

Edsall, R.M., & Peuquet, D. J. (1997). A graphical user interface for the integration of time into GIS. In *Proceedings of American Congress of Surveying and Mapping Annual Convention and Exhibition,* 1 April 1997 (pp. 182–189). Seattle, WA, USA.

Edsall, R. M., Harrower, M., & Mennis, J. L. (2000). Tools for visualizing properties of spatial and temporal periodicity in geographic data. *Computers & Geosciences*, 26(1), 109–118.

Edsall, R. M, & Sidney, L. R. (2005). Applications of a cognitively informed framework for the design of interactive spatiotemporal representations. In J. Dykes, A. M. MacEachren, & M.-J. Kraak (Eds.), *Exploring Geovisualization* (pp. 577–589). Oxford, UK: Elsevier.

Enguehard, R., Hoeber, O., & Devillers, R. (2012). Interactive exploration of movement data: A case study of geovisual analytics for fishing vessel analysis. *Information Visualization*, 12(1), 65–84.

Esri. (2012). ArcGIS Runtime SDK for iOS. Retrieved from http://resources.arcgis.com/content/arcgis-iphone/api, last accessed July 12, 2013.

Frank, A. U. (1998). Different types of times in GIS. In M. J. Egenhofer & R. G. Golledge (Eds.), *Spatial and Temporal Reasoning in Geographic Information Systems* (pp. 40–62). New York, NY, USA: Oxford University Press.

Goralwalla, I. A., Özsu, M. T., & Szafron, D. (1998). An object-oriented framework for temporal data models. In O. Etzion, S. Jajodia, & S. Sripada (Eds.), *Temporal Databases—Research and Practice* (pp. 1–35). Berlin, Germany: Springer.

Hägerstrand, T. (1970). What about people in regional science? *Papers of the Regional Science Association*, 24, 7–21.

Hajnicz, E. (1996). *Time Structures: Formal Description and Algorithmic Representation*. Berlin, Germany: Springer.

Han, J. Y. (2005). Low-cost multi-touch sensing through frustrated total internal reflection. In P. Baudisch & M. Czerwinski (Eds.), *Proceedings of the 18th Annual ACM Symposium on User Interface Software and Technology,* 23–26 October 2005 (pp. 115–118). Seattle, WA, USA: ACM Press.

Harrower, M., & Sheesley, B. (2005). Designing better map interfaces: A framework for panning and zooming. *Transactions in GIS*, 9(2), 77–89.

Hoeber, O., Wilson, G., Harding, S., Enguehard, R., & Devillers, R. (2011). Exploring geo-temporal differences using GTdiff. In G. Di Battista, J.-D. Fekete, & H. Qu (Eds.), *Proceedings of the Pacific Visualisation Symposium,* 1–4 March 2011 (pp. 139–146). Hong Kong, China: IEEE Computer Society Press.

Hornsby, K. (2001). Temporal zooming. *Transactions in GIS*, 5(3), 255–272.

Hornsby, K. & Egenhofer, M. J. (2002). Modeling objects over multiple granularities. *Annals of Mathematics and Artificial Intelligence*, 36, 177–194.

Hornsby, K., & Egenhofer, M. J. (1999). Shifts in detail through temporal zooming. In A. Cammelli, A. M. Tjoa, & R. R. Wagner (Eds.), *Proceedings of the Tenth International Workshop on Database and Expert Systems Applications,* 1–3 September 1999 (pp. 487–491). Florence, Italy: IEEE Computer Society.

Hornsby, K., Egenhofer, M. J., & Hayes, P. (1999). Modeling cyclic change. In P. P. Chen, D. W. Embley, J. Kouloumdjian, S. W. Liddle, & J. F. Roddick (Eds.), *Advances in Conceptual Modeling* (pp. 98-109). Berlin, Germany: Springer.

Ingram, A., Wang, X., & Ribarsky, W. (2012). Towards the establishment of a framework for intuitive multi-touch interaction design. In International Working Conference on Advanced Visual Interfaces, 22–25 May 2012 (pp. 66–73). Capri Island, Italy: ACM Press.

Jern, M., Brezzi, M., & Lundblad, P. (2010). Geographic information and cartography for risk and crisis management. In M. Konecny, S. Zlatanova, & T. L. Bandrova (Eds.), *Geographic Information and Cartography for Risk and Crisis Management* (pp. 379–394). Berlin, Germany: Springer.

Jern, M., & Franzen, J. (2006). "GeoAnalytics" - Exploring spatio-temporal and multivariate data. In E. Banissi, R. A. Burkhard, A. Ursyn, J. J. Zhang, M. Bannatyne, C. Maple, A. J. Cowell, G. Y. Tan, & M. Hou (Eds.), Proceedings of the *Tenth International Conference on Information Visualisation,* 5–7 July 2006 (pp. 25–31). London, UK: IEEE Computer Society.

Joo, Y., Jang, M., & Jun, C. (2010). Developing a time-series visualization technique using a temporal GIS database for urban growth simulation. *International Journal of Urban Sciences*, 14(1), 98–110.

Keim, D., Andrienko, G., Fekete, J.-D., Görg, C., Kohlhammer, J., & Melonçon, G. (2008). Visual analytics: Definition, process, and challenges. In A. Kerren, J. T. Stasko, J.-D. Fekete, & C. North (Eds.), *Information Visualization–Human Centered Issues in Visual Representation, Interaction, and Evaluation* (pp. 154–175). Berlin, Germany: Springer.

Kemp, Z., & Kowalczyk, A. (1994). Incorporating the temporal dimension in a GIS. In M. F. Worboys (Ed.), *Innovations in GIS* (pp. 89–103). London, UK: Taylor & Francis.

Kraak, M.-J. (2003). The space-time cube revisited from a geovisualization perspective. In *International Cartographic Conference*, 10–16 August 2003 (pp. 10–16). Durban, South Africa.

Kraak, M.-J. (2005). Timelines, temporal resolution, temporal zoom. In *Proceedings of the International Cartographic Conference,* 9–16 July 2005 (CDROM). A Coruña, Spain.

Krueger, M. W., Gionfriddo, T., & Hinrichsen, K. (1985). VIDEOPLACE - An artificial reality. In L. Borman & B. Curtis (Eds.), *Proceedings of the Conference on Human Factors in Computing Systems,* 14–18 April 1985 (pp. 35–40). San Francisco, CA, USA: ACM Press.

Kwan, M.-P. & Lee, J. (2003). Geovisualization of human activity pattern using 3D GIS: A time-geographic approach. In M. F. Goodchild and D.G. Janelle (Eds.), *Spatially Integrated Social Science: Examples in Best Practice* (pp. 48–66). Oxford, UK: Oxford University Press.

Langran, G. (1989). A review of temporal database research and its use in GIS applications. *International Journal of Geographical Information Systems*, 3(3), 215–232.

Langran, G., & Chrisman, N. R. (1988). A framework for temporal geographic information. *Cartographica*, 25(3), 1–14.

Lee, C., Devillers, R., & Hoeber, O. (2012, September). *Interactive temporal zoom and pan within a multi-touch geo-visual analytics environment.* Paper presented at GIScience '12 Workshop Geovisual Analytics—Time to Focus on Time, Columbus, OH, USA.

Lee, H., & Kemp, Z. (1998). Supporting complex spatiotemporal analysis in GIS. In S. Carver (Ed.), *Innovations in GIS 5* (pp. 151–161). London, UK: Taylor & Francis.

Li, X., & Kraak, M.-J. (2008). The Time Wave. A new method of visual exploration of geo-data in time–space. *The Cartographic Journal*, 45(3), 193–200.

Li, X., & Kraak, M.-J. (2012). Explore multivariable spatio-temporal data with the Time Wave: Case study on meteorological data. In A. G. O. Yeh, W. Shi, Y. Leung, & C. Zhou (Eds.), *Advances in Spatial Data Handling and GIS: 14th International Symposium on Spatial Data Handling* (pp. 79–92). Berlin: Springer.

Lundblad, P., Eurenius, O., & Heldring, T. (2009). Interactive visualization of weather and ship data. In E. Banissi, L. Stuart, T. G. Wyeld, M. Jern, G. Andrienko, N. Memon, R. Alhajj, R. A. Burkhard, G. Grinstein, D. Groth, A. Ursyn, J. Johansson, C. Forsell, U. Cvek, M. Trutschl, F. T. Marchese, C. Maple, A. J. Cowell, & A. Vande Moere (Eds.) *Proceedings of the 13th International Conference on Information Visualisation,* 15–17 July 2009 (pp. 379–386). Columbus, OH: IEEE Computer Society.

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

MacEachren, A. M., Robinson, A. C., Jaiswal, A., Pezanowski, S., Savelyev, A., Blanford, J., & Mitra, P. (2011). Geo-Twitter analytics: Applications in crisis management. In A. Ruas (Ed.) *Proceedings of the International Cartographic Conference*, 3–8 July 2011. Paris, France.

Malinconico, L.L., Sunderlin, D., Liew, C., Ho, A.S., & Bekele, K.A. (2011). An iPad and Android-based application for digitally recording geologic field data. In *American Geophysical Union Fall Meeting Abstracts*, 5–9 December 2011 (on-line database). San Francisco, CA.

Mennis, J. L., Peuquet, D. J., & Qian, L. (2000). A conceptual framework for incorporating cognitive principles into geographical database representation. *International Journal of Geographical Information Science*, *14*(6), 501–520.

Neumann, A. (2005). Navigation in space, time and topic. In P*roceedings of the International Cartographic Conference,* 9–16 July 2005 (CDROM). A Coruña, Spain.

Neumann, A. (2010). *Spatial, temporal and thematic navigation: Visualizing biographies of European artists using a task oriented user interface design approach.* (Doctoral dissertation). Eidgenössische Technische Hochschule (ETH) Zurich, Zurich, Switzerland.

Ott, T., & Swiaczny, F. (2001). *Time-Integrative Geographic Information Systems: Management and analysis of spatio-temporal data.* Berlin, Germany: Springer.

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

Peuquet, D. J. (2002). *Representations of Space and Time.* New York, NY, USA: The Guilford Press.

Peuquet, D. J., & Duan, N. (1995). An event-based spatiotemporal data model (ESTDM) for temporal analysis of geographical data. *International Journal of Geographical Information Systems*, 9(1), 7–24.

Richardson, D. B., Volkow, N. D., Kwan, M.-P., Kaplan, R. M., Goodchild, M. F., & Croyle, R. T. (2013). Spatial turn in health research. *Science*, 339(6126), 1390–1392.

Schöning, J., Brandl, P., Daiber, F., Echtler, F., Hilliges, O., Hook, J., Löchtefeld, M., Motamedi, N., Muller, L., Olivier, P., Roth. T., & von Zadow, U. (2008). *Multi-touch Surfaces: A technical guide.* Technical Report TUM-I0833: Technical Reports of the Technical University of Munich.

Schöning, J., Daiber, F., Krüger, A., & Rohs, M. (2009). Using hands and feet to navigate and manipulate spatial data. In *Proceedings of the 27th International Conference on Human Factors in Computing Systems,* 4–9 April 2009 (pp. 4663–4668). Boston, MA, USA: ACM Press.

Schreiber, F. A. (1994). Is time a real time? An overview of time ontology in informatics. In W. A. Halang & A. D. Stoyenko (Eds.), *Real Time Computing , Vol F 127* (pp. 283–307). Berlin, Germany: Springer.

Shneiderman, B. (1996). The eyes have it: A task by data type taxonomy for information visualizations. In M. Burnett & W. Citrin (Eds.), *Proceedings of the IEEE Symposium on Visual Languages,* 3–6 September 1996 (pp. 336–343). Piscataway, NJ: IEEE Computer Society.

Sinton, D. (1978). The inherent structure of information as a constraint to analysis: Mapped thematic data as a case study. *Harvard Papers on Geographic Information Systems*, 7, 1–17.

Smith, N.G. & Levy, T.E. (2012). Real-time 3D archaeological field recording: ArchField, and open-source GIS system pioneered in southern Jordan. *Antiquity*, 86(331).

Snodgrass, R.T. (1986). Temporal databases. *IEEE Computer*, 19(9), 35–41.

Tague-Sutcliffe, J. (1992). The pragmatics of information retrieval experimentation, revisited. *Information Processing & Management*, 28(4), 467–490.

Thomas, J. J., & Cook, K. A. (Eds.). (2005). *Illuminating the Path: The Research and Development Agenda for Visual Analytics*. IEEE CS Press.

Vishkaie, R.S. & Levy, R. (2012). Perception and reality: Exploring urban planners' vision on GIS tasks for multi-touch displays. In *International Conference on Interactive Tabletops and Surfaces,* 11–14 November 2012 (pp. 265–270). Cambrige, MA: ACM Press.

Worboys, M. F. (1994). A unified model for spatial and temporal information. *The Computer Journal*, 37(1), 26–34.

# Appendix A – User Evaluation Documents

**Pre-study Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment**

Date:______________ Participant ID:___________________________

Please answer the following questions to provide some background information. If any of the terms or questions are not clear please ask the researcher for clarification

1. Have you ever used a touch screen device such as a tablet computer (e.g., Apple iPad, Samsung Galaxy) or a smartphone (e.g., Android, Apple iPhone)?
   Yes ☐ No ☐

2. How frequently do you use touch screen devices?
   Daily ☐ Weekly ☐ Monthly ☐ Less than once a month ☐

3. Which activities do you normally use a touch screen device for? Check all that are applicable.
   Texting ☐ Playing games ☐ Browsing the Web ☐ Reading ☐
   Using apps (other than games) ☐ Other ☐ ______________________________

4. Have you ever used an Apple iPad?
   Yes ☐ No ☐

If you answered yes to question 4, please answer question 5. Otherwise, skip to question 6.

5. How frequently do you use an Apple iPad?
   Daily ☐ Weekly ☐ Monthly ☐ Less than once a month ☐

6. Have you ever used online maps (e.g. Google Maps), virtual globes (e.g. Google Earth) or mapping apps?
   Yes ☐ No ☐

If you answered Yes to question 6, please answer questions 7 to 9. Otherwise, skip to question 10:

7. How frequently do you use online maps (e.g. Google Maps), virtual globes (e.g. Google Earth) or mapping apps?
   Daily ☐ Weekly ☐ Monthly ☐ Less than once a month ☐

8. How frequently do you use online maps (e.g. Google Maps), virtual globes (e.g. Google Earth) or mapping apps on a touch screen device?
   Daily ☐ Weekly ☐ Monthly ☐ Less than once a month ☐ Never ☐

9. Have you ever used a time slider (a control that allows you to display data from different points in time by sliding a pointer along a line) in an online mapping application (e.g. Google Maps) or virtual globe (e.g. Google Earth)?
   Yes ☐ No ☐

10. Have you ever used a geographic information system (GIS) (e.g. ArcGIS)?
Yes □ No □

If you answered Yes to question 10, please answer questions 11 to 14. Otherwise, the survey is complete:

11. How frequently do you use a GIS?
Daily □ Weekly □ Monthly □ Less than once a month □

12. Do you have any formal training in GIS?
Yes □ No □

13. Have you ever used a GIS to look at changes in data over time (e.g. exploring data over a period of several years)?
Yes □ No □

14. Have you ever used a GIS to look at data in different temporal granularities (e.g. looked at a year of data then looked at one day from that year)?
Yes □ No □

In-task Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment
Date:______________ Participant ID:___________________________

**INSTRUCTIONS:** Please rate how strongly you agree or disagree with each of the following statements by circling the appropriate number.

The following questions relate to your experiences using the Dynamic Radial Navigation interface for selecting an initial time and panning with a single temporal unit at a single granularity.

| Initial Date Selection | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Learning to select an initial date with the Dynamic Radial Navigation Interface was easy for me | 1 | 2 | 3 | 4 | 5 |
| I found it easy to select an initial date with the Dynamic Radial Navigation Interface | 1 | 2 | 3 | 4 | 5 |
| My interaction with using the Dynamic Radial Navigation Interface to select an initial date was clear and understandable | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface to be flexible to interact with when selecting an initial date | 1 | 2 | 3 | 4 | 5 |
| It was easy for me to become skilful at selecting an initial date using the Dynamic Radial Navigation Interface | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface easy to use for selecting an initial date | 1 | 2 | 3 | 4 | 5 |

| Initial Date Selection | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Using the Dynamic Radial Navigation Interface to select an initial date enabled me to accomplish this task more quickly | 1 | 2 | 3 | 4 | 5 |
| Using the Dynamic Radial Navigation Interface improved my performance in selecting an initial date | 1 | 2 | 3 | 4 | 5 |
| Using the Dynamic Radial Navigation Interface increased my productivity in selecting an initial date | 1 | 2 | 3 | 4 | 5 |
| Using the Dynamic Radial Navigation Interface enhanced my effectiveness when selecting an initial date | 1 | 2 | 3 | 4 | 5 |
| Using the Dynamic Radial Navigation Interface made it easier to select an initial date | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface useful for selecting an initial date | 1 | 2 | 3 | 4 | 5 |

| Temporal Pan | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Learning to temporally pan to a single temporal unit with the Dynamic Radial Navigation Interface was easy for me | 1 | 2 | 3 | 4 | 5 |
| I found it easy to temporally pan to a single temporal unit with the Dynamic Radial Navigation Interface | 1 | 2 | 3 | 4 | 5 |
| My interaction with using the Dynamic Radial Navigation Interface to temporally pan to a single temporal unit was clear and understandable | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface to be flexible to interact with when temporally panning to a single temporal unit | 1 | 2 | 3 | 4 | 5 |
| It was easy for me to become skilful at temporally panning to a single temporal unit using the Dynamic Radial Navigation Interface | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface easy to use for temporally panning to a single temporal unit | 1 | 2 | 3 | 4 | 5 |

| Temporal Pan | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Using the Dynamic Radial Navigation Interface to temporally pan to a single temporal unit enabled me to accomplish this task more quickly | 1 | 2 | 3 | 4 | 5 |
| Using the Dynamic Radial Navigation Interface improved my performance in temporally panning to a single temporal unit | 1 | 2 | 3 | 4 | 5 |
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| I found the Dynamic Radial Navigation Interface useful for temporally panning to a single temporal unit | 1 | 2 | 3 | 4 | 5 |

In-task Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment
Date:______________ Participant ID:__________________________

**INSTRUCTIONS:** Please rate how strongly you agree or disagree with each of the following statements by circling the appropriate number.

The following questions relate to your experiences using the **Dynamic Radial Navigation** interface for zooming in, panning, and zooming out with a range of time selection at a single granularity.

| Temporal Zoom In | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Learning to temporally zoom in to a range of time at a single granularity with the Dynamic Radial Navigation Interface was easy for me | 1 | 2 | 3 | 4 | 5 |
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| My interaction with using the Dynamic Radial Navigation Interface to temporally zoom in to a range of time at a single granularity was clear and understandable | 1 | 2 | 3 | 4 | 5 |
| I found the Dynamic Radial Navigation Interface to be flexible to interact with when temporally zooming in to a range of time at a single granularity | 1 | 2 | 3 | 4 | 5 |
| It was easy for me to become skilful at temporally zooming in to a range of time at a single granularity using the Dynamic Radial Navigation Interface | 1 | 2 | 3 | 4 | 5 |
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| Temporal Pan | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
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| Temporal Zoom Out | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
|---|---|---|---|---|---|
| Learning to temporally zoom out to a range of time at a single granularity with the Dynamic Radial Navigation Interface was easy for me | 1 | 2 | 3 | 4 | 5 |
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In-task Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment

Date:_____________ Participant ID:_________________________

**INSTRUCTIONS:** Please rate how strongly you agree or disagree with each of the following statements by circling the appropriate number.

The following questions relate to your experiences using the **Dynamic Radial Navigation** interface for zooming in, panning, and zooming out with a **single temporal unit** at a **dynamic granularity**.

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| Temporal Zoom In | Strongly Disagree | Disagree | Neutral | Agree | Strongly Agree |
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In-task Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment

Date:______________ Participant ID:__________________________

**INSTRUCTIONS:** Please rate how strongly you agree or disagree with each of the following statements by circling the appropriate number.

The following questions relate to your experiences using the Dynamic Radial Navigation interface for zooming in, panning, and zooming out with a range of time selection at a dynamic granularity.

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Single Selection, Single Granularity Task Scenario (SS-SG)

Date:______________ Participant ID:___________________________

Scenario

Vessel Monitoring System (VMS) data have been collected from a fisheries vessel off the coast of Newfoundland. These data are collected on an hourly basis and consist of the location of the fishing vessel as well as the time and date that the vessel was at the location. You will be examining the fishing vessel over the period of one year.

When the vessel is fishing, it is usually moving slowly and possibly back and forth so the points are often clumped together. When the vessel is travelling from place to place it often moves faster so the points are farther apart and usually in a relatively straight line.

Task Scenario

This fishing vessel normally docks in Marystown. You are interested to see which months the vessel stops at the port in St. John's.

a) Select a month to start you observations

b) Pan through each month to see in which months the vessel stops in St. John's and write these months down in the space below

Months the vessel stops in St. John's:_______________________________________________

________________________________________________________________________________

________________________________________________________________________________

Range Selection, Single Granularity (RS-SG)

Date:______________ Participant ID:____________________________

Scenario

Vessel Monitoring System (VMS) data have been collected from a fisheries vessel off the coast of Newfoundland. These data are collected on an hourly basis and consist of the location of the fishing vessel as well as the time and date that the vessel was at the location. You will be examining the fishing vessel over the period of one year.

When the vessel is fishing, it is usually moving slowly and possibly back and forth so the points are often clumped together. When the vessel is travelling from place to place it often moves faster so the points are farther apart and usually in a relatively straight line.

Task Scenario

You would like to observe the general trends of which ports the vessel uses throughout different times of the year.

a) Select January
b) Zoom out to select the entire year
   Does this vessel go into port anywhere but Newfoundland? Y / N

c) Zoom in to January to March (winter)
   Which ports does the vessel stop in? St. John's☐ Marystown☐ Port Kirwan☐

d) Pan to July to September (summer)
   Which ports does the vessel stop in? St. John's☐ Marystown☐ Port Kirwan☐

e) Zoom out to July to December (second half of year)?
   Which ports does the vessel stop in? St. John's☐ Marystown☐ Port Kirwan☐

f) Pan to January to June (first half of year)?
   Which ports does the vessel stop in? St. John's☐ Marystown☐ Port Kirwan☐

g) Zoom in to April to June (spring)
   Which ports does the vessel stop in? St. John's☐ Marystown☐ Port Kirwan☐

Single Selection, Dynamic Granularity (SS-DG)

Date:______________ Participant ID:____________________________

Scenario

Vessel Monitoring System (VMS) data have been collected from a fisheries vessel off the coast of Newfoundland. These data are collected on an hourly basis and consist of the location of the fishing vessel as well as the time and date that the vessel was at the location. You will be examining the fishing vessel over the period of one year.

When the vessel is fishing, it is usually moving slowly and possibly back and forth so the points are often clumped together. When the vessel is travelling from place to place it often moves faster so the points are farther apart and usually in a relatively straight line.

Task Scenario

The fishing seasons ends on March 31st and a new fishing season begins the next day on April 1st. You want to confirm that the vessel you are looking at did not go fishing again in April before stopping in port to offload their catch from the end of March since they have done this in previous years.

The vessel supposedly traveled to the fishing area on March 28th, fished for 3 days then returned to port on April 1st by 21:00.

a) Select March
b) Zoom in to March 28th.
   Does the vessel appear to be travelling from one location to another? Yes / No
c) Pan through March 29th, 30th, and 31st
   Does the vessel appear to be fishing? Yes / No
d) Zoom out to March
e) Pan to April
f) Zoom in to April 1st
   Does the vessel appear to be heading back to port? Yes / No
g) Zoom in to April 1st at 21:00
   Is the vessel back in port? Yes / No
h) Zoom out to April

Range Selection, Dynamic Granularity (RS-DG)

Date:______________ Participant ID:___________________________

Scenario

Vessel Monitoring System (VMS) data have been collected from a fisheries vessel off the coast of Newfoundland. These data are collected on an hourly basis and consist of the location of the fishing vessel as well as the time and date that the vessel was at the location. You will be examining the fishing vessel over the period of one year.

When the vessel is fishing, it is usually moving slowly and possibly back and forth so the points are often clumped together. When the vessel is travelling from place to place it often moves faster so the points are farther apart and usually in a relatively straight line.

Task Scenario

Someone has reported some unusual activity, which may have been fishing, in an area north of (above) St. John's sometime around September 30th to October 1st. This area was closed to fishing for a month, from September 15th at noon to October 15th at noon. The general description of the vessel matches the one you are looking at although it could have also been several other vessels. The crew reports that they were not in the area and were on a trip south of (below) St. John's from September 28th 22:00 to October 9th 10:00. They say that they were not in that area at all during the time of the ban or for at least a month before and after that.

a) Select September
b) Zoom out to September to October
c) Zoom in to September 28thth to October 9th
d) Zoom in to September 28th, 22:00 to October 9th, 10:00
   Does this show a single complete trip south of (below) St. John's? A complete trip can start and end in different ports. Yes / No
e) Zoom out to September 15th to October 15th
   Was the vessel in or north of (above) St. John's? Yes / No
f) Pan to August 15th to September 15th
   Was the vessel in or north of (above) St. John's? Yes / No
g) Pan to October 15th to November 15th
   Was the vessel in or north of (above) St. John's? Yes / No

Post-task Questionnaire: Interactive Temporal Zoom and Pan within a Multi-Touch Environment

Date:_______________ Participant ID:____________________________

1. What did you like about the Text Box prototype?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

2. What did you dislike about the Text Box prototype?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

3. What did you like about the Date/Time Spinner prototype?

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

______________________________________________________________________

4. What did you dislike about the Date/Time Spinner prototype?

______________________________________________________________________

______________________________________________________________________

5. What did you like about the Dynamic Radial Navigation prototype?

6. What did you dislike about the Dynamic Radial Navigation prototype?

7. What did you like about the Linked Time Sliders prototype?

8. What did you dislike about the Linked Time Sliders prototype?

9. Do you have any general comments or suggestions?

# Appendix B – ICEHR Approval Letter

| | |
|---|---|
| ICEHR Number: | **20130335-AR** |
| Approval Period: | **July 20, 2012 – July 31, 2013** |
| Funding Source: | Co-supervisor's NSERC funding<br>Dr. Orland Hoeber, Computer Science |
| Responsible Faculty: | Dr. Rodolphe Devillers<br>Department of Geography, Faculty of Arts |
| Title of Project: | *Interactive Temporal Zoom and Pan within a Multi-Touch Geovisual Analytics Environment* |

July 20, 2012

Ms. Cassandra Lee
Department of Geography, Faculty of Arts
Memorial University of Newfoundland

Dear Ms. Lee:

Thank you for your submission to the Interdisciplinary Committee on Ethics in Human Research (ICEHR) seeking ethical clearance for the above-named research project.

The Committee has reviewed the proposal and appreciates the care and diligence with which you have prepared your application. We agree that the proposed project is consistent with the guidelines of the *Tri-Council Policy Statement on Ethical Conduct for Research Involving Humans* (TCPS2). *Full ethics clearance* is granted for <u>one year</u> from the date of this letter.

However, the Committee requires that you make the following clarifications in the consent form:

a. indicate what happens to their data collected to that point if a participant withdraws
b. on data storage for a minimum of five years, specify "as per Memorial University policy on Integrity in Scholarly Research"
c. update the phone number in the ICEHR approval statement

Also, add the ICEHR approval statement to the recruitment email and poster. Please forward the revised documents to Theresa Heath at icehr@mun.ca

If you intend to make changes during the course of the project which may give rise to ethical concerns, please forward a description of these changes to Theresa Heath at icehr@mun.ca for the Committee's consideration.

The TCPS2 requires that you submit an annual status report on your project to ICEHR, should the research carry on beyond July 31, 2013. Also, to comply with the TCPS2, please notify us upon completion of your project.

We wish you success with your research.

Yours sincerely,

M Shute

Michael Shute, Ph.D.
Chair, Interdisciplinary Committee on
Ethics in Human Research

MS/th

copy: Supervisor – Dr. Rodolphe Devillers, Department of Geography, Faculty of Arts

Director, Office of Research Services